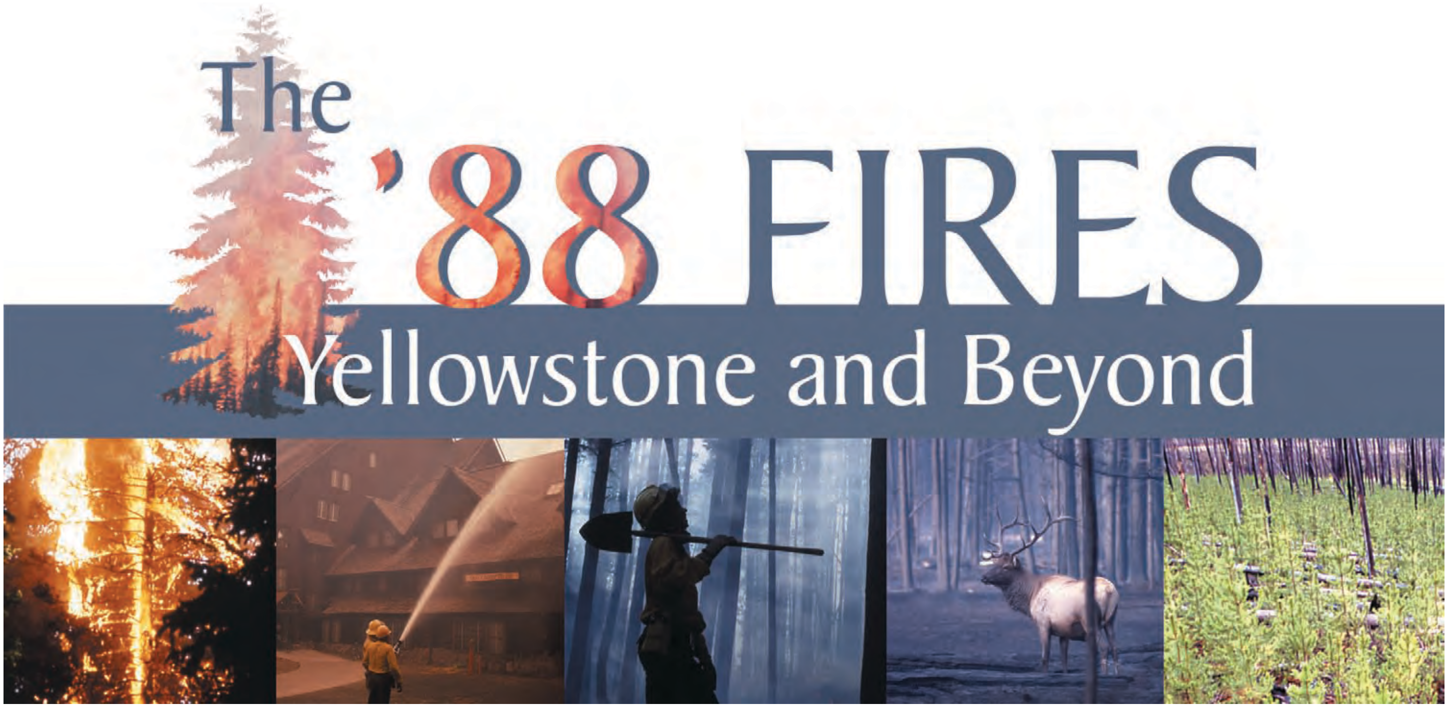
The ’88 Fires: Yellowstone and Beyond
Conference Proceedings



Edited by

Ronald E. Masters, Krista E.M. Galley, and Don G. Despain

Tall Timbers Research Station, Miscellaneous Publication No. 16

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FOREWORD

Even before it was over, the 1988 fire season was widely recognized as a milestone event in the American West. We were told by various commentators that the fires would change everything—that they would "rewrite the book" on fire behavior and fire science, and that they would reshape our ideas of public land management. Some said that the nation's fire managers and other professionals would perceive 1988 as the pivotal career event for a whole generation. In these and other ways, the amazing experiences and revelations of 1988 inspired that most dubious of historical enterprises, the writing of history before it happens.

In the intervening 20 years, things did change and history did happen. Most of the heat-of-the-moment commentary succumbed to the truism that news is not history. But many of the predictions had some truth in them. If no books were actually rewritten, a great many were revised. If the institutions that manage our public lands were not reshaped, they were given an unforgettable jolt of deep scrutiny. And if the professionals who experienced the fires didn't necessarily define their lives around 1988, they still feel that year's enduring power in our culture. This conference is sufficient proof that we will not forget 1988, or cease studying, reconsidering, disagreeing over, and marveling at what happened that summer.

This conference proceedings is also the best evidence of a grand, energetic conversation that the fires of 1988 launched. Among these many voices you will hear a tale much more complex than the saga of 1988 first revealed. It takes time to stand back far enough from an event to see all its contexts and, in a world that is changing as swiftly as is ours, even the contexts themselves are multiplying.

The fires of 1988 set us on a rich inquiry into the fate of much more than burned areas or beleaguered bureaucracies. Thanks to the participants in this conference, those fires opened countless windows into the future of our relationship with the West's magnificent landscapes. As the original event recedes into the past—and as a new generation of fire specialists, researchers, and the public engages the legacy of a fire season that many of them don't even remember—the richness of our inquiry will only increase. In that spirit, even admitting that I am now writing future history myself, it seems safe to say that the cumulative data, conclusions, debates, and even nostalgia expressed at this conference will themselves become a permanent milestone in our search for the meaning and lessons of the fires of 1988.

Paul Schullery
Yellowstone Center for Resources
November 2008

PREFACE

Don G. Despain
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It has been 20 years since the news media worldwide was consumed with the fact that Yellowstone National Park was being “destroyed” by fire. The atmosphere was rife with finger pointing, forecasts of doom and destruction, and mourning for irreplaceable loss. In the intervening years, wildland fire has been much more frequent and burned many more acres annually than in recent memory. It has become a perennial topic of newscasts keeping interest in the fate of the park alive, generating questions about the role and the effects of fire on the environment as well as on society. It has also provided much fodder for researchers from a number of fields.

The dust has had time to settle and the smoke has mostly cleared (pun intended). Many of the principals of those days are now retired and have been replaced by younger and possibly smarter, more energetic people from many walks of life. The forests of Yellowstone have grown tall enough to again block the roadside view.

Much new information has been generated about fire. The next generation of fire managers and fire researchers are well established, and better informed, and there is a level of excitement among many new students of fire who are eagerly preparing to join their ranks. Interestingly, many of the present and future fire practitioners were not yet born or were too young to be aware of the controversies that were swirling around the halls of government and academia in 1988. Therefore, it was time to convene a conference to bring together the graybeards and the young turks that both may benefit from the cross-pollination and shake their heads as they gather in separate groups to discuss the future of fire science, ecology, and management.

The purpose of this conference was to bring together those who were ending their careers and had all the answers with those in the midst of the fray who were seeking answers and those eager to join the ranks, ask new questions, and pose new ideas. Just as the fires of 1988 were not confined within the borders of Yellowstone, the scope of the conference was not confined to the problems and techniques of fire management or the results of scientific studies. The topics covered in these proceedings range from reminiscing, to fuels and fire behavior, to ways to better manage suppression efforts, to impacts on society, to the ecological impacts at the local and landscape scales, etc., as indicated by the sessions listed in the table of contents.

This proceedings is not a collection of lengthy scientific papers but is a collection of abstracts. The authors who gave oral presentations or displayed posters each submitted short abstracts of a paragraph or two giving a short synopsis of their presentation, which were included in the conference program. They were also invited to submit an extended abstract, a printed page in length covering the questions addressed, methods used, and summary of results. For those who chose to submit them, the extended abstracts replaced their shorter version for this volume; for those who did not, the short abstracts are included. Anyone wishing more information is encouraged to begin a fruitful dialogue resulting in advances and new horizons for both parties.

Eighteen extended abstracts constitute a case study of the Yellowstone portion of the 1988 fire season. The case study is intended to provide those interested in learning from that event with the basics of the significance, chronology, environment, analysis of the fire behavior, and lessons learned from this benchmark season-long event.

ACKNOWLEDGMENTS

A conference of this magnitude may begin with a few good friends killing time aĀer a coffee break but to bring it to life, nurse it through infancy, childhood, adolescence, and final maturity, it takes a community of selÈess and dedicated people. The idea was the brainchild of Paul Woodard at the University of Alberta, who has been a student of fire for more years than he is willing to admit. It came to pass through his perceptiveness and persistent prodding starting in 2006.

The capable and resourceful steering committee was chaired by Paul Woodard, our IC, and his capable assistant, Don Despain, but most of the actual work was carried out by Mikel Robinson. Dick Bahr acted as liaison with federal agencies. Roberta D'Amico got the word out and kept everyone's excitement levels high. Sarah Stevenson created the conference logo and other artwork that adorned the Web page, various brochures, notices, program guide, and proceedings.

Penelope Morgan was responsible for the expansive program. Bill Gabbert and Bill Ranieri kept the bills paid. Chuck Bushey made sure everything was available and in place. The conference facilitating company, Mountain Destinations, in the form of Veronica Haynes and Steffany Kay took care of room registration, on-site logistics, and travel arrangements for the participants; Tami Blackford was the liaison with Yellowstone National Park. Deb Bahr arranged field trips and social events for guests of participants as well as organizing the registration packets. Roy Renkin organized and coordinated the field trips and workshops. Michelle Ekstrom coordinated the exhibitors. Geneva Chong and Lori Iverson were our local agents and gave support that only a local could.

The program committee working under the direction and leadership of Penny Morgan spent many hours coming up with ideas for session topics and finding the right people to put them together consisted of Dick Mangan, Robin Hanford, Jan van Wagtendonk, Chuck Bushey, Roy Renkin, Tami Blackford, Tina Boehle, Cliff White, Greg Greenhoe, Dean Clark, Bill Romme, Marty Alexander, Roberta D'Amico, Bob Gresswell, Paul Hansen, Mikel Robinson, and Don Despain.

Kaye Gainey and Lisa Baggett at Tall Timbers Research Station patiently assisted with abstract file management and cross-checking the table of contents.

Financial and in-kind contributions were made by those organizations that are listed on the inside cover and title page. We are most grateful for their generosity.

This conference and proceedings would not have been possible without the efforts of the more than 170 presenters and approximately 450 attendees from throughout the United States and several other countries. Without them there would be no conference or proceedings, and they have our sincerest thanks for their contributions.

PLENARY

I WAS THERE

Bob Barbee
Retired Superintendent, Yellowstone National Park, National Park Service, P.O. Box 11446, Bozeman, MT 59179, USA; barbee@montanadsl.net

As Āres grew in intensity and area in Yellowstone National Park over the course of the summer of 1988, about 25,000 individuals contributed to the management efforts. I offer my perspective as one of those individuals and as the superintendent of Yellowstone at the time. The Yellowstone Āres were character-building and humbling experiences for many of us who were involved. They served as a catalyst to refocus on fundamental questions regarding the role of Āre in natural systems and the conditions and limitations of its use. The onslaught of media and parade of VIPs were new to the National Park Service. We learned the importance of excellent communications with the public, the media, and our neighbors and about recognizing the limits of technology. These and other observations and lessons learned from the 1988 Yellowstone Āres continue to be relevant and inÈuence park managers.

PLENARY

I WAS THERE

Orville Daniels
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Fire managers increasingly face larger fires with complicating social, economic, and interface factors. As the climate changes and the public's view of fire changes, the fire community will need to reevaluate how we manage fire on the landscape, our strategies, and the mechanisms we use to develop wildland fire policy. For managers confronting these complex issues, it will be important to remember and assimilate lessons learned from the past. In 1988, I had the humbling experience of being in charge of the Canyon Creek Fire in the Lolo National Forest. The '88 fire season was a learning experience that shaped the fire community. The lessons learned from that experience and fire management history continue to be relevant for managers. We need to continue to adopt some of those lessons learned to confront the challenges of future fire management in a changing environment. The fire community will need to be cohesive as agencies face budget and other issues, long-term strategy planning, and full evaluations of the effects of past fire programs.

PLENARY

MEXICO FIRE PROGRAM: PARTNERING WITH LOCAL COMMUNITIES

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Virtually all of Mexico's protected natural areas include a combination of private lands and communal lands held in trust for peasant farmers. There are restrictions on land use and land conversion, but successful conservation lies with the reserve staff's ability to work with local communities to develop compatible uses. The Nature Conservancy has found that it is possible to reconcile the fire-related needs of both ecosystems and people through a framework called Integrated Fire Management. The Conservancy's Global Fire Initiative has adopted this framework to address fire-related conservation threats everywhere we work. Come learn about community-based approaches to fire-related biodiversity threats in Mexico.

Key Question: What are the Āre behavior characteristics, ecological Āre effects, and Āre-related perceptions that rural communities and reserve managers want and need to understand in order to develop and implement prescribed Āre management plans designed to maintain the subtropical pine–oak ecosystem, meet community social and economic objectives, and prevent Āres from entering the montane broadleaved forest?

Finding Solutions: Nature Conservancy staff and partners are exploring several approaches with the people of rural communities:

- Develop a community fire management plan, including a manual for conducting prescribed burns, generated with the general assembly, for each rural community.
- Construct thematic maps with farmers from the communities representing vegetation, fuel models, and fire management zones.
- Conduct demonstration prescribed burns for forest and farming zones.
- Implement workshops that facilitate information exchange between rural communities.

PLENARY

"IT WAS THE BEST OF TIMES, IT WAS THE WORST OF TIMES, IT WAS THE AGE OF WISDOM, IT WAS THE AGE OF FOOLISHNESS. . ."—CHARLES DICKENS, 1812–1870

John D. Varley
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In 1988, when forest-consuming fires, unparalleled in human memory, were sweeping across Yellowstone National Park, television, radio, and the print media, local and national politicians, and much of the American people believed these fires to be causing devastation on a scale never before seen. A wealth of Science said otherwise. That fateful year, there were two big stories relating to the fires: one spoke to the largest firefighting effort ever assembled up to then, and the other was about what was *really happening* to one of America's most beloved landscapes. By emphasizing the sciences of fire-, landscape-, plant-, and animal ecology in long-fire-return ecosystems—a category that Yellowstone's forests fall within—millions of Americans were exposed to a new ecological perspective completely foreign to most of them: that the fires were not destroying nature as the mainstream media were reporting. Instead, the fires were doing the exact opposite, and assuring that the Yellowstone landscape would be perpetuated centuries into the future. In the Age of Smokey Bear, "going public" with this radical new story that "fire is good" was viewed by many as a risky gamble. The national media universally covered this event with a disaster–victim–villain plotline, combined with the stupendous blazes, brave firefighters, and apoplectic tourism industry; the "fire is good" story was not a fit. Indeed, during the fires and the following fall, telling the *real* story looked like a mistake that had higher odds of leading to the gallows rather than a medals ceremony. By 1989–90, it slowly became apparent—largely through emerging sociological science—that the American public was not duped by the media about the Yellowstone fires; to one degree or another they placed more faith in Nature than in CBS. Now two decades later, I believe the 1988 fires made a lasting change in the way agencies, politicians, and policymakers look at fires, and in the way the media reports fires. In doing this, I argue it has ultimately influenced the American public by making them a more informed body on these subjects.

PLENARY

ECOLOGICAL EFFECTS OF THE '88 FIRES: A STORY OF SURPRISE, CONSTANCY, AND CHANGE

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The size and severity of the 1988 Yellowstone fires surprised scientists and managers alike. However, the fires provided an unparalleled opportunity to study the effects of a large, infrequent disturbance in an ecological system minimally affected by humans. This presentation will synthesize understanding of how the 1988 fires affected forest communities, including patterns of succession, productivity, and nutrient cycling, native wildlife, and aquatic ecosystems. The 1988 fires were by no means an ecological catastrophe, and they have led to new insights about the nature, mechanisms, and importance of change.

PLENARY

WHY (FIRE) HISTORY MATTERS

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Although fire has become widely recognized as a major form of natural disturbance in recent centuries, little is known of its long-term history, its sensitivity to major climate changes, and its role in creating and altering ecosystems. Paleoecological data offer unique and critical information on past fire regimes and their response to variations in climate and vegetation over thousands of years. For example, charcoal and pollen records from the northwestern United States indicate that prolonged drought between 10,000 and 6,000 years ago led to higher than present fire activity and the development of extensive disturbance-adapted forests. Another period of high fire frequency occurred ca. 2,000 years ago. Charcoal records also reveal the extent to which prehistoric people transformed vegetation through their deliberate use of fire. In New Zealand, for example, burning of native hardwood forests occurred within decades of Polynesian arrival, and the resulting grasslands have persisted to the present day. Thus, long fire histories extend our understanding of ecosystem processes to periods of large and rapid environmental change. They also provide an important perspective by which to evaluate ongoing and future ecosystem change.

PLENARY

CLIMATE CHANGE AND WILDFIRE IN THE WESTERN U.S.

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In recent decades, increased frequency and size of large forest wildfires in the Greater Yellowstone Area (GYA) have been associated with warming, earlier springs, and intensified drought conditions. As climate continues to change, temperature and moisture deficit—a measure of drought conditions that integrates temperature and precipitation—will likely increase and contribute to the number and size of fires across the West. Climate projections for the GYA indicate the region may become substantially drier over the next 100 years, leading to increases in wildfires. By the end of this century, extremely aggressive fire seasons like that of the summer of 1988 may occur in the GYA with much greater frequency than has been indicated for the region in its recent past.

PLENARY

CHANGING FIRE REGIMES IN THE FACE OF GLOBAL CHANGE: A CANADIAN PERSPECTIVE

Mike Flannigan
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Wildland fire is greatly influenced by fuels, weather, and people. Weather is probably the most important factor for fire activity in Canada. Fire activity has been increasing primarily due to human-caused changes in our weather, namely warming and drying, and we expect increasing fire activity for the foreseeable future. As fire activity increases in the boreal forest of Canada, managers face related high costs, risks to the health and safety of people, property loss, and timber loss. Canada has developed fire management practices that may be applicable to the American West and at larger scales. Fire, which plays a major role in carbon dynamics by adding carbon to the atmosphere and by changing the carbon characteristics of forests through stand-renewing fires, is an important part of the climate system. Because of fire's relationship with global climate change, Canada is working cooperatively at the international level and includes information on wildland fires in their reports to the United Nations Framework Convention on Climate Change. Canada is preparing adaptation strategies for increased fire activity, longer fire seasons, and more ignitions and threats to communities and forests. Managing the impacts of fire activity and global climate change requires a global solution. The 2005 Canadian Wildland Fire Strategy incorporates international best practices, knowledge, and expertise. This approach is coordinated and integrated across Canada and uses education, cooperation with municipalities and aboriginal groups, promotes a more efficient use of and investment in resources, and includes a research component.

PLENARY

CHANGES IN LARGE FIRE MANAGEMENT SINCE THE 1988 YELLOWSTONE FIRES, FROM AN INCIDENT COMMANDER'S PERSPECTIVE

Steve Frye
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The summer of 1988 was a preview of wildland fire size and complexity and the attendant fire management challenges to come over the next 20 years. Large-fire managers have taken advantage of the strategies and lessons learned from 1988, such as improved and increased coordination and communication, but now face different challenges: development in the wildland–urban interface, declining resource availability, climate change, and expanding expectations for Incident Management Teams. Development in the wildland–urban interface presents the largest and most complex issues and changes for wildland fire managers since the '88 fires. Development causes managers to reposition resources to limited areas for protection and dramatically increases the number of agencies and entities with which managers engage. Firefighting resources are increasingly limited, requiring managers to think outside of the box for strategies and ask the difficult question, "When is enough, enough?" Firefighters are at the frontline of climate change as extremely aggressive fire behavior occurs in different fuel types and conditions. As a result of successful large-fire management since the '88 fires, managers are also called on to engage with an increasing array of issues and a diversity of expectations beyond wildfire management challenges. To continue to meet current response expectations and maintain necessary response capabilities, it is projected that managers will need twice the resources. Managers are frequently forced to make difficult decisions about how and where they allocate available resources and to recognize that there is an increasing number of circumstances where our capability and capacity are exceeded by the natural and built environment.

PLENARY

PAST CHANGE IN ECOLOGICAL AND HUMAN COMMUNITIES AS A CONTEXT FOR FIRE MANAGEMENT

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Since 1890, the Greater Yellowstone Ecosystem (GYE) has experienced a period of rapid climate change that favors increased fire severity. Fuel loads are building below treeline, possibly causing a shift to more severe fire. Biodiversity, land use, and fuel buildup all concur below treeline, imposing opportunities and constraints for fire management. A comparison of historical and aerial photographs and Landsat imagery shows an increase in conifer cover in selected Douglas-fir zones of the GYE, suggesting possible changes in fuel load. Coupled with a substantial decrease in fire frequency in these zones over the past 150 years, high fuel availability is likely. Similar data show that aspen is currently located in less-than-optimal habitats. Aspen grows best in biophysical settings that also favor Douglas-fir growth. It is possible that competition with Douglas-fir limits aspen distribution and partially explains loss of aspen cover. Late-seral forests experiencing a decline in diversity due to dominance of certain tree species may be diversified by the introduction of fire. However, use of disturbance to support biodiversity should favor low- and high-energy regions. Across North America, bird species richness has been associated with biophysical factors relating to primary productivity. In the GYE, predicted hot spots for bird species richness overlap with the lower Douglas-fir ecotone and areas of rural home development. With land use and climate change, the potential for challenges will likely increase in future landscapes. Fire management strategies should be tailored to local conditions within regions and across the United States.

MOVING FROM FIRE MANAGEMENT TO LEARNING HOW TO LIVE WITH FIRE

George Weldon
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The primary lesson fire managers of the U.S. northern Rockies learned from the 1988 fires was that we were not in charge of those fires. The lesson continues to be reiterated as the climate changes and recent fires easily exceed our operational capability to suppress and control; this is demonstrated by the fires of 2000, 2003, 2006, and 2007. We need to begin seeing fire as a process like earthquakes, tornadoes, and floods, which are events we cannot control or manage. For half a century, we were successful in excluding fire from the fire-dependent ecosystems that we live and work in. We are capable of delaying fires, but putting out fires in a fire-dependent ecosystem is not a sustainable operation; our fire history clearly indicates that fire will eventually occur no matter the number of fires we extinguish. It is important that we manage the public's expectations of federal, state, and local agencies' capabilities to protect property and communities; the Forest Service cannot resolve the wildland–urban interface issue and does not have the capability to protect people's homes and communities in those areas. Private landowners need to begin thinking about space that will survive a fire without protection assets rather than defensible space. It is also increasingly important to protect western watersheds as the climate changes. Managing fire for resource benefits is a major tool for protecting and enhancing watersheds. Managers will need to look for solutions to this issue and recognize that mechanical treatments will have limited effects, as we do not have the capability nor would it be desirable to treat at a scale where it would be effective because of impacts to other resources. A successful example of fire management policy is the Wildland Fire Use Program established in the Selway-Bitterroot Wilderness in 1972. After 36 years of managing fires for resource benefits, this area has smaller, less intense fires even during extreme fire weather. This both benefits resources and protects communities. Without the expansion of the Wildland Fire Use Program to other areas of the northern Rockies, multiple large fires will continue to occur, and will significantly affect people and communities.

PLENARY

WILDLAND FIRE MANAGEMENT POLICY—LEARNING FROM THE PAST AND PRESENT AND RESPONDING TO FUTURE CHALLENGES

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ABSTRACT

Since its origin as a defined functional activity, wildland fire management has been the natural resource management program with the highest risk, complexity, and greatest potential for serious negative outcomes. During this time, this program has continually grown in temporal and spatial extent, operational complexity, ecological significance, social, economic, and political magnitude, and seriousness of potential consequences. With this level of importance and dynamic stature, the value of a strong, accurately focused policy to guide programmatic development and implementation cannot be overstated.

Fire Policy: Wildland fire management policy represents a high-level course of action embracing the general goals and acceptable procedures of federal land management agencies, guides present and future decisions, and identifies procedures and means to achieve wildland fire management goals and objectives. A sound and efficient policy is built from driving factors or foundational processes that indicate a need. Such policy is composed of specific attributes or supportive processes that define exactly what it represents; and is used to guide management decisions and actions by presenting outcomes from performance and lessons learned. Historically, wildland fire management policy has been developed and modified in response to program evolution, with acceptance ranging widely from full endorsement to contentiousness and controversy. During the last 20 years, dynamic fire management issues, significant events, and increasing external awareness, scrutiny, and involvement have exerted a greater influence on policy formulation than experienced in the previous 80 years.

Learning from the Past: Past policy driving factors included incomplete knowledge of the natural role of fire and fire effects, economic concerns over natural resources, limited accessibility, limited organizational capability, safety concerns, and an agency perspective that less fire was better. These factors led to development of a policy characterized by attributes of full fire suppression. Over time, implementation of this policy provided lessons learned including: fire exclusion did not support all resource management objectives; serious consequences resulted from complete fire suppression; increased planning and preparedness constrained the application of fire for resource benefits; and increased preparedness improved long-term accountability.

Understanding the Present: Driving factors responsible for the present policy include improved state of knowledge; increased importance of community protection; improved capability; expanded interagency cooperation; wider ranging agency perspective and greater awareness of potential consequences; and escalating protection demands and expectations of success. Attributes of the present policy produce the most flexible policy to date, advocate increased use of fire for beneficial purposes, incorporate science as foundational policy element, and recognize a rapidly changing management focus to include local collaboration and population-based protection needs. Lessons learned from the present include increased knowledge of the importance of fire presence in many ecosystems; changing values associated with wildland–urban interfaces; importance of strategic and tactical decision making in light of escalating costs of fire suppression; awareness that not all fires should be suppressed and not all fires can be suppressed, plus improved understanding of the value of a balanced fire program.

Defining the Future: Recognition of lessons learned from past and present situations as well as response to policy change causal factors are prerequisite to future policy determinations. Challenges that will be faced in the 21st century will be far more complex than ever before experienced. Clear understanding of the present and definition of the future are necessary to characterize program requirements, guide management actions, and shape an effective, mature, and proactive fire management policy. Future policy driving factors are not likely to change from present ones although importance and weighting will increase, but future policy attributes must be more flexible, exhibit a broader range of perspective and direction, and promote a balanced program.

Summary: The wildland fire management program will continue to grow. Policy driving factors and considerations will continue to escalate in complexity, numbers, and importance. To meet the need for continual program improvement, a future fire policy must be responsive and provide prudence and wisdom in the management of wildland fire.

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PLENARY

FUTURE FORESTS, FUTURE FIRES, FUTURE FIRE MANAGEMENT

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Public debate regarding fire management in America's forests has been ongoing for over a century. In that time, arguments over light burning gave way to firm fire exclusion policies. By the 1960s, it was clear to most scientists and managers that fires are a natural, even essential component of many forest ecosystems and that fire exclusion is an illusion. The absence of fire in many forests actually increases the risk and severity of future fires. Yellowstone was a watershed event in the progression of our understanding of the role of fire in ecosystems and the challenges of managing it. We have since learned that the effects of management such as suppression or thinning vary among different forest types; that increased human development and access have increased ignitions, provided additional fuel, and greatly increased public risk from and attention to fire; that climatic conditions in many locations are changing in ways that may make fires more frequent or severe in the future. Just as firefighters have adopted 10 Standard Fire Fighting Orders, I propose that fire managers consider 10 Standard Fire Management Orders: 1) Know what it is you are trying to accomplish and why. 2) Set realistic goals. 3) Manage the entire process of change, not just the fire. 4) Manage less for desired future condition and more for desired future change. 5) Variation and complexity matter—conserve them! 6) Eschew arbitrary boundaries, which means almost all boundaries. 7) The world is changing—expect surprise and manage to accommodate it. 8) Pay attention to history, but not too much attention. 9) Remember, you are mostly managing people. 10) You only think you know what you're doing—be humble and manage adaptively.

CASE STUDY OF YELLOWSTONE'S 1988 FIRES

OPENING REMARKS: THE 1988 YELLOWSTONE FIRES AS A FIRE BEHAVIOR CASE HISTORY

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ABSTRACT

Case studies or case histories "provide a systematic way of looking at events, collecting data, analyzing information, and reporting the results." The value of documented case studies or histories of wildland Āres has been repeatedly emphasized by both Āre managers and Āre researchers alike. Time and time again they have proven valuable as training material and as sources of research data, and they also provide a mechanism for formalizing the basis for experienced judgment.

Several issues of *Fire Management Today* in recent years have been devoted to the subject of wildland Āre behavior case studies. For example, a standard approach to case history or study report preparation was suggested by M.E. Alexander and D.A. Thomas in the Fall 2003 issue of *Fire Management Today*, which has since been recommended by the Wildland Fire Lessons Learned Center. A case history or study report should consist of Āve main parts: 1) Introduction, highlighting the signiĀcance of the Āre; 2) Fire chronology and development; 3) Details of the Āre environment (i.e., fuels, weather and topography); 4) Analysis of Āre behavior; and 5) Conclusions or concluding remarks, including recommendations, lessons learned, etc.

The Yellowstone Āres of 1988 are widely regarded as one of those benchmark or landmark Āre seasons with far-reaching consequences. Several popular-style books exist, yet a single comprehensive case study or history document that would serve to assist those that follow in learning lessons from this landmark event and its associated experiences, unfortunately does not currently exist.

This session of the conference focusing on Āre behavior, weather, and fuels, including crown Āre modeling, long-range Āre behavior, weather forecasting, and fuels management, has been speciĀcally organized by the author and co-moderator C.J. Bushey along the lines of a Āre behavior case history or study. As a prelude to the session, this opening presentation will overview the existing literature (e.g., books, journal articles, agency publications, and conference papers) on these topics as it pertains to the Āres in the Greater Yellowstone Area and the northern Rocky Mountains during the 1988 Āre season as well as making reference to the following 17 presentations that this session comprises:

- The 1988 Fire Season in the U.S. Northern Rocky Mountains—Chuck Bushey
- What Fuel Types Burned During the 1988 Yellowstone Fires?—Don Despain
- The Chronology of the 1988 Yellowstone Fires—Bob Mutch
- Synoptic Weather Patterns and Conditions during the 1988 Fire Season in the Greater Yellowstone Area—Rick Ochoa
- Trends in Fire Weather and Fire Danger in the Greater Yellowstone Area—Chuck McHugh
- The Old Faithful Inn Fire Run in Retrospect—Dave Thom as
- Observations and ReÈections on Predicting Fire Behavior during the 1988 Yellowstone Fires—Dick Rothermel
- Burn Mapping Comparisons on Yellowstone 1988 Fires—Donald Ohlen and Don Despain
- Wildland Fire Legacies: Temporal and Spatial Constraints of Historic Fires to Current Fire Behavior—Roy Renkin, Don Despain, and Carrie Guiles
- The 1988 Yellowstone Fires and Crown Fire Modeling in BehavePlus—Tobin Kelley and Patricia Andrews
- Recent Advances in Modelling Crown Fire Initiation and Rate of Spread—Marty Alexander and Miguel Cruz
- Assessing Discontinuous Fire Behaviour and Uncertainty Associated with the Onset of Crowning—Miguel Cruz and Marty Alexander
- Spatial and Temporal Evolution of Atmospheric Boundary-Layer Turbulence during the 1988 Yellowstone Fires—Warren Heilman and Xindi Bian
- Yellowstone and Beyond: Pyrocumulonimbus Storms Sent Smoke to the Stratosphere and Around the Globe—Michael Fromm, Rene Servranchx, Dan Lindsey, Brian Stocks, and Dennis Quintilio
- Predicting Yellowstone: Decision-Support of the Past, Present, and Future—Tim Brown and Tom Wordell
- Could Fuels Management Have Altered the Outcome of the 1988 Yellowstone Fires?—Ron Wakimoto
- Closing Remarks: What Did We Learn and What Must We Do To Avoid Relearning It?—Bob Mutch

There is little doubt that we are continuing to learn, and relearn, from case histories or studies. However, as George Santayana has pointed out, "Those who cannot remember the past are condemned to repeat it."

keywords: case study, Āre environment, Āre history, Āre management, Āre weather, fuels, lessons learned.

Citation: Alexander, M.E. 2009. Opening remarks: The 1988 Yellowstone Āres as a Āre behavior case history [abstract]. Page 8 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

THE 1988 FIRE SEASON IN THE U.S. NORTHERN ROCKY MOUNTAINS

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ABSTRACT

Background: Going into 1988, the U.S. northern Rocky Mountains was following a period of severe drought, which in some areas had been ongoing since at least 1986. By the end of the summer, most of the area was in extreme drought. To that mix, add a continued lack of precipitation, record high temperatures starting in February in some areas, and extending across the entire area by August. Finally, early runoff from a limited and moisture-depleted snowpack, nearly continuous thunderstorms for ignition sources, and a record windy summer precipitated what rapidly developed into a historic Āre season.

Events: The season got an early start as light snows melted, bringing high Āre danger to area grasslands. The Ārst major Āre occurred in February, burning a wildland–urban interface in Montana. By the end of June, the entire region was at very high to extreme Āre danger, with 1000-hour timelag fuel moistures already down to 9% in some areas. These levels were comparable to danger and moisture levels usually achieved in late July or August in more normal years. Sagebrush (*Artemisia*)/grass and ponderosa pine (*Pinus ponderosa*) forest Āres during this period quickly grew to 1,000–3,000 acres in area during their Ārst afternoon, quickly outstripping initial attack capabilities. Several of these Āres became >50,000 acres before control was achieved.

By the beginning of July, most of the region was at extreme Āre danger. Temperatures continued warmer and dryer than normal throughout the month. By 27 July, the entire Northern Rockies had entered into extreme Āre danger based on ERCs. As August approached, many areas had 1000-hour timelag fuel moistures in the 8–10% range.

August and September remained hot and dry, and a new factor was added to the steadily worsening situation: wind. Periodic dry frontal systems swept across the region, causing the ongoing Āres to grow by tremendous increments, frequently tens of thousands of acres a day per Āre. On 20 August, Āres in the Greater Yellowstone Area attained the greatest acreage gains. On 6 and 7 September, the region experienced its greatest Āre spread with the passage of dry cold fronts as the Canyon Creek Fire would make the largest single-burning-period Āre run for an individual Āre in North America since at least the 20 August 1910 Āre runs, >180,000 acres. On the 9th, snow and rain started to fall on most Āres and brought the Āre season essentially to an end, though some Āres continued to burn into November.

Conclusions: Approximately 2,175,903 acres burned on lands under Āre suppression responsibilities of federal and state agencies in the Northern Rockies. Total burned acreage in the region was historically the third greatest, following the Āre seasons of 1910 and 1919. A total of 4,168 Āres were managed by government agencies during 1988.

This presentation has been developed from immediate post-season documentation of the 1988 Āre season in the northern Rocky Mountains for the U.S. Forest Service Northern Region, Fire Behavior Service Center (by the author, 1989) for the USDA, Forest Service, Northern Region; and from a contracted report for the Lolo National Forest, Missoula, Montana (by the author, 1991), and available from the Wildland Fire Lessons Learned Center Web site.

keywords: Āre, Āre behavior, Āre danger, Āre weather.

Citation: Bushey, C.L. 2009. The 1988 Āre season in the U.S. northern Rocky Mountains [abstract]. Page 9 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The ’88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

WHAT FUEL TYPES BURNED DURING THE 1988 YELLOWSTONE FIRES?

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ABSTRACT

Question: What fuel types burned during the 1988 Yellowstone fires?

Background: The risk wildland fires pose to human values through spread rate and energy release rate is dictated largely by weather and the fuels they burn. Spread rates and energy release rates also dictate whether direct or indirect methods should be used to attack a fire. Fuel characteristics vary continuously from very sparse to very dense. In the early 1970s, Rothermel's mechanistic fire spread model was used to calculate the U.S. National Fire-Danger Rating. This model was also used to predict spatial extent of wildland fires at any given time, thus providing managers another valuable tool. Nine classes designated A–I, representing the varied vegetation types from semitropical to alpine tundra, were recognized: three forest, three brush, and three grass. Fuel types were elevated to Fuel Models and were used to populate parameter fields needed for the spread model. By 1978, the number of fuel models was increased to 20, allowing finer-resolution predictions.

Fuel types are also useful in communicating characteristics of fire behavior: what to expect when fire encounters different fuel conditions. As an aid to those charged with predicting fire behavior for planning purposes either for prescribed fires or fire suppression efforts, 13 fuel classes designated 1–13 were delineated. Comparable efforts were also being made in Canada. Currently, Canadians have 17 classes that reflect their vegetation types: 12 timber (C-1 to C-7, D-1, M-1 to M-4), 3 slash (S-1 to S-3), and 2 grass types (O-1a and O-1b). It is best if the classification system is intuitive, easy to learn, and easily communicated. It is also more useful if it is robust and easily comprehended by novice and professional alike.

Fuel characteristics of nearly 80% of Yellowstone's forests are governed by the growth habit of lodgepole pine (*Pinus contorta*). The rest is divided between Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) forests and Douglas-fir (*Pseudotsuga menziesii*) forests. Lodgepole is capable of growing on very poor soils, forming a climax or long-persisting seral forest. Surface fuels consist of 2 cm of compacted duff and sparse sedges and grasses. Slightly better sites have a good cover of grouse whortleberry (*Vaccinium scoparium*), a low subshrub. On good soils in the subalpine zone, it is succeeded by Engelmann spruce and subalpine fir. The forest floor is well covered by several species of forbs, grasses, and shrubs, which combined with seedlings and saplings, provide good sub-crown fuels. Its capacity to form a complete canopy cover, together with the relative dryness of the climate, creates sparse forest floor vegetation.

Location: Yellowstone National Park, Wyoming, USA.

Results: A considerable gap exists between the surface fuels and crown fuels until saplings of the climax species (usually spruce and fir) provide an intermediate fuel layer with sufficient biomass to sustain crown fire. Therefore, successional status of the forest has a strong correlation with fire behavior. Observation of fire behavior in each of the stages made it possible to describe the expected fire behavior for each stage, making a vegetation cover type map a usable fuels map. By 1988, an ecological vegetation classification, based on forest successional stages had been developed for Yellowstone. The forest successional continuum was broken into five cover type classes from recent disturbance (0) through early (1), mid- (2), and (3) late succession to climax. Class names begin with an abbreviation of the dominant tree species followed by a number designating the stage; thus, LP2 is a mid-successional lodgepole pine forest, DF3 is a late-successional Douglas-fir forest leading to spruce and fir, etc. For climax stages, only the species abbreviation is used: e.g., SF for spruce/fir, DF for Douglas-fir, LP for lodgepole pine, etc. This naming convention helps novices remember the defining criteria and recognize the classes in the field. Measured fuel loading in each of the types can be used to parameterize fire spread models when needed. A map of Yellowstone's forest cover types was in the final stages of development with draft paper copies available and had been used by the park staff to facilitate planning and communication regarding fire behavior. These maps, along with short type descriptions and brief explanations of expected fire behavior, were made available to the overhead teams for their planning efforts. The maps were used and comments were favorable concerning their utility in describing the observed fire behavior.

Conclusions: This vegetation cover type concept was used to create a vegetation layer for a spatial cumulative effects model for the Greater Yellowstone Grizzly Bear Recovery Zone, which includes extensive areas outside the park boundaries. Fire management personnel of the different agencies surrounding the park have also used the cover type maps for fuels maps when fires occurred inside the Recovery Zone. It has proven quite robust and usable in the Greater Yellowstone Ecosystem.

keywords: cover types, fire behavior, fire management, fuel types, lodgepole, maps, planning, succession, Yellowstone National Park.

Citation: Despain, D.G. 2009. What fuel types burned during the 1988 Yellowstone fires? [abstract]. Page 10 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

THE CHRONOLOGY OF THE 1988 GREATER YELLOWSTONE AREA FIRES

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ABSTRACT

Question: Description of the chronology of the greater Yellowstone Area fires in 1988.

Background: The Greater Yellowstone Area (GYA) is made up of parts of six national forests and two national parks, Yellowstone and Grand Teton, totaling nearly 12 million acres in northwest Wyoming, eastern Idaho, and south-central Montana, USA.

Location: The Greater Yellowstone Area (centered on approximately lat 44°47′N, long 109°4′W), Wyoming, USA.

Methods: Review of published accounts and personal observations.

Results: A total of 249 fires occurred in the GYA in 1988, or twice the annual average for the area. Of the 249 fires, 31 initially were classified as prescribed natural fires: 28 in Yellowstone National Park (NP) and one each in the Custer National Forest (NF), the Bridger-Teton NF, and Grand Teton NP. Of the 28 prescribed natural fires in Yellowstone, 12 burned out at <1 acre each. The remaining 16 fires eventually were declared wildfires and grew to large size despite significant suppression actions. Both prescribed natural fires in the two national forests burned to large size and entered Yellowstone NP. The one prescribed natural fire in Grand Teton NP burned out at <1 acre. A telling statistic is the fact that the large majority of the 249 fires, 201 or 81%, were suppressed at an average size of <10 acres.

Fire occurrence in the GYA in 1988 included Beaverhead NF, 6; Bridger-Teton NF, 34; Custer NF, 11; Gallatin NF, 43; Grand Teton NP, 19; Shoshone NF, 21; Targhee NF, 57; and Yellowstone NP, 50, for a total of 249 fires. Ninety-nine of the fires were human-caused and 150 were caused by lightning.

The area within the perimeters of the fires in the GYA was approximately 1.4 million acres, with 900,000 acres of that amount lying within Yellowstone National Park. An estimated 30 to 50% of the area within the fire perimeters remained unburned.

Conclusions: The chronology presentation provides highlights of the 10 major fires, including the 411,500-acre Clover-Mist Fire and the North Fork/Wolf Lake Fire that was >500,000 acres. Other major fires included Storm Creek, Fan, Snake River Complex, Huck/Mink Complex, Hellroaring, Hunter, Fayette, and Corral Creek. The large growth of these fires often was coupled with the passage of six dry cold fronts, with steady winds of 20 to 40 miles per hour and gusts to 40 to 60 miles per hour. The 1988 fire season in the GYA was set substantially apart from prior fire seasons by the sheer scope and magnitude of the few massive fires that simply went wherever they wanted to go at any time of the day or night. Words like "spectacular" and "unprecedented" were used often to describe the fire behavior in the GYA that summer. Observers noted localized firestorms, firebrands spotting 0.5 to 1.5 miles ahead of the main fire front, extensive crown fires, horizontal roll vortices, and convection columns to 30,000 feet. The extreme fire behavior finally forced firefighters to abandon traditional perimeter control strategies in favor of protecting life and property at critical locations.

A cold front on 10 September produced strong winds, but cold moist air behind the front finally brought significant precipitation to the GYA. Cool and damp weather continued through 20 September as more storms moved into the Northern Rockies, drawing to a close one of the most tumultuous fire seasons in recent times.

keywords: 1988, fire season, Greater Yellowstone Area, prescribed natural fire, wildfire.

Citation: Mutch, R.W. 2009. The chronology of the 1988 Greater Yellowstone Area fires [abstract]. Page 11 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

SYNOPTIC WEATHER PATTERNS AND CONDITIONS DURING THE 1988 FIRE SEASON IN THE GREATER YELLOWSTONE AREA

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ABSTRACT

Question: What were the weather and climate factors related to the 1988 Greater Yellowstone Area fire season?

Background: A number of climate factors helped shape the 1988 Greater Yellowstone Area fire season. Annual precipitation in 1987 averaged about 3 inches below normal in northwest Wyoming and snowpacks measured on 1 April in 1987 and 1988 were both well below normal. The 16 April 1988 Palmer Drought Severity Index showed moderate to severe drought over the region. Aside from a rather wet April, the late winter and spring of 1988 was drier than normal. The upper air pattern for the 1987–1988 winter showed a much stronger than normal high-pressure ridge along the West Coast, with the ridge shifting over the Intermountain West during the spring. This resulted in a warmer than normal spring for Wyoming and much of the West. The Greater Yellowstone Area was cooler than normal for March, but April and May were much warmer than normal. The summer upper air pattern showed a stronger than usual high-pressure ridge over much of the country. Wyoming recorded its hottest and driest summer on record during 1988, with the Yellowstone National Park also reporting its driest summer ever. In particular, the June–August 1988 rainfall data at the Snake River (South Entrance) station was only 0.86 inches or 15% of normal, while Old Faithful reported 1.14 inches or 22% of normal, and West Yellowstone was 1.89 inches or 35% of normal.

Location: Greater Yellowstone Area (centered on approximately lat 44°47′N, long 109°4′W), Wyoming, USA.

Methods: A number of weather and climate sources were investigated, including the National Climatic Data Center and the Natural Resources Conservation Service.

Results: In addition to the hot, dry weather, the Greater Yellowstone Area had an unusually high number of strong, dry cold fronts during the summer, with fronts occurring every 5–7 days. The “Black Saturday” cold front produced 20- to 40-mph winds with gusts well over 50–60 mph on the ridges. These winds, in combination with 75–80°F temperatures and humidities <20%, caused the Clover-Mist Fire to burn approximately 55,000 acres (22,500 ha). The 6–7 September cold front produced wind gusts of 40–50 mph, with the Canyon Creek Fire in Montana growing 165,000 acres (66,800 ha). Finally, a cold front on 11 September brought rain and snow to the area for the beginning of the end of the 1988 fire season in the Greater Yellowstone Area.

Conclusions: Several weather and climate factors combined to create the 1988 Greater Yellowstone Area fire season. These included a preexisting drought, below-normal 1987 precipitation and 1987–1988 snowpack, drier/warmer late spring, and a much hotter and drier than usual summer. In addition, an unusual number of strong, dry cold fronts periodically affected the region during the summer.

keywords: climate, drought, fronts, precipitation, rainfall, snowpack, weather, wind.

Citation: Ochoa, R. 2009. Synoptic weather patterns and conditions during the 1988 fire season in the Greater Yellowstone Area [abstract]. Page 12 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The ’88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

TRENDS IN FIRE WEATHER AND FIRE DANGER IN THE GREATER YELLOWSTONE AREA

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ABSTRACT

Question: How have measures of fire danger rating based on Energy Release Component and critical fire weather parameters, specifically temperature, changed since 1988 in the Greater Yellowstone Area?

Background: Energy Release Component (ERC) is related to the available energy per unit area in the flaming front. ERC reflects the contribution of live and dead fuels to potential fire intensity and is thus considered a composite fuel moisture value and as an indicator for drought conditions and seasonal drying trends in forest fuels. In 1988, the ERC values for remote automated weather stations (RAWS) in the Greater Yellowstone Area (GYA) were either approaching or at all-time highs. Given the current emphasis on global climate change, it is also important to consider how temperature is trending over time. A recent article suggests that the average minimum winter (December–March) temperature has been increasing over time in the GYA (Saunders et al. 2007. George Wright Forum 24(1):41–81). This could lead to a reduced overall snowpack (quantity and longevity). The lack of snowpack and potential early snowpack loss would allow for heavy fuels to become drier sooner. In addition, if temperatures are trending upward in the summer as well, then during the height of fire season, weather conditions may be more favorable to severe fire behavior.

Location: National Fire Danger weather stations and United States Historical Climatology Network stations located in and adjacent to Yellowstone National Park (lat 44°27′N, long 110°50′W), Wyoming, USA.

Methods: Trends in daily ERC and maximum yearly ERC were assessed for four RAWS stations with continuous weather information from 1964 through 2007 for June to September. Temperature trends from the early 1900s through 2006 were assessed using monthly and annual temperature information from six United States Historical Climatology Network stations. The annual average, minimum, and maximum temperature, the summer period (June–August), and March only for the individual stations and pooled data were analyzed.

Results: While year-to-year and between-station variability exists, in all cases the yearly maximum recorded ERC trend has been positive over time. In 1988 Old Faithful (480107), Hebgen (244603), and Mammoth (480111) recorded their highest ERC value to date, while Island Park (102105) did not. However, 2003 saw the highest recorded ERC set for Island Park and the 1988 mark was eclipsed for Hebgen, too. Hebgen and Island Park saw an increase of 10 between the earliest recorded maximum yearly ERC compared with 2007. For Mammoth and Old Faithful the difference was 24 and 26, respectively. With the exception of the Old Faithful station for the period 1964–1987, the yearly maximum ERC trend was negative, while for the period 1988–2007 the trend in yearly maximum ERC was positive.

Pooled temperature data exhibited a positive trend for average annual, minimum, and maximum temperature. From 1978 to 2006, a steady increase for all annual measures of temperature were observed with a 1.6°F difference in annual mean temperature during this period. For March, similar trends were manifested; however, a significant upward trend starts nearly a decade earlier. Summer period (June–August) trends differed with annual average temperature and average annual maximum temperature remaining fairly constant for the period 1960–1999, with 1988 having the highest recorded values. Since 2000, both measures have been increasing. The average annual minimum temperature increased from 1980 to 1990 and decreased from 1991 to 2000.

Conclusions: This preliminary investigation into trends in fire danger and temperature in the GYA suggests that both are exhibiting a positive trend over time. Increases in ERC would be important for managers when updating fire management plans, as historical ERC values and past decision criteria may no longer be valid under changing conditions. Increases in March temperatures are important, as it relates to snowpack loss and early drying of large fuels. A visual comparison of temperature and ERC trends to the Pacific Decadal Oscillation Index (PDO) suggests that lower values (temperature and ERC) observed during the mid-1970s to mid-1980s may be related to negative values of PDO. Recent work examining climate synchronization and forest fires in the Northern Rockies found a correlation of negative PDO to cool springs and a lack of regional-fire prone years (Morgan et al. 2008. Ecology 89:717–728). While no attempt was made to correlate ERC to fire occurrence, future work in this area would strengthen this analysis.

keywords: climate change, energy release component, ERC, National Fire Danger Rating, temperature, Yellowstone.

Citation: McHugh, C.W. 2009. Trends in fire weather and fire danger in the Greater Yellowstone Area [abstract]. Page 13 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

THE OLD FAITHFUL FIRE RUN OF SEPTEMBER 7, 1988: I NEVER SAW IT COMING

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ABSTRACT

Question: Using hindsight analysis and high reliability organizing theory, could the Fire Behavior Analyst assigned to the North Fork Fire have done a better job of anticipating the timing and severity of the Old Faithful Fire run of 7 September 1988, and have used this information to alert the Type I Incident Command team to the potentially dangerous tactic of not evacuating all nonessential personnel from the Old Faithful area?

Background: Nineteen-eighty-eight had been a severe Āre year even before the Old Faithful Fire run. Major Āres had burned in the Selway-Bitterroot and Scapegoat wildernesses in Idaho and Montana. A near-miss Āre shelter deployment had occurred on a Āre west of Missoula, Montana, and unusual, downhill Āre behavior was experienced on the Ajax Āre near Wisdom, Montana. These earlier Āres were early warnings of the dramatic Āre behavior experienced in Yellowstone Park in 1988. As a Fire Behavior Analyst (FBAN) assigned to the North Fork Fire, I performed the normal duties of an FBAN, but in the park that year, the dimensionality of Āre behavior was outside the normal. First was the scale of the Āres, individual Āres hundreds of thousands of acres in size, with huge daily acreage growth common. Then there was the dilemma of mapping out fuel models over such a large contiguous area, coupled with the fact that the Āres didn't necessarily spread from a point-source ignitions but from spot Āres that oscillated back and forth in a "bump and grind" fashion. Topography, plateaus, canyons, and river drainages also had a huge inÈuence on where the Āre would spread, but the Āre environment was so dry in 1988 that Āres could, for example, spread either up or down drainages regardless of the time of day. Expert FBANs working at the Fire Behavior Service Center in West Yellowstone plotted Āre behavior on the "Hauling Chart," which displayed that most days, with the addition of wind, the Āres would be in the crowning ("hauling butt") stage. Finally, the Āres were so uncommon, so unique, that many of us became mesmerized just by their power and beauty. From the start, Āre commanders were concerned about when the North Fork Fire would reach Old Faithful Inn. The North Fork Fire, from August until the Ārst week in September, continued to spread in a southerly direction to become aligned with Old Faithful. On 3 September, a bulge of hot spots was noticed 4–5 miles southwest of Old Faithful; then a few days later, two or three Ängers of Āre developed, pointing directly at the inn. On the afternoon of 7 September, the Āre made a crown Āre run over Old Faithful, spotting over the hotel, and starting two long, Änger-shaped Āres that burned in a northeast direction for over 10 miles each. The inn was saved from burning but had not been totally evacuated.

Location: North Fork Fire and Old Faithful Inn, Yellowstone National Park (centered on approximately lat 44°47′N, long 109°4′W), Wyoming, USA.

Methods: Using the templates of mindfulness found in high-reliability organizing (HRO) theory and qualitative analysis, reconstruct the events leading up to the Old Faithful Fire run. SpeciĀcally, apply the cognitive process of disconĀrming expectations to better anticipate errors in anticipating the Āre behavior on 7 September. This process entails being preoccupied with failure, sensitive to the big picture, and wary of oversimpliĀcation.

Results: The Āre behavior forecast prepared for 7 September stated that "spot Āres detected yesterday afternoon can easily move into the Old Faithful area." Even though the Āre was expected to move into the hotel area, the lodge complex itself was not completely evacuated. Hotel service personnel, a few tourists, and ĀreÄghters (including Āre information officers with little Āre experience) still populated the area. As the Āre turned a sunny afternoon dark with billowing smoke, some people displayed panic in the confusion and chaos. A few small outbuildings and one gasoline truck burned, and embers were extinguished on the inn's roof.

Conclusions: Using HRO mindfulness as a screen, there is little doubt that the overhead team and the FBAN could have done a better job of engaging about worst-case scenarios days earlier as the North Fork Fire approached Old Faithful Inn. We did not ask the basic questions that would have challenged our expectations: What mistakes must not occur? Are we treating all unexpected events as information? Are we speaking up, being skeptical, and communicating our true thoughts? In light of earlier Āre behavior seen throughout the 1988 Āre season, should I have been surprised at seeing Āre behavior never experienced before? If the FBAN had been more fully engaged with the overhead team, using these questions as a foundation, a stronger case could have been made to evacuate Old Faithful before the North Fork Fire burned onto the complex. As it was, people were still at the inn during a chaotic period, and a single innocuous event—car wreck, helicopter breaking down, an overly panicked tourist, or a hotter building Āre—might have started a chain of events that could have had disastrous, fatal results. As it was, we lucked out and no one was hurt, but it could have easily been otherwise.

keywords: disasters, Āre behavior analyst, Āre behavior prediction, high-reliability organizing, mindfulness, North Fork Āre, Old Faithful Inn.

Citation: Thomas, D.A. 2009. The Old Faithful Fire run of September 7, 1988: I never saw it coming [abstract]. Page 14 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

OBSERVATIONS AND REFLECTIONS ON PREDICTING FIRE BEHAVIOR DURING THE 1988 YELLOWSTONE FIRES

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ABSTRACT

Question: How large could the Āres in the Greater Yellowstone Area be expected to become during the summer of 1988?

Background: The potential for severe Āre behavior in and around the Greater Yellowstone Area became established by severe drought conditions, which developed throughout the West during the summer of 1988. Several Āres had already started in and around Yellowstone Park by mid-July, necessitating establishment of a UniĀed Area Command. On 29 July, a six-member team of Āre analysts was assembled by Area Command to develop a worst-case scenario of expected Āre behavior. The team had 3 days to assess the situation and develop projections. The assignment posed several problems: the number of large Āres already established, their remote location, dense smoke over much of the area, and the uncertainty of the weather. Cold fronts moving in from the West Coast could be expected every 5 to 7 days, bringing either rain or wind. Fortunately, the forests in the park had been categorized into Āve types, predominately lodgepole pine (*Pinus contorta*), based on age, growth, and decay. These ranged from recently burned stands containing seedlings and young trees designated LP-0 to decadent stands of 300- to 500-year-old trees, many of which had fallen, creating high concentrations of dead and down fuel.

Location: Greater Yellowstone Area (lat 45°N, long 111°W), USA.

Methods: Developing a worst-case scenario proved to be impossible. As an alternative, projections were made for the most probable Āre growth by 15 and 31 August. A plan evolved for relating the Āve timber types to six weather conditions ranging from a wetting rain to one of exceptionally strong frontal winds. Two methods, climatology and forecasting, were used for estimating weather. The Āre spread model for predicting surface Āres was not applicable, so estimates of grown Āres spread rates were obtained from Āre behavior analysts currently working on the Āres.

Results: Maps for 15 and 31 August showing the probable Āre size were drawn for each weather scenario. The forecasted weather was a better match to the events of the summer than the climatology. However, our projections of expected Āre growth were exceeded by mid-August. Subsequently, new large Āres occurred and strong winds developed on an increasing frequency up until 10 September when signiĀcant rain and snow fell. Some of the most severe weather occurred in early September. These events made our projections of little use, and daily projections of expected Āre behavior became necessary. In early August, the Āres averaged about 1 mile of spread per day; by mid-August, about 3 miles; and in late August and early September, the Āres were running 7–14 miles per day. In late August, litter fuels were sampled for moisture content every hour for 48 hours. Moistures reached a minimum of around 4% late in the afternoon and held this condition until almost midnight. Consequently, Āres spread well into the night, making Āre control by backĀres virtually impossible.

Conclusions: The uncertainty of expected weather makes meaningful long-range Āre projections subject to a great deal of uncertainty. Beyond the normal 3- to 5-day weather forecast, a wetting rain or strong winds are both possible. Conditions for catastrophic Āre behavior begin with decadent stands of timber subjected to severe drought, followed by dry lightning storms and periodic strong wind events. Once a Āre becomes large and timber stands of various ages are exposed to Āre, all timber types become liable for crown Āre development and spread. Three types of crown Āre were observed: 1) a plume-dominated Āre in which the Āre suddenly erupts into a running crown Āre even at low wind conditions; 2) a plume-dominated Āre in which the convection column collapses, hitting the ground and producing extremely strong winds blowing outward from the Āre; 3) wind-driven Āre in which the wind overpowers the convection column, resulting in rapid Āre spread and lofting of Ārebrands ahead of the Āre front.

keywords: drought, Āre size, forest Āre, timber types, Yellowstone Park, wind.

Citation: Rothermel, R.C. 2009. Observations and reÈections on predicting Āre behavior during the 1988 Yellowstone Fires [abstract]. Page 15 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.) The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

BURN MAPPING COMPARISONS ON YELLOWSTONE 1988 FIRES

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ABSTRACT

Question: Do the burn severity mappings of 1988 and the more recent Monitoring Trends in Burn Severity mappings provide similar interpretations of change that resulted from the Yellowstone 1988 fires?

Background: The magnitude of wildland fires that occurred in the Greater Yellowstone region in 1988 gave rise to many questions about the effect, nature, and extent of these fires. Information was needed to address the concerns from the general public and those responsible for resource management of the lands impacted by these fires. The magnitude of the fires precluded the use of the normal inventorying methodology of aerial reconnaissance and ground survey. In response to these needs, a cooperative effort between the Branch of Fire Management of the National Park Service (NPS), Yellowstone National Park, and the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center was undertaken to map both the spatial extent of burned areas and the variation of burn severity within the burn perimeter. At that time an unsupervised classification was generated using a single Landsat Thematic Mapper (TM) image acquired on 2 October 1988, and was analyzed for the mapping of eight burn classes.

Much attention has been directed at the characteristics and frequency of wildland fire activity since 1988. To better understand these concerns, a national fire-mapping project (Monitoring Trends in Burn Severity [MTBS] project) was initiated and sponsored by the Wildland Fire Leadership Council.

Location: Greater Yellowstone Area (centered on approximately lat 44°47′N, long 109°4′W), Wyoming, USA.

Methods: The MTBS project is mapping fire perimeters and burn-severity characteristics on fires occurring 1984 through 2010. The mapping process uses the USGS archive of Landsat TM imagery for this analysis. Pre-fire and post-fire images are terrain corrected, converted to “at satellite” reflectance, processed through the normalized burn ratio transformation, and differenced to provide a measure of the level of change resulting from a fire. The differenced normalized burn ratio data are categorized into ecological severity classes.

Results: These two data sets provided an opportunity to contrast the different mapping products. A comparison of the fire perimeters between these two mapping efforts showed good general agreement. The mapping of fire effects from the NPS 1988 analysis was completed on the single-date image acquired in October 1988. This initial assessment provided good definition between burn and non-burned vegetation, easily identifying both herbaceous and timber burn boundaries. However, image characteristics from late summer have low sun illumination that cause shadow issues in regions of higher terrain. Limited areas along the eastern and northeastern regions of the park had shadow issues that prevented the interpretation of burn characteristics. Fires occurring prior to 1988 also provided some misinterpretation on the 1988 analysis. The 1979 Washburn Fire and the Sulphur and Astringent fires from 1981 (these three fires totaled 8,300 acres) all had spectral burn characteristics that caused them to be included in the interpretation of fires for 1988. The MTBS multi-date image differencing process with pre- and post-fire imagery acquired during the summer months of 1987 and 1989 avoided issues with shadows and previous burns. However, this process had some minor problems with identification of herbaceous burned areas. Comparing the burn classes identified by these two efforts was confounded somewhat by differences in burn severity class definition. An assessment comparing burn classes representing stand-replacing burn severity classes showed good agreement with 73.5% of the MTBS high-severity class being represented by NPS crown burn classes and with 78.1% of the NPS crown burn class represented by MTBS high-severity class.

Conclusions: Overall, there was good agreement between the two mapping efforts. Differences noted between the two can be attributed to differences in imagery dates used in the delineations. In either analysis, the burn severity interpretations provide a foundation for studying vegetation reaction to fire effects.

keywords: burn mapping, burn severity, remote sensing.

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WILDLAND FIRE LEGACIES: TEMPORAL AND SPATIAL CONSTRAINTS OF HISTORIC FIRES TO CURRENT FIRE BEHAVIOR

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ABSTRACT

Question: Can the spatial and temporal landscape pattern of historic Āres inÈuence the occurrence, behavior, and size of contemporary Āres in the subalpine forests of Yellowstone National Park?

Background: In an earlier analysis of Āre occurrence and behavior in Yellowstone National Park (YNP), including large-scale Āre activity in 1988, we concluded: 1) Fuel moisture was the primary determinant of the severity of any given Āre season, with threshold moisture index values near or at the 90th percentile (13% 1000-hour fuel moisture) required before signiĀcant stand-replacing crown (SRC) Āre activity occurred; and 2) Lightning-caused Āre (LCF) occurrence and SRC Āre behavior was not random, but was constrained by forest cover type (FCT) up to the 98th percentile (10% 1000-hour fuel moisture) conditions. SpeciĀcally, >250-year-old mixed lodgepole pine (*Pinus contorta*)–Engelmann spruce (*Picea engelmannii*)–subalpine Ār (*Abies lasiocarpa*) forest types (LP3, SF) were shown to ignite easily and burn readily, whereas <50-year-old recently burned pioneering (LP0) and early-successional lodgepole pine forests (LP1) did not. Extended drought through the 99th percentile, extreme wind events, and/or large expanses of active Āre front ameliorated FCT constraints to Āre behavior. Consequently, Āre occurrence and SRC Āre behavior since 1988 should reÈect similar patterns of where individual lightning-caused Āres originate, what they burn, and ultimately the size they achieve given the overriding inÈuence of weather on fuel moisture. Recognizing such relationships would be of importance to Āre managers for future planning.

Location: Yellowstone National Park (lat 44°38′N, long 110°33′W), Wyoming, USA.

Methods: Using difference-normalized burned ratio (DNBR) data, 2002 color-infrared, and 2006 color-aerial photography, we delineated the forested area burned (>50% overstory mortality) for each of 29 Āres >100 perimeter acres from 1989 to 2006. The FCT map was queried for the distribution of 432 LCF starts and the area burned by FCT. The null hypothesis, that LCF occurrence and SRC Āre behavior were random among the YNP FCTs, was tested. The behavior of individual Āres was also illustrated.

Results: Fire occurrence was not random with respect to the distribution of FCTs, but starts occurred more frequently than expected in the LP3, SF, and Douglas-Ār (*Pseudotsuga menziesii*; DF) FCTs. On the other hand, recently burned forests which occupy some 41% of the total park forested area experienced only 16% ($n = 71$) of the LCF starts. SRC Āre behavior followed a similar pattern among the seral lodgepole pine FCTs for the 44,860 acres burned since 1988. Recent burns and thinning LP1 stands (<150 years old) demonstrated a strong negative association with SRC Āre, whereas reinitiating stands (LP2, >150 years old), mixed-canopy, old-growth LP3 (>250 years old), and >300-year-old climax SF experienced a signiĀcant positive association with SRC, generally growing stronger with increasing stand age. Quantitative data were supported by the behavior of individual Āres. Free-burning Āres during years when threshold moisture levels were not achieved did not exhibit signiĀcant growth despite burning in favorable FCTs for long durations. Younger forest stands repeatedly inÈuenced the spread, intensity, and size of free-burning Āres during threshold fuel moisture conditions. Despite the limited opportunity to observe SRC Āre in these younger stands, we identiĀed that sufficient biomass (>45% ground cover) of cured herbaceous fuels and wind-driven crown Āre in adjacent highly Èammable stands were required to supersede fuel moisture/FCT interactions in recent burns and LP1, respectively.

Conclusions: Given: 1) that all of the subalpine forests of the Yellowstone plateau were born of Āre; 2) the measurable change in the likelihood for lightning-caused Āre occurrence and crown Āre behavior occurring in the lodgepole pine chronosequence between 150 and 250 years old; and 3) the behavior observed on a number of individual free-burning Āres, we conclude that historic Āres can inÈuence the occurrence, behavior, and size of current Āres. Such is a "wildland Āre legacy" that can persist for as long as 200 years under fuel moisture conditions that occur up to 98% of the time.

keywords: Āre occurrence, forest cover type, fuel moisture, stand-replacing crown Āre behavior, wildland Āre legacy, Yellowstone National Park.

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THE 1988 YELLOWSTONE FIRES AND CROWN FIRE MODELING IN BEHAVEPLUS

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ABSTRACT

Question: How methodology was developed to predict crown fire behavior.

Background: The 1988 Yellowstone fires and others like them in the Northern Region of the United States spurred Richard Rothermel to develop a methodology for predicting crown fire behavior.

Location: Northwest United States.

Methods: Rothermel used field data from fire progression maps to address the problem of how to predict the rate of spread, intensity, and size of expected crown fires. Rothermel's 1991 publication *Predicting Behavior and Size of Crown Fires in the Northern Rocky Mountains* (Res. Pap. INT-438. USDA For. Serv., Intermountain Res. Sta., Ogden, UT) provides methods for making a first approximation of the behavior of a running crown fire. Rate of spread was developed from field data correlated with predictions of Rothermel's surface fire spread model. Energy release from surface fuels was obtained from Albini's burnout model. Fireline intensity was estimated using Byram's model. Flame lengths were estimated from Thomas' model. Energy release rate, or power developed by the fire and ambient wind, was developed from Byram's equations and used to ascertain the possibility of a wind-driven or plume-dominated fire. Rothermel discussed characteristics of these fires and dangers to firefighters. In addition, a simple elliptical model was developed for estimating the area and perimeter of a large fire.

Results: Rothermel's crown fire paper is oriented for use by well-trained fire behavior analysts to use in the field without the aid of computers to assess the characteristics of running crown fires.

Conclusions: Rothermel's crown fire spread model is included in computer fire-modeling systems such as BehavePlus, FlamMap, and FARSITE. It is used in conjunction with Van Wagner's models to predict transition from surface to crown fire and for predicting active crown fire. The help system of BehavePlus includes diagrams of the relationship among input variables, models, and results. The BehavePlus fire modeling system is designed to be used by people with the training and experience needed to make informed decisions about assigning appropriate input values and interpreting results. Tables and graphs are produced as output to show the effect of a range of values on the predictions. It is worthwhile for people to use BehavePlus to gain an understanding of the models in order to better interpret results from spatial systems such as FARSITE and FlamMap. The BehavePlus program and supporting documentation, including training material, is available from www.BehavePlus.FireModels.org.

keywords: crown fire, fire behavior, modeling systems, rate of fire spread.

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RECENT ADVANCES IN MODELING THE ONSET OF CROWNING AND CROWN FIRE RATE OF SPREAD

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ABSTRACT

This presentation will provide an overview of several models and modeling systems developed by the authors over the past 10 years for simulating certain aspects of crown fire behavior. Based on a wealth of high-quality fire behavior data collected over some three decades of experimental burning principally in Canada, the authors have developed and tested several empirical and semi-physically-based models aimed at predicting the onset of crowning, the type of crown fire (i.e., passive or active) and the associated rate of spread.

Three broad types of models were developed to describe the onset of crowning. Four empirical-based models describing the probability of crown fire initiation were developed based on logistic regression analysis; these models require canopy base height, certain components of the Canadian Forest Fire Weather Index System and/or wind speed as input variables. Another logistic regression model that provides an estimate of the likelihood of crown fire occurrence relies on wind speed, fine dead fuel moisture, canopy base height, and surface fuel consumption as input variables. Fine dead fuel moisture is estimated from Rothermel's 1983 "how to" fire behavior prediction manual procedure (using the >51% degree of shading option).

To overcome some of the perceived limitations of the fully empirical models, we also developed a semi-physically-based crown fuel ignition model (CFIM). CFIM relies upon fluid dynamics and heat transfer principles coupled with some empiricism as necessary in order to predict the ignition temperature of canopy fuels above a spreading surface fire.

Models to predict the rate of spread of crown fires, spreading either by active or passive crowning regime, were developed through nonlinear regression analysis encompassing the effects of wind speed, fine dead fuel moisture, and canopy bulk density. Van Wagner's criterion for active crowning based on canopy bulk density is utilized in the passive crown fire rate of spread model and in determining when the conditions for active crown fire spread are met.

Both the onset of crowning and crown fire rate of spread models have been evaluated against experimental fire observations, including data from the International Crown Fire Modelling Experiment, and wildfire observations with favorable results, although additional research is needed in predicting passive crown fire rate of spread. Comparisons with other similar predictive models have also revealed the relative robustness of the models.

The models developed for predicting the onset of crowning and crown fire rate of spread have been integrated into two different fire behavior modeling systems. The Crown Fire Initiation and Spread (CFIS) software system comprises the empirical-based models for predicting the likelihood or probability of the onset of crowning, type of fire (i.e., surface, passive crown, or active crown), and crown fire rate of spread. It also includes a simplistic model for estimating the minimum spotting distance required to increase a fire's overall forward rate of spread, assuming a point ignition and subsequent fire acceleration to an equilibrium rate of spread based on the predicted crown fire rate of spread and ignition delay as inputs.

CFIS is considered most applicable to free-burning fires that have reached a pseudo–steady state, burning in live, boreal, or boreal-like conifer forests found in western and northern North America (i.e., they are not applicable to insect-killed or otherwise "dead" stands). Furthermore, the models underlying CFIS are not applicable to prescribed fire or wildfire situations that involve strong convection activity as a result of the ignition pattern. Level terrain is assumed, as the CFIS does not presently consider the mechanical effects of slope steepness on crown fire behavior, although this is being planned for in a future version of the system.

Pine Plantation Pyrometrics (PPPY) is a modeling system developed to predict fire behavior in exotic pine plantations found in Australasia over the full range of burning conditions in relation to proposed changes in fuel complex structure from fuel treatments. The system comprises a series of sub-models, including CFIM and elements of CFIS, that describe surface fire characteristics and crown fire potential in relation to the surface and crown fuel structures, fuel moisture contents, and wind speed. A case study application of the PPPY modeling system has highlighted the complex interactions associated with fuel treatments such as pruning and thinning have on surface and crown fire behavior potential.

The models comprising CFIS, CFIM, and PPPY and the evaluation results have been published in various scientific and technical peer-reviewed journals (e.g., *Forest Science*, *Canadian Journal of Forest Research*, *International Journal of Wildland Fire*, *Australian Forestry*, *Forestry Chronicle*). Publications describing CFIS, CFIM, and PPPY, including the CFIS software, are available for downloading from the *FIREHouse—The Northwest and Alaska Fire Research Clearinghouse* Web site (http://www.fs.fed.us/pnw/fera/firehouse).

The authors are willing to work with individuals and organizations interested in implementing and evaluating the performance of crown fire behavior models and modeling systems for use at the local level.

keywords: crown fire initiation, crown fire occurrence, extreme fire behavior, fire behavior, fire dynamics, fire potential, modeling systems, models, rate of fire spread, spotting.

Citation: Alexander, M.E., and M.G. Cruz. 2009. Recent advances in modeling the onset of crowning and crown fire rate of spread [abstract]. Page 19 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

ASSESSING DISCONTINUOUS FIRE BEHAVIOR AND UNCERTAINTY ASSOCIATED WITH THE ONSET OF CROWNING

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ABSTRACT

Question: How can one integrate the natural variation in the variables influencing fire propagation associated with the prediction of crown fire behavior?

Background: Fire behavior in horizontally or vertically discontinuous fuel complexes, such as found in certain conifer forests, is often characterized by sudden changes in rate of spread and intensity. This discontinuous behavior occurs as discrete events, where small changes in the variables driving the fire, e.g., wind speed, cause large and abrupt increases in rate of spread and energy output of the fire. These features have been observed in wildfires and quantified in experimental and prescribed fires. From a heuristic point of view, the slight changes in the fire environment conditions allow the fire to transition into a new fuel layer where distinct combustion and heat transfer dynamics lead to a higher "steady state" rate of fire spread. A fire burning under a set of environmental conditions in the vicinity (above or below) of the threshold conditions for transition into a new fuel layer can be considered to be propagating in an unstable regime. Besides the sudden changes in fire behavior, which for rate of spread can be up to an order of magnitude higher, fires in this regime present bimodality and hysteresis.

The forecast of fire behavior following the conventional method of "best prediction" based on the best estimate of input variables can lead to large errors when fire is spreading under this unstable regime. We propose an alternative method based on ensemble modeling that aims to incorporate the uncertainty that exists in the input variables. This approach allows one to estimate the uncertainty associated with fire behavior predictions, namely an error term associated with the mean prediction and present probabilistic outcomes (e.g., likelihood or probability of occurrence of a certain event).

Location: Australia, but the general results are deemed universally applicable to conifer forests.

Methods: We apply a fire behavior modeling system that describes surface fire characteristics and crowning potential (e.g., identify the onset of crowning, type of crown fire, and associated rate of spread) through a Monte Carlo ensemble method that considers the uncertainty in the estimation of the modeled weather and fuel inputs. We assess the system outputs through its application to a recently documented wildfire case study in an industrial radiata pine (*Pinus radiata*) plantation in Australia.

Results: The application of the Monte Carlo ensemble method expanded the type of outputs arising from the application of the fire behavior modeling system. The method allowed for 1) quantifying the variability in predicted rate of spread and fireline intensity through measures of variability; 2) an estimate the probability of crowning; and 3) the probability of the fire reaching certain threshold values (e.g., exceeding a fireline intensity level for direct attack suppression tactics).

Comparison between the deterministic and ensemble results indicates departures between the two models when simulations are carried out in similar conditions that lead to the onset of crowning. The ensemble method predicts higher rates of spread when the deterministic method output is below the threshold for crowning and lower rates of spread if the deterministic method indicates crowning. Outside this transitional range, the outputs from both methods are essentially equal as demonstrated through a Taylor series expansion.

The evaluation of the method against selected burning periods of the Billo Road Fire (New South Wales, Australia, 2006) provided insight into its validity to predict fire behavior, namely in quantifying intermittent crown fire behavior (e.g., percentage of crown fire occurrence or flame defoliation) and the variability inherent to such nonlinear phenomena (e.g., coefficients of variation varying between 0.13 and 1.5).

Conclusions: The present work highlights the advantage of incorporating the uncertainty in the estimation of the variables influencing the fire spread process to better assess the effect of nonlinear fire phenomena, such as the onset of crowning on free-burning fire behavior. The ensemble methods used not only enable an improved description of fire potential but also extend the range of questions that can be answered by fire behavior models, namely providing probabilistic outputs that can be linked to quantitative risk analysis.

keywords: crown fire behavior, ensemble methods, Monte Carlo, pine plantations, rate of spread.

Citation: Cruz, M.G., and M.E. Alexander. 2009. Assessing discontinuous fire behavior and uncertainty associated with the onset of crowning [abstract]. Page 20 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

SPATIAL AND TEMPORAL EVOLUTION OF ATMOSPHERIC BOUNDARY-LAYER TURBULENCE DURING THE 1988 YELLOWSTONE FIRES

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ABSTRACT

Question: Was ambient atmospheric turbulence a significant factor during the 1988 Yellowstone wildfires?

Background: Previous studies suggest that large wildfire events are often associated with episodes of significant atmospheric boundary-layer turbulence (i.e., wind gusts) that can contribute to extreme or erratic fire behavior. Wind gusts are manifestations of turbulent eddies generated by wind shear and buoyancy effects, which can be very large in the atmospheric boundary layer. The amount of energy contained in these eddies is referred to as *turbulent kinetic energy* (TKE). Simulations and predictions of TKE are now possible in many of the current research and operational atmospheric mesoscale and boundary-layer models, providing an additional tool for assessing how conducive the atmosphere may be to extreme or erratic fire behavior. For this study, the fifth-generation Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model (MM5) is used to simulate the spatial and temporal evolution and patterns of boundary-layer TKE during the 1 August 1988 to 10 September 1988 period in the vicinity of the Yellowstone fires. Fire spread rates are compared to the simulated TKE variations to assess the impact that ambient atmospheric boundary-layer turbulence may have had on the erratic and extreme behavior of the Yellowstone fires. The relative significance of ambient wind shears and thermal instability (buoyancy) in generating the turbulence environment in the vicinity of the Yellowstone fires is also examined.

Location: Yellowstone National Park (study area center approximately lat 44°30′N, long 110°30′W) and surrounding area, including the states of Montana, Wyoming, Idaho, and northern Utah, USA.

Methods: Numerical simulations using MM5 were carried out on a 4-km-grid spacing domain centered over northwestern Wyoming and covering the period of 1 August 1988 to 10 September 1988. Simulated fields of TKE, Haines Index (HI), wind speed, and Richardson number were analyzed to characterize the ambient atmospheric turbulence regimes during this period. Simulation results were also compared to observed spread rates for the Clover-Mist, Snake, and North Fork wildfires that occurred during this period.

Results: Numerical simulations revealed numerous episodes of significant boundary-layer turbulence during and in the vicinity of the 1988 Yellowstone fires. Occurrences of concurrent high HI and high near-surface TKE values (HI × TKE > 15 $m^2 s^{-2}$) were also common during the fires. Periods of rapid fire spread often occurred during periods when (HI × TKE) values exceeded the 15 $m^2 s^{-2}$ threshold, a value indicative of an ambient atmospheric environment conducive to erratic fire behavior. While peaks in near-surface TKE were generally associated with large wind shears, calculated Richardson numbers suggest that thermal instability (buoyancy) near the surface was still the dominant mechanism for generating ambient turbulence during the wildfires. Temporal variations of TKE during the wildfires were tied to the diurnal cycle, with turbulence throughout the boundary layer generated during the day and suppressed at night. Downward propagation of turbulence from above the boundary layer was not a significant factor.

Conclusions: The results from this study suggest that ambient atmospheric turbulence was significant during the 1988 Yellowstone fires and that this turbulence may have contributed to the behavior of the fires. The results are also consistent with the results from previous analyses of ambient atmospheric turbulence during wildfires in the north-central and northeastern United States, where daily predictions of near-surface turbulence and the product of the HI and TKE are now provided to fire managers (via the Eastern Area Modeling Consortium) as a tool for anticipating when ambient turbulence could contribute to erratic fire behavior. Additional analyses of ambient turbulence regimes during wildfires in the western United States are needed to determine if a predictive turbulence-based fire weather index would be effective there.

keywords: atmospheric turbulence, boundary layer, fire spread, modeling, turbulent kinetic energy, Yellowstone wildfires.

Citation: Heilman, W.E., and X. Bian. 2009. Spatial and temporal evolution of atmospheric boundary-layer turbulence during the 1988 Yellowstone fires [abstract]. Page 21 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The ’88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

YELLOWSTONE AND BEYOND: PYROCUMULONIMBUS STORMS SENT SMOKE TO THE STRATOSPHERE AND AROUND THE GLOBE

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ABSTRACT

Question: Did smoke from the Yellowstone fires of 1988 extend into the stratosphere?

Background: The historic 1988 Yellowstone fires drew immense attention to many aspects of the conflagrations. Despite the exhaustive analyses, reviews, and retrospectives, one important aspect remained unknown. On their worst days, some of the fires spawned pyrocumulonimbus (pyroCb) storms that injected smoke and other emissions into the upper troposphere and lower stratosphere. The discovery of wildfire smoke in the stratosphere was not made until 10 years after the 1988 events at Yellowstone. With the discovery of smoke in the stratosphere and techniques to identify pyroCb from space, a review of satellite data sets that enable pyroCb detection and impact assessment is possible. The applicable satellite record dates to 1979.

Location: Greater Yellowstone Area (centered on approximately lat 44°47′N, long 109°4′W), Wyoming, USA.

Methods: A global search for the peculiar clues to stratospheric smoke palls was conducted and pyroCb events were identified. A survey of these events is presented; the Yellowstone-area fires of 1988 are seen to have created several such distinctive smoke plumes.

Results and Conclusions: Multiple fires on several dates erupted into pyroCb blowups in summer 1988 resulted in these monstrous plume-driven storms. The result was volcano-like injection of smoke to jet stream altitudes and beyond, with concomitant intercontinental transport. Here we will identify the Yellowstone pyroCb "smoking guns," individual firestorms with a positive feedback dynamic that produces super-energetic pyroconvection—a process that has since been shown to perturb stratospheric aerosol optical depth on a hemispheric scale. In addition, we show evidence of stratospheric injection of smoke and relate the Yellowstone blowup conditions to the newly evolving understanding of "classic" pyroCb development.

Finally, we correlate the extreme Yellowstone pyroconvection with fire behavior indices such as Build Up Index and Fire Weather Index at two representative weather stations in Yellowstone, Mammoth and Old Faithful. Imbedded in the summer-long extreme fire weather conditions, the pyroCb blowup dates transcended even these great extreme-condition indices.

keywords: plume, pyrocumulonimbus, pyrocumulus, pyroCb, smoke, stratosphere.

Citation: Fromm, M., D. Lindsey, B. Stocks, R. Servranckx, and D. Quintilio. 2009. Yellowstone and beyond: pyrocumulonimbus storms sent smoke to the stratosphere and around the globe [abstract]. Page 22 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

PREDICTING YELLOWSTONE: DECISION SUPPORT OF THE PAST, PRESENT, AND FUTURE

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ABSTRACT

Question: If we went back in time and produced a seasonal outlook for Yellowstone 1988, what would it have looked like? How does the information differ between then and now? What have been the important advances in decision-support during the past 20 years? And what might be the decision-support topics in the next 20 years?

Background: In 1988, only a limited amount of weather station data were available, but sufficient data were available to assess regional climatic patterns, such as paper maps of the Palmer Drought Severity Index. Computer-aided climate information was extremely limited in 1988 compared with the vast amounts of data and graphics available today, and the National Oceanic and Atmospheric Administration seasonal climate outlooks were not in production until the late 1990s. Though it was widely known in April 1988 of the previous autumn–winter drought in the park, the spring season was generally wet. At the time, this led to general opinions of minimal concern regarding the fire season. However, it is likely that given the climate and fuels information available in April, Predictive Services (had they existed at the time) would have highlighted the Yellowstone region as above-normal significant fire potential, largely based on the longer-term underlying drought pattern. But it is unlikely that the extent and severity of the summer fire season would have been predicted far in advance. Further, the number of dry cold fronts and associated high wind events that were significant contributing factors during the summer would not have been predicted in the seasonal outlook.

Decision support tools in 1988 were quite limited compared with those of today. Only two tools directly related to fire weather/behavior/danger were widely available at the time. These were the National Fire Danger Rating System (NFDRS) becoming available in 1978, and the Behave program developed by the Missoula Fire Sciences Lab in 1985. Both of these tools were foundational developments and are in wide use today. Today there are at least nine major decision support tools directly related to fire weather/behavior/danger, including NFDRS, BehavePlus, FireFamilyPlus, FARSITE, FlamMap, WFAS (Wildfire Assessment System), Wind Wizard, WindNinja, and FireStem. In addition to these desktop/Internet tools, there are at least four other larger-scale systems/information for decision-support utilizing fire weather/behavior/danger, including FPA (Fire Program Analysis), WFDSS (Wildland Fire Decision Support System [replacing the Wildland Fire Assessment System]), Landfire, and Bluesky/FCAMMS (smoke tools and the Fire Consortia for Advanced Modeling of Meteorology and Smoke). Gridded weather data sets and landform data sets are becoming more readily available in these systems.

Conclusions: Given the plethora of decision-support tools today (covering the various aspects of fire business and not just fire weather/behavior/danger), there is a seeming paradox. With >30 years of tool development, each claiming to be better than what was before and many developed at considerable expense, why is the fire problem getting worse? Indeed, it is most likely that for the specific applications that each tool was developed, the information provided has been highly beneficial for decision support, leading to firefighter safety and cost savings as two of the most important factors among others. But the paradox comes from two places not being addressed by decision support tools. First, most of the increasing important influences on fire risk are non-climatic factors such as the wildland–urban interface, changing values across the landscape, public perceptions, etc. To varying extents, these factors are not purely non-climatic because, for example, population growth in the West is partially environmentally (and hence climate) driven. But current decision support tools focus primarily on the physical system and costs; they do not yet account for the various societal components that define much of the risk.

Second, and the greater underlying reason for the paradox, is that fire business currently operates in an applications framework versus an adaptation framework. What is meant by this distinction? Applications research concentrates on the incorporation of new knowledge or experience into existing models, decision processes, and practices. This is the historical and current model of technology transfer for the fire agencies (among others), and programs such as the Joint Fire Science Program. Roger Pulwarty (at a 2008 American Meteorological Society annual meeting presentation) has suggested that instead what is needed is adaptation research based upon three essentials: 1) the most important learning involves values, norms, goals, and the basic "framing" of issues in terms of the drivers and importance; 2) innovative partnerships; 3) using facilities to cope with immediate problems, and leaving slack or reserve for coping with conjunctive or future problems. Effective adaptation research is done by coproduction and its usability and legitimacy is addressed at the onset of the work. This type of research can be more closely identified with the term "end-to-end" research.

Recommendations: We offer some ideas of how decision-support might evolve and some new tools over the next 20 years:

- Gridded data will be commonly accepted in operational and fire management activities.
- Finer-scale physics models will be more commonly available, given increased computing power.
- Probabilistic forecasts will be widely available and well understood by the user community.
- There will be improved climate/fire forecasts (particularly in the areas of relative humidity, wind, and biogeophysical modeling).
- Detection-based fire growth modeling with increased usage of remote sensing by aircraft and unmanned aerial vehicles.
- Incorporation of climate predictions/extremes information into decision support tools to account for the rapidly changing climate of the 21st century.
- Development of decision support tools to support long-term (decadal–century scale) planning.
- Tools that focus on the societal components of risk.
- Tools that emphasize mitigation and adaptation strategies.

We thank Rick Ochoa for input into the presentation.

keywords: decision support tools, Predictive Services, research.

Citation: Brown, T., and T. Wordell. 2009. Predicting Yellowstone: decision support of the past, present, and future [abstract]. Page 23 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

COULD FUELS MANAGEMENT HAVE ALTERED THE OUTCOME OF THE 1988 YELLOWSTONE FIRES?

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ABSTRACT

Question: Could fuels management have altered the outcome of the 1988 Yellowstone fires?

Background: Understanding the biophysical setting in Yellowstone Park in 1988 is crucial to an understanding of the fire–fuels situation. Long-term historic fire exclusion in the park created a vast acreage of similar fuels. When the U.S. Army began their occupation of the park in 1886, they immediately began to put out fires. They suppressed 60 in that first fire season. Actual fire-history work shows a steady decrease in fire occurrence and loss of the mosaic of age classes in the dominant lodgepole pine (*Pinus contorta*) forest. By 1988 the youngest mosaic class of significant acreage was approximately 150 years old. Historically effective barriers to rapid crown fire spread (previous large fires) no longer existed in vast areas of the park.

Location: The Greater Yellowstone Area (GYA), or Yellowstone National Park, Grand Teton National Park, and the six surrounding national forests, comprise 11.7 million acres (lat 44°22′N, long 110°42′W).

Methods: A variety of published papers were reviewed and compared concerning fuel treatment effectiveness. Addressed were prescribed burning on a large scale to limit fire spread, large strategic thinning projects as currently proposed on national forests, and systematic removal of fuels adjacent to high-value structures combined with modified building design and materials.

Results: Large-scale prescribed burning was impractical given the infrequency of adequate fire weather for prescribed fire behavior to be representative of ecologically acceptable lodgepole pine fires. As for thinning, very few fuel treatments studies exist where surface fuels were known following treatment and prior to wildfire impact. Once above low-elevation, high-fire-frequency pine types, thinnings made the forest floor hotter, drier, and windier, actually increasing fire behavior, all other factors being equal. It appeared to be "fool" management instead of fuel management, as untreated controls had lower fire-induced mortality than thinned plots. Systematic removal of surface fuels directly adjacent to structure foundations, removing adjacent trees, and eliminating combustible roofing would have made the defense of structures appear less hectic and better planned than it did during the 1988 fires. A trained landscape architect could design the removal trees near buildings to look "meadow like" to most tourists. It appears that many current recommendations for protecting structures on the urban–wildland interface continue to go unheeded in the park. Current fire behavior models seem to be crudely inadequate to evaluate the worth of most fuel treatments applied to lodgepole pine forests.

Conclusions: Could fuels management have altered the outcomes of the 1988 Yellowstone fires? My answer is "no," if the outcome of concern was the vast acreage burned over months of time. The scale of such treatments needed would have been unimaginable in 1972 and such massive prescribed burning would have been socially unacceptable. I would answer "yes," if the systematic removal of surface fuels directly adjacent to structures and having noncombustible roofing materials would have made fire managers appear prepared to defend structures in a long-planned operation designed to deal with expected fire behavior.

keywords: fuel management, lodgepole pine, prescribed burning, thinning, urban–wildland interface.

Citation: Wakimoto, R.H. 2009. Could fuels management have altered the outcome of the 1988 Yellowstone fires? [abstract]. Page 24 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

CLOSING REMARKS: WHAT DID WE LEARN AND WHAT MUST WE DO TO AVOID RELEARNING IT?

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ABSTRACT

Almost every conceivable aspect of Greater Yellowstone Area (GYA) fuels, weather, and topography was covered at the Yellowstone Fire Behavior, Fuels, and Weather session. From fuel types to vegetation and fuel mapping, from crown fire modeling to fire behavior prediction, from synoptic weather patterns to fire weather and fire danger, from pyrocumulonimbus to international smoke transport, speakers established the rationale for the "off the chart" fire behavior outcomes that occurred in 1988.

The largest of the GYA fires of 1988, growing to a massive scale over the course of the fire season, served as a harbinger of what was coming in the following years. How we retain and retrieve the Lessons Learned from the 1988 GYA fires is a crucial question to be answered in a way that allows fire management personnel to modify their personal behavior to better apply the lessons from the past.

In regard to Lessons Learned from 1988, before the ashes were cold in Yellowstone, Fire Behavior Analysts (FBAs) were calling for the routine summary of an incident's fire behavior to share with other FBAs. This summary was expected to contain the general nature of observed fire behavior, verification of measurements, adequacy of fire models selected, and any techniques developed to improve prediction capability. The suggestion was made that a central repository and clearinghouse could be created to make available or distribute the information. The presence of unique fire behavior phenomena—fire storms, independent crown fires, horizontal roll vortices, and significant long-distance spotting—provided a special incentive to record these uncommon events for future recall and application.

Developments since 1988 have provided a variety of approaches to establish a focal point for fire behavior principles and the retrieval of that information in real time. In the short term, Fire Behavior Service Centers have been used successfully in extreme fire seasons to provide a spectrum of fire behavior knowledge to Fire Behavior Analysts and Incident Command Teams. These Fire Behavior Service Centers have provided historical, current, and projected fire behavior expected outcomes under a variety of weather scenarios. Also, the Wildland Fire Lessons Learned Center has Web site links to fire behavior case studies that present important fire behavior lessons learned in an easily retrievable format. Another approach under consideration is based on discussions between Forest Service scientists and representatives of Google Earth to retrieve and geographically display fire behavior for real-time Wildland Fire Decision Support Systems. We learned a lot during the Fires of 1988 and Beyond, and there is promise that those lessons and others are going to be readily retrievable in the future.

A thorough review of the major fires in the Greater Yellowstone Area in 1988 (Davis and Mutch. 1989. West. Wildlands 15(2):2–9) focused attention on seven areas needing attention to strengthen the implementation of fire management policies: fire research, planning, decision making, operational management, qualifications and training, public and firefighter safety, and public information. Capturing significant fire behavior insights for future applications is an additional issue to resolve.

Although some observers stated in the 1970s that Yellowstone National Park was not large enough to contain freely burning natural fires (and, indeed, Clover-Mist spread out of the park to the east in a major way), agencies applied lessons learned in such a significant manner that many large national parks and wildernesses in the West later developed successful prescribed natural fire programs.

Perhaps the closing lines from a poem (2008. Mutch, R.W. I was there. 3 pp.) composed following the Yellowstone and Beyond Conference provide some insights as to what might be coming in the future:

The cycle continues and life goes on
The short return interval of cascading geyser
And the long return interval of lodgepole pine fires

But to what future?

Summer seasons much longer . . .
Temperatures warmer . . .
Drought seemingly ever-present
Bark beetles now flying twice

The new shake roof on the Inn
Dry, receptive, flammable
An invitation to some later day fire?

Twenty years from now bringing what?
Unknown fire and unknown effects?

But certainly there will be this:

A complex array of images seen or imagined

Phantasmagoria—Yellowstone lives

Citation: Mutch, R.W. 2009. Closing remarks: What did we learn and what must we do to avoid relearning it? [abstract]. Page 25 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

FIRE BEHAVIOR, WEATHER, AND FUELS

A CASE STUDY OF CROWN FIRE IN AN EARLY POST-FIRE LODGEPOLE PINE FOREST

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ABSTRACT

Question: Basic crown Āre behavior measurements are presented for an early post-Āre (18 years old) lodgepole pine forest in Yellowstone National Park.

Background: Fire behavior models are an important tool for predicting rate of spread, Èame length, Āreline intensity, and other characteristics of wildland Āres. For high-Āre-intensity, stand-replacing ecosystems like lodgepole pine (*Pinus contorta*), crown Āre models are more useful than surface models but are not as well veriĀed by Āeld measurements. A compounding challenge recognized by Āre managers in Yellowstone National Park is to improve Āre behavior predictions in the extensive areas burned in the Āres of 1988 that are currently regenerating to lodgepole pine. Fires in these areas during the 2000–2006 Āre seasons were capable of extensive spread under low fuel moisture conditions and wind. Fire spread is primarily through crowning and spotting, making a crown Āre model appropriate. We used remotely triggered thermal event data-loggers, Āre monitoring observations, and fuel measurements to estimate basic crown Āre parameters for the 2006 Stinky Fire: spread rate, Āreline intensity, and mass Èow rate. Periods of measurement corresponded to transitional crown Āre behavior, making the results particularly useful for estimating the threshold mass Èow rate between passive and active phases used in crown Āre models.

Location: Northeastern Yellowstone National Park, Wyoming (lat 44°47′N, long 110°4′W), USA.

Methods: Passive and active crown Āre behavior was observed on 18 and 23 August 2006 at geo-referenced locations. Rates of spread were determined from observation and from three thermal-event data-loggers buried in the ground ahead of the Āre front. Surface and canopy fuels were measured post-Āre in an adjacent, representative stand. Fuel measurements and spread rates allowed us to calculate mass Èow rates and Āreline intensities for passive and active crown Āre behavior.

Results: Available canopy fuel load at the Stinky Fire was 0.96 kg m^{-2}. The canopy base height was essentially zero. Mean tree height in the canopy fuel plots was 2.8 m and mean maximum height was 5.9 m. Canopy bulk density was relatively high, 313 g m^{-3}. Fire behavior varied under the weather conditions observed but generally favored upslope spread aligned with the prevailing SWW wind. Passive phase spread rate was 2.6–4.1 m min^{-1}, and active phase was 11.9–13.4 m min^{-1}. Passive crown Āre mass Èow rate ranged from approximately 13 to 22 g m^{-2} s^{-1} and active mass Èow rate ranged from approximately 62 to 70 g m^{-2} s^{-1}. Resulting Āreline intensities ranged from 2,070 to 3,323 kW m^{-1} for passive crown Āre and from 9,652 to 10,833 kW m^{-1} for active crown Āre.

Conclusions: Active crown Āre spread rates were relatively slow in relation to other documented Āres, possibly due to bias (few observations from Rocky Mountain lodgepole pine forests), or due to factors related to stand age or surface fuel characteristics. Our measurements support a previously hypothesized threshold mass Èow rate of 50 g m^{-2} s^{-1} separating passive and active crown Āre behavior. Crown Āre modeling as a whole will beneĀt from Āeld observations of Āre behavior and measurements of canopy fuels. The ability to quickly assess canopy fuels ahead of unplanned wildĀres and to safely observe free-burning crown Āre behavior requires skilled Āre monitors and support staff. Agencies with the ability to ignite prescribed crown Āres or allow crown Āres to burn under free-burning prescriptions are urged to collect this information.

keywords: canopy bulk density, canopy fuel load, crown Āre, mass Èow rate, *Pinus contorta*.

Citation: Miller, E.A., R.A. Renkin, S.C. McEldery, and T.J. Klukas. 2009. A case study of crown Āre in an early post-Āre lodgepole pine forest [abstract]. Page 26 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

A PRELIMINARY ANALYSIS OF ENERGY AND FLUID DYNAMICS ASSOCIATED WITH THE THIRTYMILE FIRE

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ABSTRACT

Question: What was the root cause of the fire behavior that resulted in entrapment of firefighters on Thirtymile Fire?

Background: The Thirtymile Fire burned in central Washington during July 2001. Tragically, four young firefighters died while fighting this fire. The fire burned up the wide north/south-oriented valley through mature conifer forest without any strong synoptic flow. Firefighters initially had time to select a location from which to watch the fire; however, they were eventually forced into fire shelters. Post-fire examination of the deployment site suggested the presence of high-temperature, narrowly confined, surface-level jets that advected hot gases along the ground surface for sufficient time to scorch and/or ignite litter and dead wood on the ground. It appears that at least four of the firefighters deployed fire shelters in a location where this low-level jet occurred. The source and phyics underlying this specific fire behavior are not readily obvious. This study is an attempt to identify the underlying physical mechanisms that resulted in the observed fire behavior.

Location: Thirtymile Fire location about 30 miles north of Winthrop, Washington, USA, centered at approximately 48.5°N, 120.1°W.

Methods: Using state-of-the-art engineering computational fluid dynamics solvers, we explore possible interactions between the plumes generated by the fire, the general atmospheric flow, and the terrain features.

Results: Initial simulations explored the interaction between the low-velocity synoptic flow and the terrain. No buoyancy effects due to the presence of fires was included. The analysis indicated a general flow direction up canyon, but no obvious locations with locally high surface wind velocity that would explain the extremely high intensity fire behavior or low-level surface advective jets. A second set of simulations was conducted with the fire near the location of the deployment site simulated as an inlet (through the ground surface) of high-temperature low-flow rate gas. Two inlets were introduced in the approximate location of the conifer stand immediately east across the creek from the road and deployment site. Visual examination of the predicted surface flow in the region of the deployment zone indicate not only rotational interaction between the two plumes, which would have induced strong local turblence, but also very strong rotational turbulence at the ground surface in the vicinity of the deployment zone. The results suggest that interactions between the local but high-intensity fire burning in the mature forest combined with terrain-induced influences on the indraft to the fire base. This interaction could have led to high-intensity turbulent advection of high-temperature gases out of the primary plume of the fire across the creek and over the entrapment site.

Conclusions: A simulation of surface flow without considering the fire/atmosphere interaction did not provide an explanation for the complex fire behavior and flow that seemed to be indicated by post-fire evidence. Simulation of the fire as a simple gas inlet with high temperature and low flow provided a qualitative explanation of one possible cause of the complex fire dynamics that occurred over the entrapment site.

keywords: fire behavior, fire intensity, fire simulation, wind flow.

Citation: Butler, B., J. Forthofer, and D. Jimenez. 2009. A preliminary analysis of energy and fluid dynamics associated with the Thirtymile Fire [abstract]. Page 27 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

DETAILED MEASUREMENTS OF VERTICAL DISTRIBUTION OF RADIATION EMISSIVE POWER IN WILDLAND FLAMES

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ABSTRACT

Question: What is the intensity and spatial distribution of radiant energy emitted from wildland Èames?

Background: Fire behavior models assume or simulate the energy source for ignition to be the Èame and burning fuel in and above the fuel array. Few quantitative measurements of the emissive power as a function of vertical height above the ground have been reported.

Location: Various laboratory and Āeld study sites in Northwest Territories, Canada, and Missoula Fire Sciences Lab, Missoula, Montana, USA.

Methods: Schmidt-Boelter–style heat Èux sensors measure surface incident radiant Èux and thermopile-based sensors sense radiant emissive power from a restricted volume of Èame. Data are collected at nominally ±1 Hz. Two primary measurement sets are analyzed: one set was collected in the International Crown Fire Modelling Experiment conducted from 1997 to 2000 in Northwest Territories of Canada and the second set from Āre experiments conducted in the Missoula Fire Sciences Laboratory.

Results: Data from the International Crown Fire Modelling Experiment indicate peak values in the range of 150–200 kW/m^2. Flames were 15–24 m (50–80 feet) tall, with signiĀcant transmission of energy through the upper portion of the canopy. Peak energy levels occurred below canopy top (roughly 14 m [45 feet] tall). The data suggest that peak radiant energy will occur within the fuel array rather than in the Èame above. Measurements made in the Missoula Fire Sciences Laboratory indicate peak heat Èuxes of nominally 80 kW/m^2. Flames were 0.9–1.2 m (3–4 feet) tall. Laboratory measurements indicate strong variation in emissive power with height. We found a nearly linear decrease in radiant Èux with height. The data suggest that extrapolation of laboratory data to full-scale Āeld applications may not be appropriate in the case of crown Āres.

Conclusions: The data presented here are representative of many other data sets and suggest that peak levels in the laboratory are not representative of crown Āre intensities. Additionally, the data suggest that Èames in compact surface fuels can reach heights on the order of 10 times the fuel bed depth, while crown Āre Èames seem to be limited to maximum heights of 2–3 times the canopy height. These data suggest the need for further analysis and study but illustrate signiĀcant differences between crown Āres and surface Āres with important implications for Āre behavior modeling.

keywords: Āre behavior, Āre intensity, Āre simulation.

Citation: Butler, B., and D. Jimenez. 2009. Detailed measurements of vertical distribution of radiation emissive power in wildland Èames [abstract]. Page 28 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

Rx-CADRE (PRESCRIBED FIRE COMBUSTION–ATMOSPHERIC DYNAMICS RESEARCH EXPERIMENTS) COLLABORATIVE RESEARCH IN THE CORE FIRE SCIENCES

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ABSTRACT

Question: Describe the Rx-CADRE project.

Background: The Rx-CADRE project was the combination of local and national fire expertise in the field of core fire research. The project brought together approximately 30 fire scientists from six geographic regions and seven different agencies. The project objectives were to demonstrate the capacity for collaborative research by bringing together individuals and teams with a wide range of fire monitoring expertise and equipment from across the United States and Canada in order to instrument prescribed burns in the southeastern United States. A concurrent workshop was organized that brought fire and fire effects modelers into the mix, creating the linkage between data generation and data use for fire and fire effects model validation and development. The group documented fire–atmospheric dynamics on prescribed fires in southern pine (*Pinus palustris*) woodlands of varying size, ranging from 10 to 1,000 ha. Specifically, we 1) compared in situ and remote-sensed heat environments of prescribed burns, 2) documented coupled atmospheric interactions, 3) produced validation data sets for coupled fire–atmospheric dynamic models, and 4) related fire behavior to first-order fire effects. On the fully instrumented fires, the group collected data on pre-burn fuel loads, post-burn consumption, ambient weather, in situ convective dynamics, plume dynamics, radiant heat release (both from in situ and remote sensors), in situ fire behavior, and select fire effects.

Location: Florida panhandle and southwestern Georgia, USA.

Methods: Six prescribed burns were fully instrumented with in situ, remote sensed, and real-time weather observation equipment over a period of 6 days at Eglin Air Force Base outside of Pensacola, Florida, and the Jones Ecological Research Center in Ichauway, Georgia. The collaborative effort allowed for a detailed understanding of fire behavior with relation to fuels consumption and monitored fire effects. The Rx-CADRE experiments brought together diverse fire research backgrounds into a concentrated field effort. Research correlating fire behavior (both in situ and remotely sensed) with fire effects, fuels consumption, and emissions sampling were conducted seamlessly and repetitively on each of the burn units. Fire behavior collected data with multiple in situ fire behavior sensor packages, wireless trigger cameras. Infrared (IR) cameras were used to calibrate the in situ fire behavior data. Fuel plots were systematically located in a two-chain (132 feet) grid in each of the units. Plot centers were marked, flagged, and numbered. Organic material, including grass, downed woody material, and litter, was collected before and after the fire. Moisture samples were also collected before each burn. Post-fire effects quantified cover fractions of soil, ash, litter, and vegetation in twenty 1-m^2 plots arranged systematically within each prescribed burn block. These plots were co-located with the fuel consumption plots. Aerial IR sensing was used to characterize the time course of heat release over entire burn units. Ground-based IR sensors were used to calibrate the aerial imagery. Real-time atmospheric interactions were conducted by measuring the micrometeorology and turbulence of fire-induced circulations. Additionally, some air quality measures, including $PM_{2.5}$ and CO_2 concentrations, were measured in the plumes.

Results and Conclusions: The Rx-CADRE experiments demonstrated the ability for collaborative and coordinated prescribed fire field research, which is a success in itself. The experiments were conducted repetitively and safely at each of the six individual burn units. The logistics associated with organizing experiments at this scale are monumental, and the success record is unsurpassed for field burns. A data collecting meeting is scheduled for fall 2008 and will also cover the preplanning process for subsequent follow-up burns in spring 2009.

keywords: fire behavior, fire effects, fire weather, Rx-CADRE.

Citation: Jimenez, D., B. Butler, K. Hiers, R. Ottmar, M. Dickenson, R. Kremens, J. O'Brien, A. Hudak, and C. Clements. 2009. Rx-CADRE (Prescribed Fire Combustion–Atmospheric Dynamics Research Experiments) collaborative research in the core fire sciences [abstract]. Page 29 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

METHODS FOR OBTAINING DETAILED WIND INFORMATION TO SUPPORT FIRE INCIDENT MANAGEMENT

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ABSTRACT

Question: What tools exist for simulating surface wind flow to support fire incident management decisions?

Background: Wind is one of the primary environmental variables influencing wildland fire spread and intensity. Indeed, wind and its spatial variability in mountainous terrain is often a major factor in the fire behavior associated with firefighter entrapments and/or fatalities (e.g., South Canyon Fire 1994, Thirtymile Fire, and Price Canyon Fire). Nevertheless, methods to obtain measurements and/or estimates of local wind speed and direction are not readily available. In many cases, wind information available to fire incident personnel is limited to weather forecasts and/or weather observations from a few specific locations, none of which may be actually near the fire. This study presents two tools that have been recently developed to supply detailed surface wind predictions.

Methods: Two models have been developed: 1) WindWizard consists of a solution of the governing differential equations describing conservation of mass and momentum for a computation domain constructed over the terrain of interest; 2) WindNinja solves only the conservation of mass equations for the same application.

Results: The process of producing gridded wind information consists of importing elevation data in the form of digital elevation model files into the computational fluid dynamics software and solving the equations to determine the flow speed and direction everywhere within the domain. The results from this set of calculations are then used to determined surface wind speed and direction at a fine scale (i.e., nominally 100 m) everywhere on the terrain of interest. Wind modeling for a specific fire typically consists of simulating several different combinations of wind speed and direction. The simulations are selected to match a forecasted scenario or are based on historical weather patterns. The simulation accounts for the influence of elevation, terrain, and vegetation on the general wind flow. Output files are geo-referenced so that they can be incorporated into standard Geographic Information Systems. Transfer of results from the wind simulations to fire managers and field personnel can occur in three different forms: 1) images consisting of wind vectors overlaid on a shaded relief surface image, 2) wind vectors displayed in GoogleEarth images, and 3) text files of wind speed and direction for use in fire model simulations. When wind vectors are displayed on maps, the fire perimeter and marked prominent landmarks can be added to orient the viewer. WindWizard, the most accurate method, requires about 1 hour of computational time per simulation and is available commercially. WindNinja is less accurate but much faster computationally and available at no cost.

Conclusions: These two tools can provide significant added value and accuracy to fire behavior forecasts. They can also be useful for improving prescription accuracy for prescribed fires, and have direct application to firefighter and public safety. Additional information is available online at www.firelab.org.

keywords: fire behavior, fire modeling, fire weather, wind flow.

Citation: Butler, B., D. Jimenez, J. Forthofer, M. Finney, L. Bradshaw, R. Stratton, C. McHugh, and K. Shannon. 2009. Methods for obtaining detailed wind information to support fire incident management [abstract]. Page 30 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

A NEW TOOL FOR FIRE MANAGEMENT DECISION SUPPORT

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ABSTRACT

Question: Can Fire Weather meteorologial services for Āre managers be improved with a new product combining Predictive Services and National Weather Service forecast information?

Background: A new experimental tool combining information on fuel dryness and forecasts of lightning probability has been jointly developed by meteorologists from the Eastern Great Basin Coordination Center (EGBCC) and the National Weather Service office at Salt Lake City, Utah (NWS-SLC). Research by the EGBCC found that the wildland fuel conditions may be as, or more important than whether thunderstorms are wet or dry with respect to the start and rapid growth of Āres and associated resource response. Meteorologically, forecasting and issuing warnings for dry lightning activity is very difficult, in part because of the subjectivity in differentiating between wet and dry thunderstorms in both time and space. In the new product, the EGBCC forecast of signiĀcant Āre potential is combined with an experimental lightning probability forecast developed at the National Centers for Environmental Prediction, Storm Prediction Center (NCEP-SPC) in Norman, Oklahoma. Meteorologists at the NWS-SLC gather the component information, review, and disseminate the new Āre weather guidance. The goal of the experiment is to develop an easy-to-use, objective tool to assist in Āre management decision support throughout Utah.

Location: Utah and Arizona, USA, portions of the EGBCC area of responsibility, centered at lat 39.2°N, long 111.65°W.

Methods: The NCEP-SPC provides gridded lightning forecasts via the NWS interoffice communication system to the NWS-SLC. Scripts automatically downscale the 40-km original gridded lightning probability forecasts to a local 2.5-km grid at the NWS-SLC. Scripts retreive the daily EGBCC forecasts of Dryness Level information and combine the two pieces of the new product within the NWS-SLC Graphical Forecast Editor. NWS-SLC meteorologists review the information and disseminate the product via the Internet.

Results: The experimental product demonstrated that the NWS-SLC, EGBCC, and NCEP-SPC meteorologists were able to integrate daily updates to a fuel dryness and a lightning probability forecast. The product was successfully disseminated through the summer of 2008 via the Internet. Comments from Āre managers across Utah were positive in the use of the new product for resource allocation and daily decision support. Subjectively, the NCEP-SPC lightning probability forecasts captured the surges of increased lightning activity and lulls in activity through the summer. Fire starts occurred preferentially where Dry and Very Dry fuel dryness levels overlapped with 20 to 40% probability of 10 or more lightning strikes in the NCEP-SPC forecasts. Higher lightning probability forecasts may be associated with areas of more vigorous convection and storms more likely to produce signiĀcant rainfall. Hits on the new Web page totaled 3,185 visits for June, July, and August.

Conclusions: The product should be expanded to other parts of the EGB Geographic Area and possibly other geographic areas across the western United States. Further veriĀcation of the NCEP-SPC lightning forecasts should be undertaken, as well as veriĀcation of signiĀcant Āre potential as developed by the EGBCC Predictive Services meteorologists.

keywords: Āre weather, fuel dryness, lightning, predictive services, Utah.

Citation: Sharples, S., P. Bothwell, E. Delgado, C. Gibson, and M. Struthwolf. 2009. A new tool for Āre management decision support [abstract]. Page 31 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

USING FUELS AND FIRE BEHAVIOR TO DETERMINE CONTRIBUTING FACTORS FOR FIRE TYPE

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ABSTRACT

Question: Which factor(s) (i.e., vegetation, topography, weather, current Āre behavior) most contribute to Āre type?

Background: Fire behavior measurements collected during active wildĀres are paramount to Āre behavior research. Many of the existing Āre behavior models are based on laboratory data, data collected during experimental burns, or a combination of the two. The use of controlled experiments is understandable given the inherent difficulties and hazards associated with collecting data in wildland Āre situations. Although not perfect, with advancements in technology it is possible to gather Āre behavior data on actively burning wildland Āres. Using various sensors and digital cameras in Āreproof boxes, it is possible to gather information on Āre type, rate of spread, Èame height, Èaming duration, and Āre temperature during a wildĀre. Ninety-three sites at 10 Āres were installed from 2003 through 2008 in Arizona, California, Idaho, Montana, and Georgia to gather such data. Three of the 10 Āres were wildland use and the remainder wildĀres. Of the 93 sites visited, 72 had burned. Fire behavior ranged from low-intensity backing surface Āres to active crown Āres. In addition to Āre behavior data, pre- and post-Āre vegetation and fuels data were collected at all sites.

Location: From 2003 through 2008, we successfully collected data on 10 wildland and wildland Āre use Āres in California, Arizona, Montana, Idaho, and Georgia, USA, in coniferous forest ecosystems.

Methods: Pre- and post-Āre vegetation and fuel characteristics were measured at each site to characterize, ground, surface, ladder, and canopy fuel conditions. Fire behavior data were collected using digital cameras in Āreproof boxes and with various sensors. Temperature sensors (thermocouple connected to a data logger) were used to triangulate rate of spread and gather Āre temperature information at various heights. At some sites, an anemometer was used to gather site-speciĀc wind-speed data.

Results: Mean (and range) canopy characteristics and fuel conditions pre-Āre varied widely between the 55 sites: canopy base height was 3.4 m (0.3–12.5 m), canopy bulk density was 0.130 kg m^{-3} (0.016–0.471 kg m^{-3}), and tree density was 290 trees ha^{-1} (8–2,935 trees ha^{-1}). Understory vegetation (combination of shrubs, herbs, and grasses) averaged 10.9 tons ha^{-1} (0–147.0 tons ha^{-1}). Surface fuels (1-, 10-, and 100-hour) averaged 9.0 tons ha^{-1} (0–33.2 tons ha^{-1}). Fire behavior also varied between study sites. Thirty-six burned with low- to moderate-intensity surface Āre, 13 as passive crown Āre (surface Āre with single-tree or group torching), and seven as crown Āre. Temperature ranged from 44°C to >1,100°C, and Èame height ranged from <0.3 m to >50 m.

Exploratory statistics (classiĀcation and regression tree and/or canonical correspondence analysis) will be used to determine which factors contributed to the different Āre types. Factors that will be considered include topographical information (slope and aspect); vegetation characteristics (i.e., stand density, dominant species, canopy base height, and canopy bulk density); fuel characteristics (live and dead loading); Āre behavior (i.e., rate of spread, Èaming duration, and temperature); and weather (relative humidity, temperature, and wind speed).

Conclusions: "Real-time" Āre behavior and fuels data were collected at 10 Āres over the past 5 years. During this time, our methodology has been Āne-tuned to maximize data collection. Fire behavior sensors failed at some sites due to high temperatures that melted cameras, rate-of-spread sensors not buried deeply, and equipment malfunction. As a result, new rate-of-spread sensors and different camera placement protocols were developed, resulting in a high success rate in the most recent Āres sampled. Our fuel sampling protocol has also been modiĀed to capture data relevant to management needs and potential Āre behavior model validation. Although not perfect, the data we have collected are unique and can be used to assess the factors that most contribute to Āre type in coniferous forest types across the United States.

keywords: active wildĀre, coniferous forest, Āre behavior, fuels.

Citation: Vaillant, N.M., and J. Fites-Kaufman. 2009. Using fuels and Āre behavior to determine contributing factors for Āre type [abstract]. Page 32 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

FLAME LENGTHS ASSOCIATED WITH PONDEROSA PINE REGENERATION MORTALITY

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ABSTRACT

Question: How does susceptibility of ponderosa pine to prescribed fire change with regeneration size?

Background: The sustainability of fuel reduction treatments requires maintenance of low densities of ladder fuels. Because mechanical thinning of small trees is often not economical, there is interest in using prescribed fire to achieve this objective. Managers need the ability to predict mortality of small trees based on potential fire behavior in order to tailor burn prescriptions to meet their regeneration reduction/maintenance target objectives. To address this management need, we observed fire behavior during two prescribed burns in the Black Hills of South Dakota and monitored ponderosa pine (*Pinus ponderosa*) seedling (<1.4 m tall) and sapling (diameter at breast height [dbh] 0.25–10 cm) mortality 1 year post-fire.

Location: Black Hills National Forest (Medicine Burn: lat 43°56′N, long 103°42′W; Buffalo Burn: lat 44°07′N, long 103°32′W), South Dakota, USA.

Methods: We established plots within the Medicine (n = 25) and the Buffalo (n = 20) burn units. Fire behavior was monitored during the fall prescribed burns using a video camera. Flame heights were estimated at each plot using a post with 0.15-m intervals as a reference point. We used logistic regression to develop models that predict the probability of mortality based on observed flame lengths and regeneration height and dbh.

Results: The flame-length mortality model indicated that seedlings were more susceptible to typical prescribed fire behavior than sapling-sized ponderosa pines. The seedling–flame length mortality model indicated that seedlings <0.6 m tall were highly susceptible to short flames (<0.2 m). Seedlings between 0.6 and 1.4 m tall were susceptible to flame lengths <1 m tall. The sapling–flame length mortality model predicted flames exceeding 1.5 m were needed for high mortality in saplings 2.5 cm dbh, and flame lengths exceeding 2 m were required for saplings >5 cm dbh. For both seedlings and saplings, as fire severity on the forest floor increased, less foliage damage was required to induce mortality.

Conclusions: The differences in mortality thresholds for ponderosa pine seedlings and saplings highlight their susceptibility to different damage pathways and give managers several options when designing burn prescriptions. For seedling mortality, fast-moving fires that inflict high levels of crown damage or slow-moving fires that produce moderate crown and ground damage can be used. Tall flames that allow some crown consumption are required for substantial sapling mortality. Otherwise, more intense, slow-moving fires are needed to inflict high levels of ground damage with moderate amounts of crown damage. The flame length–regeneration size relationship highlights the need for managers to burn when regeneration is seedling-sized to avoid flame lengths that could increase the risk of fire escaping or overstory mortality. Results of this study are intended to provide managers with benchmark flame lengths needed to cause ponderosa pine seedling and sapling mortality for regeneration reduction and maintainence during prescribed fire operations.

keywords: Black Hills, burn prescriptions, fire behavior, fire effects, logistic regression, mortality, ponderosa pine, prescribed fire.

Citation: Battaglia, M., S. Smith, and W.D. Shepperd. 2009. Flame lengths associated with ponderosa pine regeneration mortality [abstract]. Page 33 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

A NEW CANOPY WIND REDUCTION FACTOR MODEL FOR FIRE BEHAVIOR ANALYSIS

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Wind speed is an important parameter influencing wildland fire behavior. Analysts attempting to simulate fire behavior using operational fire models must specify the midflame wind speed. Determining this value is not straightforward because most weather forecasts or measurement stations provide wind speed data that are not at the midflame height. If a vegetative canopy is present above a burning surface fire, the determination of midflame wind speed is even more convoluted. This work describes a new canopy flow model to assist in determining midflame wind speed for fires burning under a vegetative canopy. A one-dimensional momentum equation is solved numerically with turbulence closure. The effect of the canopy elements on the momentum and turbulence is included. The model is compared with current techniques used in wildland fire.

AVHRR NDVI, 7-DAY TIME-SERIES COMPOSITES AS POTENTIAL INDICATORS OF FIRE SIZE AND FREQUENCY IN MISSISSIPPI

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NASA-funded collaborative studies by the Mississippi State University Departments of Forestry and Geosciences, and the USGS have used linear additive GIS models to determine fire potential in Mississippi and regionally in the Gulf Coastal Plain. Mississippi has on average 3,760 wildfires each year that require personnel and resources to extinguish (average number of wildfires calculated based on historic fire data acquired from Mississippi Forestry Commission). These fires result in annual burning of >60,000 acres (http://www.mfc.state.ms.us/Forest%20Protection.htm). Analysis of 14 years of AVHRR NDVI, 7-day composites in Mississippi indicated that NDVI is significantly negatively correlated with fire frequency and fire size (Pearson's r, $P < 0.05$). Fire frequency was significantly correlated with NDVI in seven of nine physiographic regions, with strongest correlations occurring in the Loess Hills ($r = -0.388$) and the North Central Hills ($r = -0.381$). Fire size was significantly correlated with NDVI in five of nine Physiographic regions, with strongest correlations occurring in the Black Prairie ($r = -0.399$) and the North Central Hills ($r = -0.361$). Seasonal variations in NDVI "departure from average" are currently being analyzed using "time-series" statistical analysis to assess patterns of NDVI fluctuations from normal as an indicator of fire potential. Graphs of departure from average NDVI and fire frequency indicate a lag between elevated fire potential and the expression of fire potential associated with lower NDVI. This phenomenon may be associated with vegetation vigor linked to fluctuations in oscillation indices (Dixon et al., in press). Fire potential models for the southern United States will benefit from increased understanding of the interrelationships of NDVI, weather, and physiographic regions, similar to fuels–weather–topography models used to predict fire behavior.

A NUMERICAL MODELING STUDY OF DRY CONVECTIVE REGIMES ABOVE WILDLAND FIRES

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Forest fires have a profound impact on atmospheric circulations due primarily to the large temperature anomalies produced by the fire. The fundamental dynamics through which a forest fire and its environment interact to yield different convective regimes is still not well understood. This study uses the Advanced Regional Prediction System (ARPS) model to investigate the impact of the environmental wind profile (i.e., far upstream, undisturbed by fire) on dry convection above a prescribed heat source of an intensity and spatial scale comparable to a wildfire. Dimensional analysis of the fire–atmosphere problem provides two relevant parameters: a surface buoyancy parameter that addresses the amount of heat a parcel of air receives in transiting above the fire, and an advection parameter that addresses the degree to which the environmental wind advects updrafts away from the fire. Two-dimensional simulations are performed wherein the upstream surface wind speed and mixed-layer mean wind speed are varied independently in order to better understand the fundamental processes governing organizational mode and updraft strength. The result of these experiments is the identification of two primary classes of dry convection: plume and multicell. Plume cases are simulated with weak mixed-layer advection and are subdivided into intense plume and hybrid classes based on the degree of steadiness within the convection column. Hybrid cases appear as columns of largely discrete updrafts versus the more continuous updraft column associated with the intense plume mode. Multicell cases develop with strong mixed-layer advection and are subdivided into strong and weak classes based on the depth of convection. Intense plume and strong multicell (hybrid and weak multicell) cases develop when the surface buoyancy is large (small). The talk concludes with a discussion of the degree of nonlinearity that is likely to exist at the fireline for each of the convective modes; nonlinear fire behavior is most likely for the intense plume mode and least likely for the weak multicell mode. Knowledge of the sensitivity of convective mode to upstream conditions consequently provides information about the degree of nonlinear fire behavior expected for a given wind profile upstream of the fire.

FIELD-SCALE FIRE RADIANT ENERGY AND POWER MEASUREMENTS

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We have conducted a series of very well instrumented wildland fire experiments on small plots (approximately 4 m on a side) using a purpose-built dual-band infrared radiometer. Using two infrared bands and wide angle (60° field of view [FOV]) sensors, we can measure the radiant energy directly, without regard to either occupied FOV or the effective emissivity. This technique is generally called *two-band thermometry*. The main goal of these experiments is to relate fuel consumption to remotely sensed physical observables such as fire radiant power and fire radiant energy. The common features of these experiments are overhead infrared detectors to measure radiant flux; visible videography from three orthogonal vantage points to monitor fire position, velocity, and behavior; thermocouples to monitor time of arrival; witness rods to assist in fire motion measurements; gas sensors to measure the products of combustion; and near-fire weather measurements to allow accurate correlation of observed effects from these instruments. We will describe both the equipment and calibration procedures for the overhead infrared measuring system, and describe the results from these field-scale experiments in Vinton Furnace, Ohio. In general, our results agree with that of Wooster (2002. Geophys. Res. Lett. 29:2027–2031) and show a linear dependence of radiant flux on fire radiant energy.

USING ARTIFICIAL LANDSCAPES TO ISOLATE THE FACTORS CONTROLLING BURN PROBABILITY

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Burn probability (BP) modeling techniques combine the stochastic components of fire regimes (ignitions and weather) in landscapes of known fuels and topography with sophisticated fire growth algorithms to produce high-resolution spatial estimates of the relative likelihood of burning. The spatial output from BP models represents a critical need for quantitative risk analysis and landscape-scale planning. Despite independent concurrent efforts to develop BP models, and several applications in real landscapes, the specific influence of environmental factors on BP patterns is not well understood. This study generated BP patterns for highly simplified artificial landscapes and examined these patterns within a factorial design to discern the importance of ignitions, fuels, and weather. Specifically, five experimental factors were evaluated for their influence on patterns in mean BP and BP variability: 1) mean fire size, 2) fuel configuration, 3) spatial ignition pattern, 4) fire size distribution, and 5) direction of fire spread. The relative importance on BP was evaluated for each factor, as well as their two-way interactions. Results demonstrate how surprising and complex BP patterns can be produced from very simple inputs. Although all five experimental factors influenced BP, they contributed unequally to mean BP and the variability in BP; certain factors (e.g., mean fire size) primarily influenced BP over the entire landscape (global effects), whereas others (e.g., fuel configuration, spatial ignition pattern) were mainly responsible for its redistribution in space (local effects). Interactions among factors were important and in some cases produced counterintuitive BP patterns. These results will be crucial to understanding BP patterns that are created with more complex inputs (i.e., real landscapes) for the purposes of quantitative risk analysis. Furthermore, they point to the inherent complexity of fire spread processes and provide further support for the use of realistically accurate fire spread techniques to predict landscape-level BP.

1988 HAINES INDEX VALUES IN YELLOWSTONE AND COMPARISON WITH CLIMATOLOGY

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Weather conditions during the 1988 Yellowstone fires have frequently been described as unusually conducive to wildfires. Past studies have looked at surface weather conditions during the fires. Using the North American Reanalysis data for the Yellowstone region, we compare the Haines Index during the Yellowstone fires of 1988 with climatological conditions for the period 1961–2000 to determine how the aboveground fire environment compared with "normal" conditions.

THE CLIMATOLOGY OF THE HAINES INDEX AS VIEWED FROM THE NORTH AMERICAN REGIONAL REANALYSIS

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The Haines Index, also known as the Lower Atmosphere Severity Index, has been used as an effective tool to indicate the potential for wildfire growth by measuring the dryness and stability of air over a specific region. This paper will present a climatology of the Haines Index for North America based on the temperature and moisture fields from the recently released North American Regional Reanalysis (NARR). The NARR data set is a long-term (from 1979 to present) and dynamically consistent meteorology and hydrology data set for North America. Compared with its global counterpart, the NARR data set has much higher spatial (32-km grid spacing) and temporal (3-hourly) resolution and is derived based on a more sophisticated land surface model and data assimilation algorithm. Because of these features, the NARR-based climatology of the Haines Index is expected to be more detailed and accurate compared with other existing climatologies based on coarser-resolution data sets. The paper will discuss the spatial distribution of the Haines Index values, their seasonal variations, and the climatological trends for extreme wildfire fire behavior as indicated by high values of Haines Index for various regions in the United States.

FLAME, FIRE SCIENCE FOR THE FIRELINE

Jim Bishop

After the Yellowstone fires, Rothermel developed crown fire nomograms, and I and Mark Beighley wrote in *Fire Management Notes* about crown fire behavior. That information contributes to the FireLine Assessment MEthod (FLAME), a practical prediction tool. FLAME is now incorporated in the new S-290 course. Purpose: Bring fire behavior science to fireline firefighters to inform life-safety decisions. Recommendation: Make firefighters and others aware of FLAME and its place in current training. FLAME applies fire behavior observation and modeling in a unique way. It provides a simple, fireline-practical way to predict change in fire behavior—systematic application of fire behavior science to support safety and suppression decisions. From ongoing fire behavior and expected conditions, a firefighter can see how rate of spread (ROS) will change and can find the spread time for fire to reach a given place. Unforeseen change leads to fireline accidents and failed control efforts. Main output is the ROS-ratio, expressing degree of change in ROS. High ROS-ratio is a "common denominator" in fatalities. Applying the ROS-ratio to current fire spread predicts future spread-time. In four fatality cases, FLAME predictions match reconstructed ROS-ratios within an average 9% and could have foretold the dangerous change in spread time. FLAME requires assessment of only two dominant drivers of short-term change, fuel type and effective wind speed (EWS), with relative humidity for fine-tuning. A simple three-step worksheet is applied in minutes and is adaptable to conditions. The process is systematic, ensuring that each key factor is addressed. FLAME heightens situational awareness and guides implementation of LCES. Fire behavior data provide the dependence of ROS on EWS in each of three fuel types (litter, crown foliage, grass). An equation expresses the dependence of ROS on fuel type and EWS, which then generates the FLAME user table. FLAME has been reviewed by fire scientists for technical validity and successfully taught in fire behavior courses.

IN SITU WILDFIRE FIRE BEHAVIOR AND FUEL CHANGES IN TREATED AND UNTREATED AREAS IN ARIZONA, CALIFORNIA, AND FLORIDA

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In situ data on fire behavior, and pre- and post-fire fuels during wildfires in Arizona, California, and Georgia were collected to evaluate differences in treated and untreated areas with varying fuels, weather, and topography. Brown's planar intercepts, Burgan and Rothermel photo series, oven-dried weights, and tree density, diameter, and crown dimension inventories were utilized to determine fuel loading (ground, surface, understory, and overstory) and moisture. Fire behavior metrics were measured with heat-triggered video cameras, sensors to measure rate of spread, and sometimes temperature. Of 39 sites on three fires, 18 burned with low- to moderate-intensity surface fire, 10 as high-intensity surface fire, and 11 as crown fire. Sites with crown fire included initiation of crown fire, passive crown fire, or active crown fire. Data on rate of spread, flame length, fire intensity, and fuel consumption were analyzed. Surface fuel (1- to 100-hour size) consumption varied from 25 to 100%. Litter and duff consumption ranged from 4 to 100%. Live fuel consumption varied from 10 to 98%. Crown scorch and consumption varied widely with fire behavior. Reduced fire behavior and fuel consumption were observed in treated sites compared to untreated sites. A secondary objective was development and evaluation of methods that could be conducted safely, rapidly, and in close cooperation with Incident Management Teams in dynamic wildfire setting with active suppression. There were fire behavior sensor failures at some sites due to high temperatures that melted cameras, rate-of-spread sensors not buried deeply, and equipment malfunction. As a result, new rate-of-spread sensors and different camera placement protocols were developed, resulting in a high success rate in the most recent fire sampled in Georgia. Insights into fuel loading, configuration, and moisture contributing to crown fire initiation were gained. Implications for more robust methods that will yield more reliable fire behavior data are summarized for use in future efforts. This type of data is very difficult to obtain during free-burning wildfires, particularly crown fire, but has great value and potential for use in validation and improvement of fire behavior and fuel models. It is easy to design a sound protocol before a fire but very difficult to implement realistically on a free-burning wildfire—one of the best ways to develop a robust approach that works is through trial and error. Recommendations for future improvements based on our trials and errors are summarized.

FUELS AND FUELS MANAGEMENT

FIRE FUEL TYPE CLASSIFICATION AND BIOMASS ESTIMATION USING DEGREE OF SOIL HUMIDITY AND LANDSAT TM DATA

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ABSTRACT

Question: Can degree of soil humidity and Landsat data be used as a general method to estimate fire fuel classification and aboveground biomass?

Background: Estimation of aboveground biomass (AGB) is necessary for studying productivity, carbon cycles, nutrient allocation, and fuel accumulation in terrestrial ecosystems. Remote sensing techniques allow examination of properties and processes of ecosystems and their interannual variability at multiple scales because satellite observations can be obtained over large areas of interest with high revisitation frequencies. Many studies have demonstrated that indices such as spectral vegetation index, simple ratio, Normalized Difference Vegetation Index, and corrected Normalized Difference Vegetation Index obtained from satellite data are useful predictors of leaf area index, biomass, and productivity in grasslands and forests. Stand-level biomass is frequently calculated from linear and nonlinear regression models established by species with field measurements. Although estimates of AGB vary with species composition, tree height, basal area, and stand structure, bole diameter at breast height (dbh) is the most commonly used and widely available variable for calculating AGB. Numerous regression models have been developed to estimate AGB in many regions; while these models are accurate at the tree, plot, and stand levels, they are limited when considering spatial pattern analysis of AGB across the landscape. In order to scale AGB estimates to the landscape level, the estimates must be linked with various vegetation indices derived by remote sensing data. The purpose of this study was to classify fuel types in the Central Interior region of South Korea and investigate the spatial patterns of fire hazard potential in forest by using remotely sensed data combined with field observations.

Location: On-site survey area (lat 36°21′N, long 128°19′21″E) for fuel type classification, Uiseong-gun, Gyeongbuk-Do, Korea.

Methods: AGB and surface biomass (SB) were calculated from tree height, dbh, and dry weight of 10 × 10-m quadrats in 54 survey plots. AGB was calculated with the following equation: $W = aD^2H$. Correlations between AGB and SB were analyzed by the degree of relative soil humidity. A cover type map of the forest area was made by hybrid classification method (Maximum Likelihood Classifier and K-means) with Landsat Thematic Mapper (TM) data. Multiple regression analysis was carried out with AGB values computed from field observations and band reflectance derived from Landsat TM data to estimate correlation of remotely sensed data and AGB. Finally, a biomass map was produced by estimation equations for fuel types.

Results: Field observations indicated that AGB and SB collected through field survey were strongly related with the relative soil humidity. Thus, we classified coniferous forests (C) into three fuel types (moderately moist, C-1; slightly dry, C-2; and dry soil, C-3), considering the relationships of AGB and SB of *Pinus densiflora* with soil humidity. Hardwood (H) and mixed (M) forests were recognized as different land cover types. The cover type map for the study area was generated with the three land cover types (C, H, M) by a hybrid classification method using Landsat TM data. Then the cover type map was overlaid with the thematic map that defined degree of soil humidity to generate the fuel type map including five different fuel types. To produce a biomass map, AGB values computed from field survey data, including tree height and dbh, were coupled with band reflectance derived from Landsat TM data through multiple regression analysis. The result of correlation between AGB and band reflectance showed that $AGB = -45.329 \times R_1 + 9.353 \times R_7 + 2825.36$ ($R^2 = 0.8736$) for C-1 type; $\log(AGB) = 0.3246 \times R_1 + 0.4304 \times R_7 - 18.0872$ ($R^2 = 0.5326$) for C-2; $AGB = 0.6002 \times R_3 + 0.1166 \times R_7 - 16.5703$ ($R^2 = 0.6663$) for C-3; $AGB = 0.4171 \times R_1 + 4.4826 \times R_4 - 241.0938$ ($R^2 = 0.6115$) for D type; and $AGB = -9.5309 \times R_1 + 2.5071 \times R_7 + 593.2628$ ($R^2 = 0.7086$) for M type. The relationship between predicted AGB (ton/ha) from remote sensing–based models and the AGB computed from field observation is $AGB_{Estimated} = 20.231 + \ln(AGB_{Observed}) - 28.839$ ($R^2 = 0.638$).

Conclusions: A relatively good relationship exists between AGB estimate and band reflectance of Landsat data from five fuel types by degree of soil humidity. Furthermore, there is a possibility that fuel accumulation in forest ecosystems, a necessary input for most fire models, can theoretically be determined by AGB. Therefore, distribution of AGB across the landscape is necessary for quantifying landscape-level fuel accumulation and its relationship to fire behavior and intensity. By combining our soil type map and the AGB map, fuel type and amount may be determined, which can be useful information for studying fire ignition and spread across the landscape. Such information could be helpful for resources managers to conduct fuel reduction operations to prevent catastrophic fire risk. Therefore, fuel type classification, AGB estimation using degree of soil humidity, and Landsat TM data can be used as baseline information for future landscape-level studies such as estimating fire hazard potential.

keywords: aboveground biomass, fire hazard potential, fuel type, reflectance, soil humidity.

Citation: Won, M.S., K.S. Koo, M.B. Lee, and W.K. Lee. 2009. Fire fuel type classification and biomass estimation using degree of soil humidity and Landsat TM data [abstract]. Page 38 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

FLORIDA'S CANOPY FUELS INVENTORY PROJECT: DEVELOPING AN APPROACH TO STATEWIDE CANOPY FUELS MAPPING

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ABSTRACT

Question: How to economically quantify and map canopy fuels statewide in Florida?

Background: Fuels mapping techniques to date have identified surface fuels rather than canopy fuels, whereas the most damaging wildfires in our nation's forests involve canopy/crown fires. Sanborn, in cooperation with the Florida Division of Forestry, has developed new methods to derive vegetation classes that have unique canopy characteristics. These in turn govern potential crown fire type and intensity because they correspond to canopy fire behavior variables: canopy ceiling height (CCH), canopy base height (CBH), and canopy bulk density (CBD). The selected processes incorporate both remote sensing and forest inventory approaches that leverage the work of Fire Program Solution's (FPS) Don Carlton. These data will be integrated into the Wildland Fire Risk Assessment System that land and fire managers use for coordinating the risk from wildland fire in Florida.

Location: State of Florida, USA.

Methods: The first task was to develop a vegetation classification system that could adequately manage canopy fuel variable mapping. This system incoporated species groups, canopy closure, and height components. Next, the state is being classified using multidate Landsat TM and shuttle radar imagery. Once this phase is completed, a "tree list" database is used to access canopy fuel characteristics information. These data can be linked to the map, creating a statewide inventory for CBD, CBH, and CBD.

Results: Our presentation covers the approach we chose to create these necessary data + sets. The approach successfully combines multi-date Landsat imagery to track the changing landscape and leverages off the Shuttle Radar Topography Mission to help determine the height component of the map. Plot data collected will capture the key characteristics of the canopy from which canopy fuel variables can be estimated, using the modeling program "CM3Batch" developed for this purpose by FPS.

Conclusions: The project being developed in Florida uses many data sets that are available to other states. The methods developed as part of this project can be applied to many areas where a canopy fuel data set is required and can be used to complement other fuels data for fire behavior modeling and wildland fire risk assessment.

keywords: canopy, fuels, fire, imagery, remote sensing, risk assessment.

Citation: Brenner, A.J., J. Brenner, D. Carlton, and J. Hoyt. 2009. Florida's canopy fuels inventory project: developing an approach to statewide canopy fuels mapping [abstract]. Page 39 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

FIRE SEVERITY AND SPATIAL DISTRIBUTION OF FUELS ESTIMATED USING PRE- AND POST-LiDAR–DERIVED FUEL MEASUREMENTS

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ABSTRACT

Question: Can pre- and post-fire LiDAR data quantify the contribution of three-dimensional fuel structure to fire spread and intensity in a high-intensity crown fire?

Background: The assessment of the effect of three-dimensional fuel structural characteristics on wildfire behavior has been limited for two primary reasons: 1) the random occurrence of wildfire makes the placement of pre-fire measurements nearly impossible, and 2) the inability to quantify and map structural parameters over a significant spatial extent. The first of these problems was addressed in this study through chance, with an approximately 8,200-ha wildfire occurring directly on our study area. The use of Light Detection and Ranging (LiDAR) technologies to accurately quantify biometric and fuel loading parameters at the landscape level has become a promising methodological solution to the second problem.

We have taken advantage of this rare opportunity to couple pre- and post-fire LiDAR data sets to quantify and characterize the effects pre-fire loading on fire severity. Previous research indicated that LiDAR metrics are highly correlated with stand biomass ($r^2 = 0.65$; Skowronski et al. 2007. Remote Sens. Environ. 108:123–129), maximum canopy bulk density (CBD) ($r^2 = 0.92$; Skowronski, unpublished data), and the vertical distribution of canopy structural components at discrete locations, with minimal spatial integration.

The specific study area includes an 8,200-ha, wind-driven crown fire that occurred on 15–16 May 2007 in the Pine Barrens of New Jersey. The fire burned aggressively for 2 days across a wide variety of fuel types ranging from pitch pine (*Pinus rigida*) and scrub oak (*Quercus* spp.) in the uplands to forested wetlands dominated by mixed hardwoods, creating a mosaic of fire intensities across the landscape.

Location: Warren Grove Gunnery Range (lat 39.72146°N, long 74.35975°W), New Jersey, USA

Methods: The study area was approximately 18,700 ha and included the 8,200-ha wildfire. Profiling LiDAR was collected over the study area in April 2004 and December 2007, and post-processed into pseudo-plots following Skowronski et al. (2007. Remote Sens. Environ. 108:123–129). Plots were calibrated to biometric measurements, including aboveground biomass and CBD profiles organized as discrete 1-m height bins for each plot. Plots were categorized by wildfire intensity, and variables were analyzed using traditional and spatial statistics.

Results: Total canopy fuel load did not account for increased fire intensity (high intensity = 0.297 kg m^{-2}, low intensity = 0.417 kg m^{-2}, and no fire = 0.329 kg m^{-2}). However, maximum CBD in high-intensity plots was 27 and 30% greater than the low-intensity and no-fire plots, respectively. However, the fuel load of high-intensity plots in canopy bins 1–3 m in height was 25% more than in the low-intensity fire and 27% greater than in no-fire plots. Conversely, the fuel loading in the remainder of the height bins (bins >3 m in height) was 37% lower than in the low-intensity plots and 17% lower than in the no-fire plots.

Spatial statistics illustrate contrasts in the continuity of fuel in different burn intensities. Moran's *I*-statistic indicates that the high-intensity area was 34 and 24% more spatially autocorrelated in bins <7 m in height, while being 18 and 28% less autocorrelated in all bins than unburned and low-intensity areas, respectively. The Getis–Ord Gi* statistic averaged 1.29 in the high-intensity fire, indicating high autocorrelation of high values in these bins, while averaging −0.15 and 0.39 for unburned and low-intensity plots, respectively.

Measurements indicate a mass loss of 1,859 g m^{-2} in areas of high-intensity fire. Canopy fuel loss was estimated to be 245 g m^{-2} and 100 g m^{-2} in areas of high and low intensity, respectively. Biomass loss was poorly characterized when using typical LiDAR-derived parameters, as opposed to the canopy height profile approach.

Conclusions: Spatial and structural configuration of canopy fuel are major contributors to wildland fire intensity. Our results indicate that high fuel loading in the lower portion of the canopy may significantly affect the intensity of fire, while total fuel loading may be a less robust predictor of fire behavior. Additionally, the spatial autocorrelation, or contiguousness, of fuels also contributes to the propagation of fire through the canopy. Many of these results would be inconclusive utilizing only standard LiDAR parameters, which are unable to accurately characterize subtle variations in canopy fuel structure because of the inherent overgeneralization of these metrics. This study verifies the use of LiDAR for the study of fuel loading and spatial distribution, even using a simple profiling system.

keywords: biomass, canopy bulk density, canopy height profile, CBD, CHP, LiDAR, wildfire.

Citation: Skowronski, N.S., K.L. Clark, M.J. Duveneck, R.F. Nelson, and J.L. Hom. 2009. Fire severity and spatial distribution of fuels estimated using pre- and post-LiDAR–derived fuel measurements [abstract]. Page 40 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

SNAG AND COARSE WOODY DEBRIS ABUNDANCE AND CHARACTERISTICS IN A FREQUENTLY BURNED *QUERCUS GARRYANA* WOODLAND

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ABSTRACT

Question: How abundant are snags and coarse woody fuels in a frequently burned Oregon white oak (*Quercus garryana*) woodland, what is their decay status, and what relationships exist between these structural elements?

Background: Snags and coarse woody fuels (or coarse woody debris [CWD]) are important structural elements of forest and woodland ecosystems, providing long-term storage sites for nutrients and moisture, as well as essential habitat for certain wildlife. Snags and CWD also provide fuel for wildland Āres, though the role of Āre in snag and CWD recruitment and retention is unclear. Fires can injure trees through crown scorch and bole charring; multiple Āres may create basal cavities that can lead to stem failure. In frequently burned woodlands, snags and CWD (particularly decayed wood) may be limited, as low-intensity Āres kill few mature trees and consume dead wood.

In Redwood National Park, California, a robust prescribed Āre program was initiated in 1991 following a century of Āre exclusion; burning objectives included restoration and maintenance of woodland structure and species composition. Although pre–suppression-era abundance of snags and CWD within the woodlands is unknown, it is likely that these woody elements were maintained at relatively low levels under a high-frequency Āre regime. Changes in woodland structure following Āre exclusion (i.e., stem densiĀcation and increased fuel loading), combined with a recently initiated burning program, complicate our interpretation of current snag and CWD abundance.

This research quantiĀes snag and CWD abundance and characteristics in a frequently burned *Quercus garryana* woodland (ca. 5-year Āre return interval). Additionally, we examine the relationship between live and dead overstory structure, as well as the relationship between coarse woody fuels and overstory structure.

Location: The Schoolhouse Peak burn unit within the Bald Hills of Redwood National Park, California, USA, about 22 km from the PaciĀc Ocean (lat 41°08′59.8″N, long 123°53′25.7″W).

Methods: A systematic sample (based on a random start) of 20 0.08-ha plots were installed within the burn unit and the following variables were measured: live overstory basal area ($m^2\ ha^{-1}$); snag density, diameter at breast height (dbh), and decay class (1–5); and coarse woody fuel loading (1000-hour: >7.62 cm; planar intercept method) and decay status. Descriptive statistics and simple linear regressions between overstory structural variables and fuel loading were calculated using Number Crunching Statistical Systems.

Results: Mean live tree basal area was 13.9 $m^2\ ha^{-1}$ and was positively correlated with snag basal area (mean = 2.8 $m^2\ ha^{-1}$; $R^2 = 0.21$, $P = 0.04$), although variation was high in both (coefficient of variation [CV] = 0.63 and 0.90, respectively). Snags were abundant (mean snag density = 95.9 snags ha^{-1}) but patchily distributed, ranging from 0 to 284 snags ha^{-1} among plots. Snag diameters averaged 19.6 cm and ranged from 7.6 to 48.5 cm (standard error = 1.27 cm, CV = 0.28). Mean snag diameter was negatively related to live basal area ($R^2 = 0.37$, $P = 0.007$). 51.0% of snags were categorized in decay class 2 (loosened bark, sound wood), while 40.0% fell within decay class 3 (little bark, surface softening); only 5.2 % of snags were categorized in decay classes 4 and 5 (soft, spongy wood).

Coarse woody fuel loading was variable across plots and consisted of very little highly decayed wood. Sound and rotten 1000-hour fuel loading (>7.6 cm) was 8.4 and 15.2 mg ha^{-1}, respectively, with high variation in both (CV = 131.9 and 408.5%, respectively). Most coarse woody fuels fell within decay classes 2 and 3 (51 and 40%, respectively). Coarse woody fuel loading >12.7 cm (diameter) was almost double that in a large-scale California oak woodland study in stands with similar live tree basal area. No relationships were found between coarse woody fuel loading and overstory structure, or between coarse woody size and overstory basal area ($P > 0.05$).

Conclusions: SigniĀcant relationships between snag abundance and size, and live basal area suggests stand density is an important factor inÈuencing snag abundance; snag recruitment in higher-density stands may be increased by susceptibility of small trees to Āre injury. Decades of Āre exclusion has allowed surface fuels, snags, and CWD to persist in these woodlands; abundance of these features may be a relict from this past era, and future burns may slowly consume this material. The lack of signiĀcant relationships between overstory structure and CWD may have resulted from high variability among plots or the omission of key explanatory variables. The lack of decayed wood in this ecosystem is evidence of the role of Āre in manipulating the character of dead wood in frequently burned ecosystems. Future work should focus on monitoring snag and CWD abundance to illuminate the role of frequent Āre in recruitment and retention of these important ecosystem features.

keywords: coarse woody debris, decay, forest structure, fuel load, oak woodlands, prescribed Āre, snags.

Citation: Engber, E.A., and J.M. Varner III. 2009. Snag and coarse woody debris abundance and characteristics in a frequently burned *Quercus garryana* woodland [abstract]. Page 41 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

ECOLOGICAL EFFECTS OF MASTICATION FUELS REDUCTION TREATMENTS IN COLORADO

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ABSTRACT

Question: What are the ecological impacts of mastication fuels reduction treatments in Colorado ecosystems?

Background: Recent large-scale, severe wildfires in the western United States have prompted extensive fuel treatment programs to reduce potential wildfire size and severity. Often, unmerchantable material is mechanically masticated because removing the material is cost-prohibitive. Mastication treatments involve shredding, chopping, or chipping small trees and/or shrubs into small chunks and leaving the material on-site. Managers and the public are interested in understanding the impacts of this additional woody material on forest ecosystems so that they can evaluate potential benefits and costs of these treatments. We initiated a regional study across three Colorado ecosystems: 1) lodgepole pine (*Pinus contorta*); 2) mixed conifer (lodgepole pine, limber pine [*Pinus flexilis*], poderosa pine [*Pinus ponderosa*], and Douglas-fir [*Pseduotsuga menziesii*]); and 3) pinyon pine–juniper (*Pinus edulis–Juniperus* spp.) to determine how mastication treatments alter the distribution of woody biomass and how these changes affect the understory, fuels and fire behavior, and ecosystem function. We will assess the effects of mastication using three complementary approaches. Our principal approach compares measures of understory, fuels and fire behavior, and ecosystem function between mechanically treated sites and paired untreated controls. We will compare understory production and cover, tree regeneration, fuels and modeled fire behavior, soil nutrients, moisture, and temperature in masticated sites with adjacent, untreated stands. Our second approach uses small-scale manipulations of woody debris depth to examine the influence chip depth has on chip decomposition, soil nutrients, and understory recovery. Our third approach integrates measurements made at the study sites into a process-level ecosystem model to assess how mastication treatments and the associated thinning and changes in forest structure alter site carbon balance.

Location: Colorado Front Range, Colorado Plateau, Fraser Valley, San Luis Valley, Uncompahgre Plateau.

Methods: We located and established 18 sites that were masticated at least 2–4 years ago. At each study site, a masticated area was paired with an adjacent untreated reference control. Three 50-m transects were established in each treatment within a study area. Along the transects, 25 1-m^2 quadrants were used to assess fuels, vegetation, and soil N and C. Fuel depth manipulation experiments were installed in each ecosystem site with three treatment depths.

Results: The data analysis for this project is still in its infancy. However, we have some preliminary results from sites established in 2007 on surface fuel loads in the lodgepole pine and mixed-conifer sites. In both ecosystems, mastication treatments substantially increased surface fuel loadings. Total woody debris loadings in the mixed-conifer sites increased from 8 Mg/ha in the reference control to 38 Mg/ha in the masticated treated areas. The increase was even greater on the lodgepole pine sites. These sites had 9 Mg/ha in the reference control and increased to 50 Mg/ha in the masticated treated areas. The increase in total woody debris was concentrated in the smaller fuel size classes (<2.54 cm). This change in fuel bed characteristics will likely influence surface fire behavior.

Conclusions: Our study will provide information needed to develop "Best Management Practices" for mastication treatments for southern Rocky Mountains and the Colorado Plateau. This poster is intended to provide background information and methodology for our study.

keywords: biomass, carbon, Colorado, fire behavior, fuel manipulation, fuel treatment, mastication, nitrogen, plants, soils.

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EVALUATING THE EFFECTIVENESS OF FUEL TREATMENTS FOR MITIGATING SEVERE WILDFIRE EFFECTS

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ABSTRACT

Question: Do fuel treatment units burned through by wildfire actually mitigate severe fire effects?

Background: Since the inception of the National Fire Plan in 2000, millions of dollars have been spent on fuel treatments to restore healthy ecosystems and reduce hazardous fuel loads, especially in the wildland–urban interface (WUI), where people and property are particularly at risk from wildfire. Whether are not fuel treatments are "working" or "not working" is an important question, given the great expense of implementing fuel treatments, the purportedly greater expense of not implementing them (as has been argued), and the many acres of hazardous fuel conditions still remaining to be treated. Many large wildfires in the Northern Rockies and Intermountain West during the 2007 fire season threatened communities, impacted natural resources, and inevitably tested some of these fuel treatments. The three large regional 2007 wildfires sampled were the East Zone and Cascade Complexes, which burned through WUI fuel treatments in the Payette and Boise national forests (respectively) in central Idaho, and the Egley Complex, which burned through silvicultural treatments in the Malheur National Forest in northeastern Oregon. The WUI treatments in Idaho were implemented primarily to protect people and property, while the silvicultural treatments in Oregon were implemented to improve forest productivity and health. However, all treatment units sampled in this study also reduced hazardous fuel loads that can contribute to intense fire behavior and severe fire effects. This research focused on the natural resource impacts that could be assessed retrospectively, to test the null hypothesis that fire effects on vegetation and soils should be the same on treated lands as in untreated lands, in the absence of any treatment effect. This null hypothesis was tested with field data using a paired-site sampling approach, and with remotely sensed data by comparing a Landsat satellite–derived index of burn severity, the delta Normalized Burn Ratio (dNBR), between treated and untreated lands.

Location: The Secesh Meadows (lat 45°15′0″N, long 115°49′30″W) and Warm Lake (lat 44°38′40″N, long 115°41′20″W) communities in Idaho and the Emigrant Ranger District (lat 43°49′30″N, long 119°32′0″W) in Oregon, USA.

Methods: Fire effects on vegetation and soil were compared between field sites randomly placed within treatment units and on adjacent untreated sites having similar slope and aspect. A paired-site sampling methodology was chosen to control for variation in the topographic and fire weather components of the fire triangle and better isolate the fuels component. Paired *t*-tests were used to test for significance. We installed 20 site-pairs in Idaho and 35 site-pairs in Oregon.

Results: Most fire effects on vegetation and soils—tree mortality, proportion of the overstory and understory charred, amount of mineral soil exposed—were significantly lower on treated sites than on untreated sites. At Secesh Meadows, where pile-and-burn treatments were implemented in 2006, less severe fire effects occurred in treatment units where the piles had been burned as prescribed. Where the piles had not yet been burned as prescribed but burned in the wildfire, more severe fire effects occurred. At Warm Lake, treatment units dating back to 2000 all were effective at mitigating severe wildfire effects. In Oregon, forest silvicultural treatments dating back to 1986 that involved some form of forest thinning and fuels treatment generally mitigated severe fire effects from the 2007 Egley Complex, with field observations and preliminary field data analysis suggesting that the more recent treatments more effectively mitigated severe fire effects. In addition, analysis of Burned Area Reflectance Classification (BARC) map data indicated a lower proportion of severely burned pixels inside treatment units than outside them on untreated lands. The continuous dNBR values (from which BARC maps are classified) were also lower at treated sites than at untreated sites. These differences were significant in Oregon but not in Idaho, perhaps due to data gap problems with Landsat 7 imagery—a problem that will be remedied by using QuickBird satellite imagery in the future.

Conclusions: The WUI fuel treatments tested by the 2007 wildfires in Idaho were implemented primarily to protect people and property in rural communities at risk. This goal was accomplished, as no structures were lost, and the fuel treatments greatly facilitated fire suppression efforts. At Secesh Meadows, more severe fire effects were observed in some treatment units where the piled fuels from 2006 had not yet been burned, showcasing the importance of treating fuel piles expediently. Overall, however, fuel treatments were generally effective in mitigating severe fire effects in both Idaho and Oregon; thus, the null hypothesis is rejected. The silvicultural treatment units sampled in Oregon all involved commercial or pre-commercial thinning and fuels treatment, thus serving as surrogates for fuel treatments implemented prior to the 2000 National Fire Plan. The 1986–2006 range of these treatments will allow assessment of the duration of fuels treatment effectiveness in ponderosa pine (*Pinus ponderosa*) forests.

keywords: burn severity, dNBR, fire effects, fuel treatment, Interior Northwest, Landsat, National Fire Plan, northern Rocky Mountains, QuickBird.

Citation: Hudak, A.T., P. Morgan, S.A. Lewis, P.R. Robichaud, and Z.A. Holden. 2009. Evaluating the effectiveness of fuel treatments for mitigating severe wildfire effects [abstract]. Page 43 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

ESTIMATING SOIL EROSION AFTER FIRE AND FUEL TREATMENTS IN COAST REDWOOD: A GIS-BASED APPROACH

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ABSTRACT

Question: What is the potential soil erosion under four scenarios, including no treatment, thinning, prescribed fire, and wildfire, based on an approach that utilizes GIS and established erosion and fire effects modeling procedures?

Background: Erosion following wildfire or fuel treatments is of major concern to land managers and is directly related to the amount of vegetative cover removed, soil properties, topography, and precipitation patterns. A major shortcoming of many erosion models is that plot-level data are regularly used to designate slope and vegetation across an entire landscape, which has the potential to grossly misrepresent the high degree of topographic and vegetative complexity across a given watershed. Geographic information systems (GIS), however, provides the capacity to better estimate how soil movement is affected by topography and changes to vegetation via fire or fuels treatments.

The objectives of this research were to

1) Develop a methodology for estimating landscape-level soil erosion, utilizing GIS and established erosion and fire effects modeling procedures.
2) Estimate potential soil erosion under four scenarios, including no treatment, thinning, prescribed fire, and wildfire.

Location: Swanton Pacific Ranch (UTM 37.069364, −122.209648) near Santa Cruz, California, USA, in a 100-year-old second-growth forest of coast redwood (*Sequoia sempervirens*).

Methods: Surface fuel loading, canopy coverage, and other vegetation characteristics were measured in 33 field plots. Changes to surface fuel loading and canopy coverage were simulated in FOFEM (v. 5.5) under three scenarios: 1) thinning 50% of the overstory basal area with no change in surface fuels, 2) prescribed fire, and 3) wildfire. Each treatment affected the cover management factor (C-Factor) in the Revised Universal Soil Loss Equation used to estimate potential erosion across the watershed.

Results: Compared with the untreated landscape, both thinning and the prescribed fire resulted in ~10% greater sediment loss in the first year following treatment. Thinning affected canopy coverage but had little effect on surface fuels, based on unpublished data at the site. Prescribed fire removed surface fuels but had little effect on canopy coverage. The wildfire treatment, however, increased erosion by 74% compared with the untreated stand, the result of removing both 66% of the canopy coverage and also 85% of surface fuels.

Conclusions: Vegetation cover, both in surface fuels and canopy coverage, acts to buffer soil erosion. The C-Factor is extremely important in the Universal Soil Loss Equation because it measures the combined effect of all interrelated cover and management variables. Unfortunately, it also is one of the most difficult to obtain because of the wide range of environmental variables affecting it. In conclusion, the GIS-based approach to estimate soil erosion following fire and fuel treatments is both extremely powerful and promising. However, managers must be aware of the need for multiple types of complex spatial data, which are potentially difficult to obtain and cost-prohibitive.

keywords: erosion, fire, FOFEM, fuel treatments, GIS, redwood, *Sequoia sempervirens*, Universal Soil Loss Equation.

Citation: Just, E.J., and C.A. Dicus. 2009. Estimating soil erosion after fire and fuel treatments in coast redwood: a GIS-based approach [abstract]. Page 44 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

LONG-TERM EFFECTS OF SALVAGE LOGGING ON COARSE WOODY DEBRIS DYNAMICS IN DRY FORESTS AND ITS IMPLICATIONS TO SOIL HEATING

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ABSTRACT

Question: In dry forests what is the relative influence of coarse woody debris, in the presence or absence of salvage logging, on effects such as soil heating and root mortality?

Background: Because of land management practices of the 20th century, such as fire exclusion, fire suppression, grazing, and the selective removal of fire-tolerant ponderosa pine (*Pinus ponderosa*), dry forests in the eastern Cascades of Washington have changed in fuel and vegetation structure. Under proper fuel and weather conditions, these forests are recently burning more frequently with high severity to create large-scale stand-replacement events that were not historically experienced. After these high-severity fires, much or all of the aboveground biomass was converted to coarse woody debris (CWD). Managers use salvage logging as a tool to recoup any post-wildfire economic loss, but its ecological role has been called into question. Most of the literature found on salvage logging dealt with short-term effects, and none were experimental in nature. Although studies suggest that projected fire behavior may increase immediately after salvage logging because of fine fuels from tree fall and yarding, others suggest that fine fuel loading over longer time frames will converge as ground fuel mass from sites not salvaged would increase when snags convert to logs. As dry forests dominated by ponderosa pine recover after having experienced high-severity wildfires, the dry summer conditions and long fire seasons almost guarantee that future wildfire will occur and threaten the young post-fire forest stands with another stand-replacement event. In the meantime, no experimental or retrospective study was found that looked at the long-term effects of decisions to salvage log severely burned dry forests. The dynamics of post-wildfire CWD and the implications of salvage logging on potential future fire severity of prescribed fires or wildfires is not clear. An opportunity to do a retrospective study on this question revealed itself in four large stand-replacement fires that occurred in dry forests in eastern Washington.

Location: Okanogan-Wenatchee National Forest (lat 47°41′54″N, long 120°19′25″W), Washington, USA.

Methods: Total biomass, log biomass, and percent cover were estimated in each stand and analyzed in a stratified randomized sampling design with the factors fire unit (ages 1, 11, 17, 35 years), salvage option (presence or absence), and aspect (dry or mesic). Log decks were instrumented with thermocouples to map lethal heating (60°C) under burning logs. Live Douglas-fir (*Pseudotsuga menziesii*) dowels used as root surrogates were also buried under each log and tested afterward for cambial tissue condition.

Results: In unsalvaged units, total CWD biomass averaged 60 Mg ha^{-1} across all sites. However, the proportion of logs to snags increased over the chronosequence. In 35 years, there was no clear temporal pattern to CWD biomass change. Salvaged units had lower log biomass than unsalvaged units, except for the most recently burned site, where salvaged stands had higher log biomass. Mesic aspects also had higher log biomass than dry aspects. Experimentally burned logs produced lethal surface temperatures extending up to 10 cm laterally beyond the logs. Logs burned in late season produced higher surface temperatures than those burned in early season. Thermocouples buried at depth showed mean maximum temperatures declined exponentially with soil depth. Large logs, decayed logs, and those burned in late season caused higher soil temperatures than small logs, sound logs, and those burned in early season. The live 1.25-cm-diameter × 10-cm-long Douglas-fir dowels indicated that cambial tissue was damaged to 10-cm depth and to 10-cm distance adjacent to burned logs. When lethal soil temperature zones were extended out to 10 cm from each log, lethal cover ranged up to 24.7% on unsalvaged portions of the oldest fire, almost twice the lethal cover on salvaged portions.

Conclusions: Dry forest fire regimes in eastern Washington have shifted from low- to mixed- or high-severity regimes and burn more frequently with high intensity, which develop levels of CWD biomass and cover beyond historic levels. These fire-prone ecosystems are also dry enough that decomposition is slow. In the meantime, recovering forests remain at risk to wildfire, and it may be difficult to perform prescribed burns in recovering dry forests with high levels of CWD because smoldering logs from fires may increase fine root mortality, which increases the likelihood of tree mortality, and increase smoke output. Regardless of salvage logging, soil heating from smoldering logs will be a concern. Salvage logging can reduce the level of CWD. When CWD levels are high, it may be better to schedule prescribed fires during the spring when the amount of CWD consumption and area burned is less. Longer-term ecological effects of excessive levels of CWD should be factored into the decision-making process.

keywords: coarse woody debris, *Pinus ponderosa*, salvage logging, soil heating, Washington, wildfire.

Citation: Monsanto, P.G., and J.K. Agee. 2009. Long-term effects of salvage logging on coarse woody debris dynamics in dry forests and its implications to soil heating [abstract]. Page 45 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

CAPABILITIES AND LIMITATIONS OF SMALL-SCALE EQUIPMENT FOR FUELS REDUCTION IN THE WILDLAND–URBAN INTERMIX

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ABSTRACT

Question: What are the capabilities, limitations, and productive elements of using labor-intensive small-scale equipment for stem-wood or whole-tree removal in wildland–urban intermix fuels treatment in a multistoried mixed-conifer stand?

Background: Throughout the United States, there has been an increase in the number of homes built in rural, forested areas known as the wildland–urban intermix (WUI). Naturally occurring wildland Āre and human-caused ignitions put structures and humans, especially homeowners and Āre suppression personnel, at great risk. The protection of human life and property as well as the safety of Āre suppression personnel are major concerns in the WUI. Landowners and land managers need to modify forest stand structures adjacent to homes and other buildings in order to increase the probability that buildings will survive and property damage and insurance losses will be reduced in the event of wildĀre. Forest stands in the natural state can be thinned, and stand structures can be modiĀed to reduce the risk of a surface Āre climbing into tree crowns and traveling from crown to crown. To accomplish stand structural changes, many small trees with little or no commercial value must be cut and the fuels resulting from these operations must be treated. These operations are costly due to the low value of the trees to be harvested, the small areas treated, and the sensitive homesite nature of the properties. Typical large-scale timber harvesting equipment is not usually suited for WUI treatments because of high equipment mobilization costs and the visual impacts of disturbed soils and damaged residual trees. Cost-effective methods of fuel reduction in the WUI may be realized by using labor-intensive small-scale wood-harvesting equipment commonly used in European and Scandinavian countries.

Location: A homesite area in a mixed-conifer multi-canopy forest (lat 46.51°N, long 116.54°W) near Moscow, Idaho, USA.

Methods: An elemental time study approach was used to evaluate four labor-intensive, low-capital-cost, small-scale wood-harvesting systems. Observations were made to determine the capabilities, limitations, and cost components of a tracked mini-skidder, an all-terrain vehicle (ATV) with skidding arch, a tracked skid steer loader, and a wheel tractor/grapple loader both with radio–remote-controlled skidding winches. The study was an independent evaluation of each machine rather than a comparison.

Results: Whether working on snow or over slash, traveling longer distances or winching logs to roadside locations, each system tested had an operational niche. Labor was the single most inÈuential cost associated with these systems, exceeding 80% of the operating costs for some equipment. The systems tested did not have an abundance of power. Work techniques were used to reduce hang-ups, minimizing residual stand damage. Additionally, soil disturbance was minimal across all studies. In most cases, grasses and forbs remained intact on the skid paths, reducing the visual impacts. Cost per 100 cubic feet of stem wood removed ranged from $26 to $50. After all costs were considered, including hand-piling and burning of treatment slash, the net revenue ranged from a positive $398 to a negative $297 per acre. The ATV with skidding arch works well over longer distances in a downhill mode on cleared trails. ATVs are commonly owned and available and, with the addition of a skidding arch, landowners and contractors are ready to go to work. The Iron Horse tracked mini-skidder moves slowly and is best suited for short downhill skids but works very well over slash and snow. Winching systems attached to skid steer or wheeled tractor base machines need to work from stand trails or woods roads, are effective for up- or downslope winching and can handle larger logs. A radio-remote winch control is very effective and increases production. Each system has an operational niche.

Conclusions: Small-scale systems have a low capital investment, a low operating cost, are easily transported, and have low site impacts with high social acceptance. The disadvantages include a high manual labor component, safety issues with employees, low productivity, and a lack of small-scale contractors. Many landowners may have equipment and the basic woods working skills to do their own harvesting of small-diameter trees. While revenue from the harvest of small-diameter may not completely pay for fuel reduction treatment costs, the beneĀts associated with small-scale equipment may offset costs sufficiently to persuade homeowners and landowners to initiate fuel reduction treatments on their property.

keywords: fuel reduction, mini-skidder, skidding arch, small-scale equipment, tractor winch, wildland–urban intermix.

Citation: Osborne, H.L., H. Lee, J. Halbrook, and G. Davis. 2009. Capabilities and limitations of small-scale equipment for fuels reduction in the wildland–urban intermix [abstract]. Page 46 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

FOLIAR MOISTURE OF *LITHOCARPUS DENSIFLORUS* AFFECTED BY SUDDEN OAK DEATH AND THE RESULTING CROWN FIRE POTENTIAL

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ABSTRACT

Question: Does sudden oak death lower the foliar moisture of tanoaks, allowing for a greater potential for tree torching and crown Āre?

Background: *Phytophthora ramorum*, the pathogen recognized as causing the forest disease known as sudden oak death (SOD), has reached epidemic proportions in central and northern California coastal forests and woodlands. First detected in 1995 in the San Francisco Bay area, it has quickly spread north and south along the coastal forests and woodlands from Monterey to Humboldt County and isolated areas of southwest Oregon. Tanoak (*Lithocarpus densiflorus*) is particularly susceptible to SOD, with overstory mortality exceeding 95% in many stands. As tanoak typically comprises one-third or more of the basal area in these coastal forests, the change in canopy fuel and the possibility of crown Āre is a considerable concern among Āre officials and land managers throughout the affected and projected areas of SOD infection. The virulence of SOD is especially troublesome considering the fact that dead foliage is retained on infected trees for 1 year or more. *P. ramorum* infects tanoak stands and ultimately kills individual trees, leading to changes in aerial and surface fuel structures. As these changes progress over time, four distinct phases of decline can be considered. Phase 1—Individual trees are infected, crowns become yellow with reduced density, and foliar moisture may drop as the leaves begin to die. Phase 2—The entire tree is left standing dead with leaves attached. Phase 3—Leaf drop occurs, adding considerable litter fuel to the forest Èoor fuel bed, thereby elevating surface Āre hazard; the canopy Āre potential is reduced while surface Āre hazard more of a concern. Phase 4—Branches, limbs, and entire stems begin to fail, falling to the forest Èoor, resulting in a substantial increase in surface fuel loading in all woody time-lag classes. This project focuses on phases 1 and 2, as these phases (especially phase 2) demonstrate the most acute Āre danger in SOD-affected tanoak forests. As dead trees are left standing in a "leaf-on" state, individual trees can torch during a Āre, and the potential exists for Āre spread to adjacent infected and uninfected crowns. The assessment of crown Āre potential requires the consideration of four parameters: Āreline intensity (FLI), crown base height (CBH), crown bulk density (CBD), and foliar moisture content (FMC). Of these parameters, FMC is the primary factor that is changing as SOD-infected trees die. The purpose of this study was to measure and track the FMC of healthy tanoaks, tanoaks infected with SOD, and dead tanoaks with leaves attached throughout the spring and summer seasons. We hypothesized that FMC would decrease with infection, resulting in an increase in crown Āre ignition and spread potential.

Location: Humboldt County, California, USA, infected stand (lat 40°08′29″N, 123°49′72″W) and 69 km from this site, an uninfected control (lat 40°46′08″N, 123°52′05″W).

Methods: Foliar moisture samples were collected monthly from tanoak trees in Humboldt County, California, from 21 March through 22 August 2008. Individual trees were selected in an area of known SOD infection where SOD has been known to exist in the stand since 2004. A second sampling site, 69 km from the infection site, was established as an uninfected control.

We sampled 25 tanoak trees each month ($n = 8$ live uninfected tanoaks, $n = 10$ live SOD-infected tanoaks, and $n = 7$ standing dead tanoaks with leaves attached). Each month we collected >1-year-old leaves, new leaves, and woody twigs (0.0–0.6 cm) from tanoaks. All samples were collected from the lower one-third of the canopy on the south aspect of each tree between 1300 and 1600 hours to minimize effects of diurnal variation. Samples were sealed in polyethylene bags, weighed wet, then oven-dried at 70°C to a constant weight. Data were analyzed across categories of infection (noninfected, infected, and dead) using repeated-measures analysis of variance. For each collection date, moisture contents of infection categories were compared using Tukey–Kramer post hoc means separation.

Results: FMC of leaves from uninfected trees and infected trees did not change signiĀcantly from March to August 2008 ($P = 0.14$). The 6-month mean FMC for uninfected trees was 81.2% (SE = 1.7%), and infected trees were 77.0% (SE = 1.5%). FMC of dead leaves was signiĀcantly lower than both uninfected and infected leaves for all months, with a mean of 8.7% across the 6-month sampling period (SE = 1.8%, $P < 0.001$). FMC of dead trees over the same period revealed a signiĀcant drop in moisture from a high of 11.11% in May to an average of 5.9% in August (SE = 1.9%, $P < 0.001$). FMC of twigs followed a similar pattern. Uninfected twig FMC averaged 73.3% (SE = 2.9%) over the 6-month period. Infected twig FMC had an average of 71.4% (SE = 2.0). No signiĀcant change in FMC was found for twigs of uninfected or infected trees among all months ($P = 0.59$). FMC of dead tree twigs was signiĀcantly lower than uninfected and infected tree twigs, with a mean of 11.9% ranging from a maximum of 17.8% in May to a minimum of 8.7% in August (SE = 2.4%, $P < 0.001$). The moisture content of new leaves differed between the uninfected and infected trees, indicating infected trees had a lower mean FMC across the months sampled ($P = 0.02$). No signiĀcance was found between the healthy trees in the known SOD area and the trees sampled in the control group for leaf FMC ($P = 0.13$). The 6-month mean twig FMC at the control site was 82.9% (SE = 1.1%, $P < 0.01$), signiĀcantly higher than that of the uninfected trees at the known SOD site.

Conclusions: Trees suffering from *P. ramorum* do not necessarily undergo a signiĀcant drop in FMC in the early infection stage. In fact, infected trees showed considerable new leaf growth during the spring and early summer season, albeit not as vigorous as in the uninfected trees sampled. New leaf (<1 year) FMC was signiĀcantly lower in the infected trees than in the uninfected trees. The slight lowering of mean FMC for the infected tree leaves >1 year may be because many leaves sampled had considerable dead margins and/or tips, a symptom we observed on several SOD-infected tanoaks. Throughout the sampling period, FMC remained almost unchanged, with ranges of ±2% in uninfected leaves, ±3% in uninfected woody twigs, ±4% in infected leaves, and ±7% in infected woody twigs. The largest difference among the three infection categories was between the foliage of the dead trees and the leaves of uninfected/infected categories. Mean dead-leaf FMC levels dropped as summer developed, allowing moisture to reach below 5% in some cases. Surface litter moisture beneath these trees, by comparison, averaged 7% moisture during the midsummer months. Overall, tanoak has a very low FMC when compared with other trees. For example, Douglas-Ār (*Pseudotsuga menziesii*), a species associated with tanoak throughout much of its range, has an FMC of 147%. This property alone may increase the chances of canopy Āre ignition and spread. Future work will track FMC of tanoak across infection categories for the remainder of the year, establish a range of expected CBH in affected stands, and estimate the changes in CBD as the disease progresses. Quantifying and understanding these properties will be a giant step forward toward the ability to more accurately model crown Āre potential and behavior in the expanding SOD infection in tanoak forests.

keywords: crown Āre, Āre behavior, foliar moisture content, sudden oak death, tanoak.

Citation: Kuljian, H.G., J.M. Varner, and C. Lee. 2009. Foliar moisture of *Lithocarpus densiflorus* affected by sudden oak death and the resulting crown Āre potential [abstract]. Page 47 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

CALCULATING ACCURATE ABOVEGROUND DRY-WEIGHT BIOMASS OF HERBACEOUS VEGETATION IN THE GREAT PLAINS

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A study was established in 2006 to look at six reservations in the Great Plains region of the Bureau of Indian Affairs to compare three individual methods of calculating aboveground dry-weight biomass to determine the least resource-intensive method. FIREMON data were collected in the four agencies, utilizing a modified FIREMON plot layout that included plot description, fuel loading, and cover frequency. Additionally, grasses were clipped and weighed on ten 20 × 20-inch frames per plot. The same study was repeated in 2007 with all sample points being remeasured. This paper will examine the results from the 2006 field season and compare these results with those generated in 2007. The results of this study provide an accurate regional bulk density constant that can be used to generate accurate dry biomass calculations, which eliminates the need for resource-intensive field methods.

FUEL SUCCESSION FOLLOWING HIGH-MORTALITY WILDFIRE IN EASTERN SLOPE CASCADE MIXED-CONIFER FORESTS OF OREGON

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Complex interactions between past management practices, climatic variation, and cumulative disturbance events alter forest structure and composition, potentially causing increased intensity and extent of present-day wildfires. Limited research evaluating post-fire fuels dynamics reduces the ability of public land managers to develop sound, scientifically based management plans and make decisions incorporating ecological processes. To provide managers with some insight into these dynamic processes, we conducted a chronosequence study to evaluate accumulation of wildland fire fuel complexes for 24 years following high-mortality fire events in eastern slope Cascades mixed-conifer forests. The specific questions evaluated in the study were 1) What are the fall rates and decomposition rates of *Pinus ponderosa* and *Abies grandis/Abies concolor* snags following high-mortality fire events? 2) What are the decomposition rates of downed woody detritus following high-mortality fires? 3) How do fuel complexes develop through time? Mixed-conifer forests are characterized by *Pinus ponderosa* dominance, but, depending on past stand history, either *Abies grandis*, *Abies concolor*, or *Pseudotsuga menziesii* may be codominant. Standing and down dead detritus and growth of live biomass are the primary sources of fuel in post-fire environments. Results from the study indicate that within the first 5 years post-fire, 90% of small branches (<2.5 cm) on remnant snags senesce, contributing to 1-hour and 10-hour fuel loads, but decomposition decreases these fuels rapidly. Approximately 15% of remnant snags fall within 5 years, increasing 100-hour and 1000-hour fuels. Live fuels increase as shrubs, dominated by *Ceanothus velutinus* and *Arctostaphylos patula*, quickly occupy high-mortality sites, averaging 65% cover within 5 years. Fall rates of snags rapidly increases between 5 and 15 years post-fire, adding to 100-hour and 1000-hour fuel loadings. Approximately 65% of all snags have fallen by year 15, and within 24 years approximately 85% of all snags have fallen. Shrubs dominate live fuels with continued growth in height and continuity. One-hour and 10-hour fuels experience little accumulation during this period, but litter accumulation from shrub leaf abscission increases. Shrub species begin to self-prune branches after 15 years, inputting 1-hour and 10-hour fuels at an increasing rate. Fuel size class and continuity have considerable influence on fire behavior, with 1-hour fuels being the primary factor in fire spread and intensity. Decomposition and variable fuel inputs following high-mortality fire limits risk of elevated fire spread and intensity when reburning occurs, suggesting management priorities may be best directed towards unburned sites.

SOLAR RADIATION–DRIVEN VARIATION IN FINE FUEL MOISTURE CONTENT ON NORTH- AND SOUTH-FACING MOUNTAIN SLOPES

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Decision support tools such as the Canadian Forest Fire Danger Rating System (CFFDRS) exist to aid managers in assessing and integrating the numerous factors inÈuencing the potential for dangerous wildÃre behavior. One component of CFFDRS, the Fire Weather Index (FWI), uses common weather inputs to create numerical rankings of Ãre danger related to wind conditions and the moisture content of surface fuels. Outputs of the FWI system represent standard fuel conditions on Èat terrain and in a closed-canopy jack or lodgepole pine stand. Realistically, Ãre managers must constantly adapt these baseline measurements to suit their local surroundings. Managers in regions with complicated topographical features often Ãnd large discrepancies between predicted and actual fuel moisture conditions on slopes. The underlying models within the FWI System fail in mountainous terrain because they do not contain a component to represent incoming solar radiation, a key factor inÈuencing variation in mountain climate. Although simple physical relationships can be used to estimate temperature and relative humidity changes related to elevation, it is difficult to accurately quantify the length of exposure and amount of solar radiation received at the forest Èoor. In complex topography, slope angle and orientation coupled with time of year and latitude create a complicated mosaic of solar energy conditions. These differences are further complicated by the fact that the FWI System does not explicitly take solar radiation (and variations therein) into account. This study aims to address the difference in predicted and actual moisture content found on slope by creating a comprehensive plan to collect litter and duff samples on north- and south-facing slopes. Along with this destructive sampling of litter moisture, a system of weather stations will be installed to describe solar radiation and in-stand microclimatic conditions in relation to slope percent and orientation. Because the drying and wetting cycles of Ãne fuels are the most sensitive to changes in microclimatic conditions, a calibration factor will be calculated to allow Ãre managers to adjust the moisture content predicted by Fine Fuel Moisture Code from standard Ãre weather stations. The relationship between solar radiation, slope, and aspect and in-stand moisture conditions will be discussed and a database of knowledge will be created to allow future calibration of all FWI outputs.

STEREO PHOTO SERIES FOR QUANTIFYING NATURAL FUELS

Robert Vihnanek
Supervisory Forester, USFS

Stereo Photo Series for Quantifying Natural Fuels Volume III: Lodgepole Pine, Quaking Aspen, and Gambel Oak Types in the Rocky Mountains. Roger D. Ottmar, Robert E. Vihnanek, and Clinton S. Wright. U.S. Department of Agriculture, Forest Service, PaciÃc Northwest Research Station, PaciÃc Wildland Fire Sciences Laboratory, Fire and Environmental Research Applications Team, 400 North 34th Street, Suite 201, Seattle, WA 98105, USA. This natural fuels photo series is a set of data and photographs that collectively display a range of natural conditions and fuel loadings in a wide variety of ecosystem types throughout the Americas from central Alaska to central Brazil. Fire managers are the primary target audience of the natural fuels photo series, although the data presented will also prove useful for scientists and managers in other natural resource Ãelds. Volume III includes sites in three major fuel types in the Rocky Mountains: lodgepole pine, quaking aspen, and Gambel oak. For each site, the publication presents wide-angle and stereo-pair photographs supplemented with information on living and dead fuels and vegetation, and where appropriate, stand structure and composition within the area visible in the photographs. The sites in each volume provide a basis for appraising and describing woody material, vegetation, and stand conditions in their respective ecosystems.

DERIVING FARSITE-READY CANOPY FUEL PARAMETERS FROM LiDAR DATA

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Crown fires are the most dangerous of wildfire types and common in the western United States. They travel at speeds of kilometers per hour (versus meters-per-minute surface fires and centimeters-per-minute ground fires) and are more difficult to suppress than surface fires because of their high intensity. There is a strong need to successfully model crown fire behavior due to the vast natural resource damage they cause, the costs associated with property loss, large suppression efforts, and risks to human safety. Modeling fuel distribution and crown fire behavior, therefore, are crucial for fire management activities such as planning prescribed burning or the prediction of fire spread in ongoing fires. Light Detection and Ranging (LiDAR) imagery has proven to be useful for mapping forest structure. We created several algorithms for LiDAR point data processing that are computationally uncomplicated and portable to forests of varying condition, spanning a range of topographic environments, and consisting of multiple tree species both coniferous and deciduous. We were also able to demonstrate that accurate determinations of forest structural metrics, such as canopy height, canopy base height, and canopy volume, can be obtained with submeter, 1-m, and even 3-m resolution data at the hectare plot scale. LiDAR data were also used to calculate canopy bulk density, canopy fuel, and foliar biomass. Linear regression and multivariate models formulated from forest data in other settings (as published in the literature) are not universally applicable to forests around the northern Rocky Mountain region and not suitable for widespread application. Our models demonstrate that forests of mixed-canopy shape classes are not be amenable to a single regression equation approach, but that waveform analysis has great potential for classifying an image by canopy shape for individual algorithm treatment. These data layers can provide firefighters with more accurate inputs to fire behavior models such as FARSITE, a software tool used within the U.S. Forest Service to forecast the spread of wildfires. Our high-resolution data layers will lead to enhanced software simulations that can reduce firefighting risks and improve wildfire control.

TRANSPORT EFFECTS ON CALORIMETRY OF POROUS WILDLAND FUELS

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Computational fluid dynamics and other modeling techniques are rapidly being developed to describe wildland fire behavior. One aspect of fire modeling, in general that requires refinement, is the understanding of fire behavior in porous fuel beds. This presentation details the design, methodology, results, and data analysis of a series of tests that examined the effect of transport processes on the burning of two fuels that form porous fuel beds, *Pinus halepensis* and *Pinus pinaster*. Calorimetry is used to measure a fuels heat release rate (HRR) and HRR is used extensively in computer-aided fire models to characterize fire behavior. This test series was conducted using standard fire testing equipment, both a cone calorimeter and a factory mutual fire propagation apparatus (FPA). New sample holders were designed that allowed different flow rates to be established in the fuel beds by having different openings, 0, 26, and 63%, in the surface area of the baskets. The two fuels had different surface-to-volume ratios that created different internal transport properties in the fuel beds during combustion. Flow was measured using a laser imaging technique. The cone tests were done only for natural convection flow conditions. The FPA tests used both natural convection and forced-flow test conditions. The test conditions in the cone and the natural convection condition in the FPA were intended to be similar to a no-wind condition in a wildland fire. The forced-flow condition was intended to simulate a wind effect. The tests examined how the various flow conditions established in the porous fuel beds affected the HRR of the fuels. The key finding for wildland fuel testing and modeling was that transport in the depth of the fuel bed layer was the limiting process on HRR. With a forced flow, an increase in a fuels surface-to-volume ratio increases the HRR. For a given fuel, the HRR was always significantly higher when the fuel bed was able to establish flow in the entire depth of the fuel layer. The air flow in the fuel layer increased HRR, either when induced by natural convection (the flame effects only) or forced by inlet air test conditions. The surface-to-volume ratio affected HRR differently for natural convection and forced-flow test conditions. The main conclusion was that the major factor controlling HRR was the ability of the porous fuel beds' internal transport properties to enhance flow during combustion. This effect needs to be tested in a broader range of fuels that create porous beds under natural conditions in wildland fires.

PARCEL-BASED RISK RATING TO MOTIVATE FUEL MANAGEMENT

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Several western U.S. communities are conducting risk assessments on a parcel scale in order to create a more fire-safe community. This highlights two jurisdictions in Contra Costa County, California. There are several common elements in parcel-based risk assessment. First is an assessment of the wildland fire hazard facing the community, often in terms of potential fire behavior. The second is the selection of factors most important in mitigating the hazard. Typically these are factors that support fire-suppression response, fuel management, and features of the structure. Mitigation modifying the hazard result in risk can be portrayed on a parcel scale or aggregated to a community scale. Both jurisdictions chose to utilize aerial hyperspectral and LIDAR information to gather attributes required for a parcel-based risk assessment. Hyperspectral information enabled data collection through one event and extraction of many environmental attributes at a high level of detail without extensive post-analysis ground verification. LIDAR captures vertical spatial arrangement of shrub and canopy fuels. Detailed structural material composition, FBPS fuel models, canopy fuel characteristics, and other information needed to determine fire behavior were extracted. FlamMap was used to categorize fire hazard. All data were combined within district-wide GIS databases; each parcel was assessed for its potential risk from a wildland fire. Two jurisdictions developed different strategies to support actions to lower fire risk. One jurisdiction is using risk assessment to determine compliance with adopted ordinances and regulation; enforcement is emphasized. Those factors not addressed by regulation were treated as opportunities for inspectors to educate the parcel owner about how to further enhance fire safety. The output and attributes are used by the jurisdiction for internal information, decision making, and individual education of parcel owners. Another jurisdiction weighted heavily factors not covered by ordinances. In this case, the rationale was to enforce the ordinances but to also heighten the weight given to those unregulated factors the individual parcel owner can change. In the older community, this includes retrofitting structural features (skirting decks, changing eave or vents, making address signs more visible) or other features addressed in new construction but not in existing structures. Output and attributes are displayed in a public Web site, allowing property owners to visualize the fire risk, learn which factors contributed to the risk assessment, and take recommended actions to reduce their exposure to wildland fire.

UNTREATED AND PROTECTED OWL HABITAT ON THE PLUMAS NATIONAL FOREST FROM THE ANTELOPE AND MOONLIGHT FIRES

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Fire effects and evidence of fire behavior in treated, untreated, and protected owl habitat were compared for two wildfires that occurred on the Plumas National Forest during 2007. Complementary approaches were applied, including analysis of satellite data, post-fire field plots, and in situ measurements and observations of fire behavior and fuels during the fires. Remote sensing data were obtained from USFS Pacific Southwest Region fire remote sensing specialist. A stratified random selection of points was generated from a grid representing relative canopy cover change (relative dNDBR). Strata included untreated areas, protected owl habitat, areas treated for fuel reduction or timber harvest, and recent wildfires (80%) compared with other untreated areas (mean of 70%). Observational and in situ data in treated areas showed reduced fire behavior and effects (overstory tree crown consumption) in treated areas compared with untreated areas for most treatments. Some older harvests and recent mastication treatments showed greater crown consumption and evidence of fire behavior. A classification regression tree analysis of remote sensing data for the Moonlight Fire was conducted. A greater variety of types and ages of treatments overlapped with the Moonlight Fire and were compared. Results showed that treatment type was the most important explanatory variable for changes in canopy cover. Thinning and burning were separated from salvage, no treatment, mastication, or older timber harvests. Time since treatment (>10 or <10 years) was the next split in the thin/burn branch and elevation in the other branch. Observations suggested that large blocks of untreated areas (especially protected habitat) contributed to intense, fuel-driven, plume-dominated fire behavior that overwhelmed treated areas. Implications for management are that the amount of area treated, type of treatment, and time since treatment influences fire behavior and fire effects.

WILDLIFE AND FIRE

THE ECOLOGICAL NECESSITY OF SEVERE FIRE: AN EDUCATION MESSAGE STILL NOT HEARD

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ABSTRACT

Question: Is the black-backed woodpecker relatively restricted in its distribution to severely burned forest conditions?

Background: Insight into the importance of severe fire in any ecosystem can be gained through careful consideration of the ecology of plant and animal species that are restricted in their habitat distribution to severely burned conditions. After the fires of 1988, I compiled published bird survey data available from studies conducted within a limited number of vegetation types and found that one bird species, the black-backed woodpecker (*Picoides arcticus*), was relatively restricted to burned forest conditions. However, these data were derived from a literature-based meta-analysis of studies that differed in duration and survey methodology, and that were conducted across a relatively small number of vegetation types. Some 13 years later, the U.S. Forest Service Northern Region Landbird Monitoring Program has amassed one of the largest bird point-count databases of its kind, with sample locations drawn from a wide range of unburned vegetation types across northern Idaho and western Montana. By combining those data with data collected from additional locations distributed across >50 fires that had burned in western Montana during the past 20 years, I was able to ask whether the black-backed woodpecker is relatively restricted to burned forest conditions and, if so, whether its probability of occurrence also varies significantly with fire severity.

Location: Northern Idaho, western Montana, and Yellowstone and Grand Teton national parks, USA.

Methods: Bird survey points were spaced 250 m apart and were distributed along 10-point transects that were themselves distributed in a geographically stratified manner. Field observers visited a total of 16,465 locations across a wide range of unburned and burned vegetation types. The sample included 3,128 points distributed within 50 different recently burned forests. Bird surveys were conducted using a standard 10-minute point-count protocol. Fire severity surrounding points was determined from the proportion of trees that were green-needled, brown-needled, and blackened within 50 m of the survey point.

Results: After summarizing 20 years of data systematically collected from >13,000 survey locations distributed across nearly every vegetation type occurring in the Northern Rockies, it is clear that the restricted distribution pattern is not an artifact of problems with the earlier meta-analysis. The black-backed woodpecker is generally restricted in its habitat distribution to burned forest conditions. Moreover, within burned forest perimeters, the woodpecker was absent most of the time from unburned portions, and it became more common as fire severity increased. Finally, the woodpecker was significantly less likely to occur in forests that were recently harvested either before or after fire. The probability of occurrence decreased incrementally with intensity of harvest.

Conclusions: These restricted distribution patterns have profound implications because they bring into question the hypothesis that the severe fires we see burning in many, if not most, western forests are “unnatural” or “unhealthy” and suggest instead that severely burned forest conditions across a broad range of forest types (not just in Yellowstone but elsewhere throughout the West) must have occurred naturally for millennia. Not only does this woodpecker occur in more severely burned forests, but it is also significantly less abundant in forests that have been recently harvested either before or after fire. For obvious (and perhaps some not-so-obvious) reasons, this story has yet to reach politicians, public land managers, and the public-at-large, most of whom continue to view such fires as catastrophic events, and feel the need to conduct management activities that are clearly incompatible with the needs of post-fire specialists like the black-backed woodpecker.

keywords: black-backed woodpecker, fire history, fire regime, mixed-conifer forest, severe fire.

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DISENTANGLING BOTTOM-UP AND TOP-DOWN EFFECTS OF FIRES ON MONTANE UNGULATES

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ABSTRACT

Question: What is the relative importance of the bottom-up effects of Āre versus predation by recolonizing wolves on elk population dynamics?

Background: Fires can affect wildlife populations in diverse ways through direct and indirect community responses. For example, ungulate herbivores such as elk (*Cervus elaphus*) can be inÈuenced by bottom-up changes wrought by Āre, and for ungulates that specialize on early-seral plant species, Āre is often thought to have a positive effect on population dynamics. Previous studies documented short-term but signiĀcant effects of the '88 Yellowstone Āres on elk population growth rates and hence size. Indeed, restoration of ungulate populations is often an express goal of the application of prescribed Āre and is used by government and private foundations (e.g., Rocky Mountain Elk Foundation). However, Āre can also have an indirect negative effect on ungulates in systems where Āres inÈuence the distribution of the predators of large herbivores. Because theory predicts the distribution of predators to match the distribution of food resources of their prey, predators such as wolves (*Canis lupus*) may also select burned habitats if they are favored by ungulates such as elk. These indirect top-down effects of Āre on ungulates have not been as studied as the bottom-up effects of Āres on ungulates. While elk may select burned habitats for foraging, we hypothesize that top-down effects of wolf attraction to burned habitats will negate any potential population impact of Āres on ungulate populations.

Location: Eastern slopes of Alberta in and adjacent to Banff National Park (lat 51°15′N, long 116°00′W), Alberta, Canada, from 2001 to 2005.

Methods: We used a resource selection function (RSF) framework and previously published RSF models for GPS-collared elk as a function of wolf predation risk and Āres in an area with >250 km^2 of burns ranging in age from 1986 to the present. This allowed us to design landscape scenarios for both wolf presence/absence and Āre size and elevation to determine the relative effects of both on elk habitat quality and projected population size.

Results: Elk and wolves selected for recently burned forests, grasslands, and shrub meadows within the Ārst 2–5 years following Āre, similar to previous studies for ungulates. In a landscape context, wolves strongly selected for larger, lower-elevation burns during summer. Elk similarly selected lower-elevation burns, although they also showed selection, albeit weaker, for higher-elevation burns. In terms of our landscape scenario evaluations, wolves, elevation, and Āre size, the presence or absence of wolf predation had by far the largest impact on both elk habitat quality and potential population size compared to the characteristics of Āre. Thus, top-down effects swamped the positive effects of Āre observed in the absence of wolves.

Conclusions: This landscape simulation study suggests that the positive effects of Āre on ungulates may be swamped by top-down changes to wolf predation risk because wolves select Āres following burns. In this sense, at least in Banff, the hypothesis that wolf predation and Āre may interact to negate Āre's bottom-up beneĀts is supported. In the context of attractive sinks and ecological traps, this suggests that low-elevation Āres act as attractive sinks for elk because of the abundant forage and higher wolf predation risk there. It is important to note that this apparently counterintuitive result is consistent with selection for Āres maximizing relative Darwinian Ātness of individual elk given historic Āre history in many montane systems. This landscape simulation study used empirically derived wildlife–habitat–Āre RSF.

keywords: ecological trap, Āre, predation, resource selection, trophic cascade, Yellowstone National Park.

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TRI-TROPHIC INTERACTIONS: IS THE NORTHERN RANGE ELK HERD LESS VARIABLE WITH WOLVES AND FIRE?

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We built models immediately following the 1988 fires to anticipate the consequences of the fires to ungulates in Yellowstone. Since that time, the system has become more complex because wolves were reintroduced in 1995. Using spatially explicit resource selection functions of elk habitat selection, wolf predation risk, and models of vegetation abundance with succession, we updated our predictions from the tri-trophic interactions among elk, wolves, and vegetation on Yellowstone's northern range. We explored the effects of 1) stochastic variation in climate, 2) fire-mediated influence on vegetation, and 3) wolf predation on the dynamics of elk populations. From our simulation results, we hypothesize that the large scale of the fires and rapid wolf recovery have contributed to lower variance in elk abundance in recent years compared with the period prior to the 1988 fires.

INTERACTIVE EFFECTS OF FIRE, UNGULATES, AND WOLVES IN YELLOWSTONE NATIONAL PARK GRASSLAND

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Fire and ungulates have profound effects on grassland ecosystems. Fire increases grassland production, nutrient cycling, and the quality of forage for herbivores. Ungulates can stimulate plant productivity and nutrient cycling in some grasslands. Because grasslands are heterogeneous habitats, where the amount of fuel available to carry fire varies spatially, the effect of fire on grasslands has a strong spatial component. In grasslands with abundant ungulates, herbivores often graze, i.e., remove fuel, in a non-uniform manner. Consequently, the effect of herbivores on grassland processes will be heterogeneous and the spatial manner in which habitat is grazed should have an effect on the properties of grassland fire. Finally, predators can change the spatial pattern in which ungulates graze their habitat. Therefore, large herbivores and predators can interact in complex ways to influence the intensity and behavior of fire in grasslands. In this talk I will describe results from grassland studies in Yellowstone National Park, spanning a 17-year period, that suggest strong interactive effects of ungulates and wolves on the intensity and behavior of grassland fire. Yellowstone ungulates stimulate grassland plant and soil processes, and these facilitating effects have a strong spatial component. Prior to wolf reintroduction, ungulate grazing intensity increased with aboveground plant production, with patches in the landscape that supported the greatest forage production experiencing the greatest grazing intensities. These preferred grazing sites generally occurred in depressions or at the base of slopes. After wolves were reintroduced, ungulates no longer preferred the high-productive, low-visibility sites, presumably because ungulates favored to graze slope and hilltop sites where they could be more predator vigilant. This recent wolf-induced shift in the way that Yellowstone ungulates graze grassland should lead to changes in the intensity and/or spatial pattern of future grassland fires.

WILDFIRE IN THE WINTER RANGE OF SIERRA NEVADA BIGHORN SHEEP

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As the largest relict population of Sierra Nevada bighorn sheep (*Ovis canadensis sierrae*), the Mt. Baxter herd is important to the recovery of this endangered species. The Mt. Baxter herd has been the main source population for translocations aimed at restoring Sierra Nevada bighorn sheep to their historic range. In July 2007, the Seven Oaks wildfire burned half of the winter range of the Mt. Baxter herd of Sierra Nevada bighorn sheep. Low-elevation winter ranges provide snow-free foraging areas and an opportunity to take advantage of spring green-up. I examine the effect of the Seven Oaks Fire on bighorn sheep forage and nutrition. This is a comparative study in which I quantify differences in forage quantity and quality, as well as diet quality and composition between the Mt. Baxter range and nearby unburned range of the Sawmill Canyon herd. Forage quantity was measured with double sampling and comparative yield methods. Samples of dominant forage species were analyzed for nitrogen and digestibility. Diet quality and composition was determined from nitrogen analysis and microhistology of fecal samples collected at three times throughout the season of winter range use. I hypothesize that differences will exist in forage quantity and quality and also in diet quality and composition between the Sawmill Canyon and Mt. Baxter herds that will elucidate the impact of the Seven Oaks Fire. Monitoring and managing the Mt. Baxter herd is important for the recovery of Sierra Nevada bighorn sheep. This information will allow us to model the effect of future wildfire events on nutritional status and growth rates in this important population. In addition, our results will help direct future management using prescribed fires to enhance and restore habitat.

SIMULATING LONG-TERM CONSEQUENCES OF CLIMATE CHANGE AND FIRE MANAGEMENT ON WILDLIFE HABITAT SUITABILITY IN GLACIER NATIONAL PARK, MONTANA

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We used Fire-BGC, a mechanistic forest succession model, to examine ecological responses to climatic variability and Āre regimes within forested landscapes at Glacier National Park. We used a full factorial experimental design with multiple scenarios to assess the effects of climate change and Āre management on landscape structure, composition, and function. Spatial and temporal changes in grizzly bear (*Ursus arctos horribilis*), elk (*Cervus canadensis*), and Canada lynx (*Lynx canadensis*) habitat suitability were modeled in response to climate- and Āre-mediated changes in vegetation species composition and forest successional stage for a pair of watersheds (approximately 93,000 ha). Results suggest that climate changes stimulate vegetation species conversions and amplify Āre dynamics; Āre exclusion results in homogeneous landscapes and increasing risk of large Āres; spatial characteristics of wildlife habitat are both climate and Āre driven; and that resiliency to climate- and Āre-driven landscape change varies across wildlife species. Results of the project demonstrate the sensitivity of forested landscapes to changes in climate and Āre regimes, and quantify the spatial and temporal effects of landscape change on three key wildlife species.

MODELING RELATIONSHIPS BETWEEN FIRE, CARIBOU, WOLVES, ELK, AND MOOSE IN THE CANADIAN ROCKY MOUNTAIN NATIONAL PARKS

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Woodland caribou (*Rangifer tarandus caribou*) are listed as threatened within Alberta under the Wildlife Act and nationally under the Species at Risk Act. Banff and Jasper national parks maintain populations of woodland caribou, although numbers in both parks have declined since the 1980s. Caribou declines outside of the national parks are thought to be related to habitat loss and/or increased mortality associated with resource extraction industries. The cause of declines within the national parks, where resource extraction does not occur, is less clear; however, this may also be related to predation and habitat loss. Parks Canada is mandated to use prescribed Āre to maintain a natural disturbance regime and may rely on Āre as a tool to manage outbreaks of mountain pine bark beetle. While Āre can improve habitat for some species (i.e., elk and grizzly bear), it may be detrimental to species that rely on older seral stage forests (i.e., caribou). Less direct effects of Āre on caribou are also possible when caribou herds come into contact with greater numbers of predators whose populations have been buoyed by increased total numbers of prey. Fire can inÈuence caribou directly by altering habitat quality, and indirectly by inÈuencing habitat use and movement patterns of other ungulate species and predators. The goal of this project is to provide Parks Canada with guidelines to optimize beneĀts from Āre (e.g., providing habitat for grizzly bear, reducing mountain pine beetle attack risk) while minimizing negative effects on woodland caribou.

FOREST DISTURBANCE, ASPEN, ELK, AND PEOPLE: LESSONS FROM ROCKY MOUNTAIN AND BANFF NATIONAL PARKS

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Long-term disturbances such as Āre and mountain pine beetles historically favored regeneration of trembling aspen on low-elevation ungulate winter range. However, in the last 100–150 years, reduced activity by Native Americans, predator control, and Āre suppression have increased elk densities and decreased Āre disturbance rates, resulting in a major decline in trembling aspen and other plant species regeneration in several national parks. In the last decade, both Banff National Park (Alberta) and Rocky Mountain National Park (Colorado) started programs to restore montane plant communities. Both parks have, or are adjacent to, areas of high human use and urban areas occupying large portions of elk winter ranges. Further, both parks have compromised carnivore assemblages, and because of high values-at-risk, aggressive Āre-suppression programs. Restoration programs in both parks have included controversial proposals to directly reduce elk densities (culling or translocation), fencing select areas, restoration of natural predators where possible, followed by prescribed burning where elk densities are low enough for vegetation regeneration. Active management at this scale has required documentation of the long-term range of variability in these ecosystems, a clear understanding of current land-use impacts, extensive public involvement in management planning and environmental assessment, and ongoing complex interactions with parks' staff and stakeholders in adaptive management programs. In the next decade, these restoration programs will likely become more holistic, including potentially reintegrating the long-term role of Native Americans in park ecosystems, and more actively involving stakeholders in park management and monitoring.

EFFECTS OF PRESCRIBED FIRE ON REPTILE AND AMPHIBIAN BIODIVERSITY PATTERNS IN NORTHERN LONGLEAF ECOSYSTEM RESTORATION

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We investigated the effects of the reintroduction of prescribed fire on herpetofauna in the northern longleaf (*Pinus palustris*) ecosystem currently undergoing restoration in the Talladega National Forest, Alabama. The longleaf pine ecosystem is the principal ecosystem in the Coastal Plain of the southeastern United States, but it has declined from an estimated 92 million acres to <3% of that figure. The longleaf ecosystem and component species have evolved in a context of periodic fires. The Talladega National Forest–Oakmulgee District is within the "northern zone" of the longleaf ecosystem that is unique from southern populations in the Gulf Coastal Plain physiographic province. There is virtually no information on the effects of fire management on vertebrate biodiversity patterns in this region. Amphibians and reptiles are two of the most important components of the longleaf ecosystem. Their sheer numbers, species diversity, and sensitivity to environmental change make amphibians and reptiles unique indicator species that could be used to monitor the successful restoration of this endangered ecosystem. A 3-year sampling effort funded through the Joint Fire Science Program using multiple trap arrays in stands with different burn regime histories yielded 2,170 individuals and 45 species of amphibians and reptiles; this represents the first known herpetofaunal survey of this ecosystem. We found significantly lower diversity measures (Shannon Diversity Index and Evenness) in longleaf stands recently burned (0–1 years since last burn) versus those with >20 years elapsed since last burn. There was no significant relationship between diversity measures and season of burn (dormant versus growing); however, further investigation is needed to adequately determine this relationship. Additionally, multivariate community analyses indicate a significantly different herpetofaunal community for stands characterized by 0–1 years since last burn than in all other burn treatments. This community is primarily composed of herpetofaunal species common to open, scrub-type habitat, with *Cnemidophorus sexlineatus* serving as a strong discriminant species across all burn treatments. As a whole, our species inventory for northern longleaf is atypical of that commonly accepted for "classic" longleaf ecosystems in the lower Coastal Plain. This suggests that management regimes designed for the lower Coastal Plain may not be adequate surrogates for understanding the dynamics of northern longleaf in the upper Coastal Plain.

SCIENCE AND POLICY IN MANAGING WESTERN NATIONAL PARK ECOSYSTEMS

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Yellowstone National Park has gone through three science-management-policy phases involving the Northern elk herd: 1) protection without being informed by science; 2) herd control informed by Park research; 3) no control that altered Park resources, and was accompanied by Park science that supported the policy, but its inferences were contrary to the scientific evidence. To avoid such circuitous paths, and based on modern principles of public-policy setting, American national parks need the following structure of policy setting and management for ecological resources. 1) Each park needs an ecologically explicit goal for its ecological resources. 2) Because the parks belong to the American people, these goals should be decided on by coalitions of concerned public interests, not agency officials. 3) Achieving this might require legislation that would also specify that parks would be free to employ whatever management was needed to achieve the goals. 4) Management should be accompanied by well-designed monitoring efforts. 5) The entire process should be illuminated by independent, objective science, but science would not express a preference for goal options.

FIRE ECOLOGY: PLANT RESPONSES

FACTORS RELATED TO CANADA THISTLE PERSISTENCE AND ABUNDANCE IN BURNED FORESTS IN YELLOWSTONE NATIONAL PARK

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ABSTRACT

Question: What proportion of lodgepole pine stands that burned in Yellowstone National Park in 1988 are presently occupied by Canada thistle, and which environmental or biotic factors might explain the persistence or abundance of Canada thistle in these stands?

Background: Plant communities throughout Yellowstone National Park (YNP) may be threatened by the spread of Canada thistle (*Cirsium arvense*), including forested stands that have been impacted by disturbances, such as those caused by the 1988 Āres. We developed this project to track the dynamics of Canada thistle as succession progresses following disturbance in YNP. In June 2006, we revisited regenerating lodgepole pine (*Pinus contorta*) stands that had been previously sampled in 1999. Initially, we observed that where Canada thistle had been abundant in the past, it appeared to have diminished since 1999, and in some cases disappeared. We had two main objectives: 1) to determine if Canada thistle abundance and persistence differed between years or among sites within regenerating lodgepole pine stands, and assess which environmental factors may be related to the variability; and 2) to establish whether plant community composition differed among sites in either 1999 or 2006, and analyze which plant species were associated with different groups. We hypothesized increases in Canada thistle among sites between 1999 and 2006 due to the continued development of the plant community following the 1988 Āres. Based on previous work, we predicted that Canada thistle cover should be positively related to the percentage of sand in the soil and negatively related to sapling density due to shading from regenerating stands. Burn severity should be positively related to Canada thistle cover because more severe crown Āres would leave the herbaceous understory relatively undisturbed and would allow more sunlight to reach the understory vegetation. Finally, we hypothesized that species preferring different environmental conditions should be associated with the absence and disappearance of Canada thistle, and more similar species, such as other species in the family Asteraceae, should be found where Canada thistle has persisted, invaded, or is dominant.

Location: Yellowstone National Park (lat 44°36′N, long 110°30′W), Wyoming, USA.

Methods: We selected 30 sites from a pool of 90 throughout YNP that were previously sampled in 1999. We also sampled Āve new sites where Canada thistle was dominant. Within each plot we measured slope, aspect, herbaceous percent cover, located additional species, and extracted two soil samples. We measured sapling density, herbaceous leaf area index (LAI), and herbaceous annual net-primary productivity (ANPP). We used Shannon diversity and equitability indices, SPSS 14.0 for univariate tests, and PC-ORD 4.20 for multi-response permutation procedures and indicator species analysis. We determined total C and N, bulk density, NH_4^+, NO_3^-, particle size, pH, and electrical conductivity (EC) for each soil sample.

Results: Canada thistle cover decreased in seven, did not change in 17, and increased in six sites between 1999 and 2006. It persisted in three of nine sites where it was found in 1999, disappeared in the remaining six, and invaded four new sites. It was present where native species cover, richness, diversity, LAI, and ANPP were high ($P < 0.004$). It was also present where slope, total soil C, and silt were high, and where sapling density and sand were low ($P < 0.05$). Canada thistle was found in 7% of the sites where surface Āres occurred compared with in 48% of the sites where crown Āres occurred, and it persisted and was dominant where richness was high ($P < 0.001$). Where Canada thistle persisted, total soil C was high ($P = 0.045$), and where it was dominant slope was steep ($P = 0.029$) and NO_3^- was high ($P = 0.030$). The amount of sand in the soil was high where Canada thistle had not persisted, ranging from 40.0 to 86.2%, compared with 23.8 to 42.5% ($P = 0.033$). Community composition differed in 2006 where Canada thistle was absent, disappeared, invaded, persisted, and was dominant ($A = 0.063$; $T = -4.549$; $P < 0.001$). Rush (*Juncus*), dock (*Rumex*), strawberry (*Fragaria*), sedge (*Carex*), ragwort (*Senecio*), and clover (*Trifolium*) were indicative of sites where Canada thistle invaded. Canada thistle and wheatgrass (*Agropyron*) were associated with sites where Canada thistle was dominant, and foxtail barley (*Hordeum jubatum*) and Canada goldenrod (*Solidago canadensis*) were indicative of sites where Canada thistle was absent.

Conclusions: Canada thistle diminished in 67% of our sites, indicating that it may not always be an aggressive invader. It was present in areas with high species diversity, suggesting that diverse communities could be more susceptible to invasion than other areas. Canada thistle established on sites low in nutrients but persisted where nutrients were abundant. It has difficulty surviving where light is limited, suggesting that healthy forested systems could resist Canada thistle. Regeneration of tree seedlings could reduce its impact because Canada thistle is susceptible to shading. Since other nonnatives and Asteraceae species were most often found with Canada thistle, managers should consider communities supporting these species priority areas for monitoring. Where Canada thistle persists it does not seem to be altering ecological processes or reducing diversity and could be considered naturalized. This study demonstrates the dynamic nature of an invasive species 18 years following disturbance.

keywords: Canada thistle, *Cirsium arvense*, diversity, environmental factors, Āre, invasive species, nonnative, soil, Yellowstone National Park.

Citation: Schoessow, B.R., and D.B. Tinker. 2009. Factors related to Canada thistle persistence and abundance in burned forests in Yellowstone National Park [abstract]. Page 57 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

DEVELOPMENT OF WHITEBARK PINE COMMUNITIES FOLLOWING THE 1988 YELLOWSTONE FIRES

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ABSTRACT

Question: What are the patterns of early post-fire whitebark pine community development with respect to mesic versus xeric sites in the Greater Yellowstone Area, and how do early patterns relate to pre-fire forest community composition?

Background: The role of fire in renewing whitebark pine (*Pinus albicaulis*) communities in the Greater Yellowstone Ecosystem (GYE) is complex, and little is known with respect to early conifer community development. In the GYE, whitebark pine may occur as a minor seral component at the lower limits of the upper subalpine zone, at about 2,550 m elevation. Associated conifers typically include Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa* [= *Abies bifolia*]), and lodgepole pine (*Pinus contorta*). We tested the following hypotheses: 1) the proportional representation of whitebark pine diminishes with advancing succession; 2) early community composition and conifer densities vary with site moisture conditions and seed sources; 3) the conifer composition of early post-fire communities differs relative to that of later successional stages (represented by the pre-fire forest); and 4) viable whitebark pine regeneration is limited to relatively early-seral stages, prior to canopy closure.

Location: Henderson Mountain (HM), Gallatin National Forest (lat 45°5′N, long 109°91′W), Montana, USA; Mt. Washburn (MW), Yellowstone National Park (lat 44°82′N, long 110°45′W), Wyoming, USA.

Methods: In 1990 we installed 275 plots, each 20 m^2 in area, for a total of 50 plots each on xeric and mesic burned sites (HM and MW), 25 plots each on control unburned xeric and mesic sites (HM), and 25 plots on a mesic, mixed-severity burn site (MW). Plots were revisited every year to 1995 and again in 2001. Each year, we gathered regeneration data for all conifers and tracked whitebark pine seedlings. We determined the composition of the pre-fire forest on 30 × 30-m plots.

Results: The pre-fire forest communities on Henderson Mountain were dominated by subalpine fir, and on Mt. Washburn by lodgepole pine and subalpine fir on the xeric site and lodgepole pine and Engelmann spruce on the mesic sites. Whitebark pine represented from 0 to 13% of the burned overstory. Whitebark pine seedlings first appeared in burned study sites in 1991 on almost all study sites. Whitebark pine regeneration density increased very slowly over time, but subalpine fir and lodgepole pine increased more rapidly between 1995 and 2001 on some study sites. By 2001, the relative proportions of conifers were similar to the pre-fire composition on all sites, with whitebark pine a minor component. As of 2001, densities of whitebark pine regeneration were similar between the burned and unburned sites on Henderson Mountain, but seedling growth increments as of 2005 were 2.6 times greater in the burned treatments. Fire appears to be required for healthy whitebark pine growth, and whitebark pine regeneration in late-seral communities is unlikely to grow to be reproductive trees.

Conclusions: Referring to the original hypotheses, 1) whitebark pine regeneration first appeared on all burned study sites in 1991 and increased slowly in density through 2001; 2) early post-fire community composition varied with moisture condition and seed source availability; 3) early post-fire proportional conifer composition was very similar to that of the pre-fire forest on all study sites; and 4) viable whitebark pine regeneration appeared to be confined to successional stages before canopy closure.

keywords: 1988 fires, forest succession, Greater Yellowstone Area, *Pinus albicaulis*, subalpine forests, whitebark pine.

Citation: Tomback, D.F., A.W. Schoettle, K.M. Grompone, M.J. Perez, and S. Mellmann-Brown. 2009. Development of whitebark pine communities following the 1988 Yellowstone fires [abstract]. Page 58 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

MICROSITES FACILITATING WHITEBARK PINE SURVIVAL FOLLOWING THE 1988 YELLOWSTONE FIRES

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ABSTRACT

Question: Which microsite conditions facilitated the survival of whitebark pine (*Pinus albicaulis*) seedlings after the 1988 Yellowstone Āres, and how did this vary with study area?

Background: Microsites reÈect seed caching preferences of Clark's nutcrackers (*Nucifraga columbiana*), primary seed dispersers for whitebark pine. Whitebark pine communities, which comprise important habitat for grizzly bears (*Ursus arctos*), are threatened both by the exotic pathogen white pine blister rust (*Cronartium ribicola*) and by native mountain pine beetles (*Dendroctonus ponderosae*). Restoration requires planting seedlings or seeds with genetic resistance to blister rust. Our results identifying microsite features that correlate with survival should guide selection of seedling or seed planting sites in the Greater Yellowstone Area.

Location: Henderson Mountain (HM), Gallatin National Forest (lat 45°5′N, long 109°92′W), Montana, USA; Mt. Washburn (MW), Yellowstone National Park (lat 44°82′N, long 110°45′W), Wyoming, USA.

Methods: In 1990, we established 100 circular plots, each 20 m^2, in mesic and xeric study sites (50 plots per site) on Henderson Mtn., and 100 similar plots in mesic and xeric study sites (50 plots per site) on Mt. Washburn, all in stand-replacing burns following the 1988 Yellowstone Āres. We followed individual whitebark pine seedlings from 1990 to 1995 and in 2001 for MW plots, and to 2005 for HM plots. Data were analyzed with logistic regression and Cox proportional hazards model.

Results: For Henderson Mtn., presence of understory vegetation, wood debris, and standing dead trees were highly signiĀcant predictors of seedling survival; grazing on seedlings was a signiĀcant negative predictor. For Mt. Washburn, char depth and presence of duff were highly signiĀcant negative predictors of seedling survival, whereas the presence of wood debris, dead trees, gopher disturbance, and shade signiĀcantly increased seedling survival. For Mt. Washburn in particular, classiĀcation of seedlings in "living" vs. "dead" categories using the predictive model was highly successful, particularly for "living" seedlings. These results may well suggest that some shade, vegetation, or debris cover may reduce thermal stress for seedlings and/or retain soil moisture. We observed many healthy whitebark pine seedlings growing among the roots of standing dead trees or alongside fallen trees.

Conclusions: For both study areas, the presence of wood debris and dead trees facilitated seedling survival. Also, for the south-facing HM study area, microsites with vegetation may have served a similar role. These results can be used to develop a planting protocol for whitebark pine seedlings for restoration projects, which are being undertaken in the Greater Yellowstone Area.

keywords: 1988 Yellowstone Āres, restoration, seedling microsites, seedling survival, stand-replacing Āre, whitebark pine.

Citation: Tomback, D.F., M.J. Perez, K.M. Grompone, and A.W. Schoettle. 2009. Microsites facilitating whitebark pine survival following the 1988 Yellowstone Āres [abstract]. Page 59 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

A FRAMEWORK TO EVALUATE POST-FIRE TREE MORTALITY LOGISTIC MODELS

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ABSTRACT

Question: What framework, methodology, and criteria can be used to evaluate several logistic post-fire tree mortality models using previously collected data?

Background: The use of a hypothesis testing framework to develop models has resulted in the accumulation of a large amount of information regarding the relationship of predictor variables, (e.g., crown scorch and bole char severity) and tree response (i.e., live or dead) following both prescribed and wildfire. This is particularly true for both ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*). However, for future management and research applications, previously constructed models for these two species need to be evaluated for their predictive abilities as well. Logistic regression models that appear to adequately fit the data from which they were developed, may in fact have poor classification (i.e., predictive) ability. A main concern regarding model applicability is the scope of inference a model represents and its predictive ability outside of this scope. It remains to be seen if models developed for a specific geographic region, fire type, and tree species can be effectively applied to a larger scope. In addition, many models have been built using a small number of trees. More recently, however, data sets of post-fire tree mortality are based on larger sample sizes. Although some model evaluation/validation work has been conducted recently, no framework has been presented to independently evaluate several models simultaneously using larger data sets covering a more comprehensive geographic scope. We present a framework in which post-fire logistic regression tree mortality models are applied to independent post-fire data sets of ponderosa pine. We compared models and data from three different regions in the western United States, and from both prescribed fires and wildfires that have occurred over the past 20 years to answer questions regarding model inference.

Location: Data for this analysis were collected in three regions in the western United States: northeastern Oregon; northern Arizona and New Mexico; and the northern Rocky Mountains, including Montana, Idaho, and Wyoming.

Methods: We obtained 5,000 simple random samples of 300 trees from each of five large regional post-fire mortality data sets (combinations of region and fire type). Six previously published post-fire logistic regression models were applied to each individual sample. Models were ranked based on the distribution of the 5,000 values of the area under the receiver operating characteristic (ROC) curve (AUC) for each model. A model's ability to reduce the probability of false positives (i.e., classified as dead when alive) was also explored.

Results: The six post-fire tree mortality models demonstrated that the accurate classification of trees as dead or alive can vary widely. The 5^{th} percentiles for AUC values were as low as 0.53 and the 95^{th} percentiles were as large as 0.94. Although average AUCs were generally above 0.7, the lowest average AUC was 0.63 and the highest was 0.91. Average AUC among models applied within a particular region varied by as much as 0.25. Average AUC for a single model applied to five data sets varied by as much as 0.23. In general, models from the same geographic region as the data set did better than models from the same fire type. That is, for a data set from a given region and fire type, models from that same region were frequently ranked higher, regardless of fire type, than models from different regions. However, in the comparison where a model from the same region as the data set did not exist, models from the same fire type achieved slightly higher accuracy. Although some models performed well according to average AUC values, their ability to reduce false positives while maintaining accuracy varied. In order to maintain a false positive rate of no more than 10%, the median cutoff value was 0.73 with a range of 0.07 to 0.98. The capability of a model to use lower cutoff values to reduce false positives resulted in increased accuracy of predicting mortality accurately (i.e., sensitivity), while higher cutoff values reduced the accuracy of mortality predictions.

Conclusions: Using a simulated random sampling approach from five large data sets representing different regions and fire types, we were able to evaluate several post-fire logistic tree mortality models and incorporate the use of ROC curve characteristics commonly used in post-fire tree mortality research. This analysis demonstrated the need for multiple criteria to assess the predictive capabilities of post-fire mortality models. The average ROC curve area as well as the upper and lower bounds both provide useful information for model evaluation. We also found that examining cutoff values to reduce false positives and increase sensitivity was an interesting and useful measure to better understand model classification bias. The framework, methods, and criteria presented here can be used to answer further questions regarding the evaluation of post-fire tree mortality models, such as comparing model classification of tree mortality among different tree species.

keywords: logistic models, ponderosa pine, post-fire tree mortality, prescribed fire, wildfire.

Citation: Woolley, T., L.M. Ganio, D.C. Shaw, and S. Fitzgerald. 2009. A framework to evaluate post-fire tree mortality logistic models [abstract]. Page 60 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

SURFACE FIRE DAMAGE AND REGENERATION PATTERNS IN DECIDUOUS FORESTS AT BUKHAN MOUNTAIN NATIONAL PARK, KOREA

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ABSTRACT

Question: What are the restoration dynamics of understory plants after surface fire damage in broadleaf forest?

Background: Forest fire is one of the major destructive processes in forest ecosystems. Understanding its influence on ecosystem and rehabilitation processes is important for land managers to plan for ecosystem restoration and fire management. The severity of forest fire varies depending on such factors as fire intensity, species composition, and precipitation pattern. Fires generally damage aboveground vegetation and combust the soil organic layer. However, forest fires generally consume little of stumps and root tissues except within a few millimeters below the soil surface. After fire, new branches develop from adventitious or epicormic buds of stumps of shrubs or herbs. Surface fires kill only shrubs and herbs, not trees. Sprouts also grow again from the live buds of shrubs and herb stumps. The Bukhansan National Park has a policy of preferring natural regeneration as a rehabilitation plan after fire. After fire, the number of sprouts and the degree of dominance by those sprouts differ among species.

Location: Bukhansan National Park (lat 37°38′N, long 126°59′E), Seoul, Korea, in 2006.

Methods: Seven hectares of deciduous forest on the east side of the park was burned on 29 April 2006, and vegetation damage and regeneration patterns were monitored for 2 years post-fire. Tree mortality was assessed using a 20 × 20-m plot. For understory vegetation, signs of fire damage on trees, root collar diameter, diameter at breast height (DBH), and mortality of shrubs, and species, individuals, and coverage of herbs were measured at five 5 × 5-m plots at the bottom slope position.

Results: The surface fire killed 93% of trees with ≤5 cm DBH and only 5% with ≥5 cm DBH. Among the killed trees, 97% resprouted in the same year of fire occurrence. The number of sprouts per stem in the first year was 13, 6, 5, 3, and 4 for *Rhododendron mucronulatum*, *Lindera obtusiloba*, *Acer pseudo-sieboldianum*, *Symplocos chinensis* f. *pilosa*, and *Stephanandra incisa*, respectively. In the second year, the number of sprouts was 8, 7, 3, and 4 individuals for *Rhododendron mucronulatum*, *Acer pseudo-sieboldianum*, *Symplocos chinensis* f. *pilosa*, and *Stephanandra incisa*, respectively. The average heights of dead *Rhododendron mucronulatum*, *Lindera obtusiloba*, and *Stephanandra incisa* were 210, 96, and 67 cm, respectively. The mean sprout heights of *Rhododendron mucronulatum*, *Lindera obtusiloba*, and *Stephanandra incisa* were 21, 29, and 29 cm, respectively, in the first year, and 35, 42, and 49 cm, respectively, in the second year. The importance value (IV) of *Athyrium yokoscense* in herb stratum was 26 and 19% in the first year and second year, respectively. The IV values of *Lespedeza maximowiczii*, *Disporum smilacinum*, and *Symplocos chinensis* f. *pilosa* were 8, 5, and 7%, respectively, in the first year, and 10, 4, and 6%, respectively, in the second year.

Conclusions: Results suggest that the understory species in the broadleaf forest at Bukhan Mountain National Park have adapted to fire disturbances by sprouting from stumps or roots; therefore, they are expected to show rapid post-fire restoration characteristics. We plan to evaluate fire history by using dendrochronological methods, morphological features of shrubs with active sprouting, and restoration of forest pattern using remote sensing techniques.

keywords: broadleaf forest, forest fire, regeneration, sprouting.

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THE FIRE EFFECTS INFORMATION SYSTEM—SERVING MANAGERS SINCE BEFORE THE YELLOWSTONE FIRES

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This presentation will describe the current status of the Fire Effects Information System (FEIS) and explore lessons learned from this 23-year-old project about the application of science to fire management issues. FEIS contains literature reviews covering biology and fire ecology for approximately 1,100 species in North America: plants and animals, native and nonnative. Established in 1985 and continually updated, the system has served managers, researchers, students, and the general public for >20 years. Species reviews in FEIS provide information that can help managers plan a prescribed fire, write a fire or fuel management plan, determine the need for post-fire rehabilitation, or assess the potential for increase of invasive species after fire. FEIS is cited in nearly half of EISs written by federal wildland fire managers. Research Project Summaries, a recent addition to FEIS, supplement species reviews and provide information on fire effects for an additional 250 species. To ensure that the latest science is within reach of the manager seeking information, FEIS reviews are clearly organized and widely available on the Internet. Reviews are updated depending on needs identified by users and support available. To use science syntheses effectively, managers must combine critical reading with understanding of the local ecosystem and its condition. FEIS reviews are constructed to convey general patterns of plant and animal response reported in the literature and also to describe exceptions to those patterns. Managers can use this information to infer the likelihood that local responses will fit the patterns and exceptions reported in the literature. FEIS reviews identify uncertainties, contradictions in research findings, and knowledge gaps so managers and planners can be aware of inconsistent findings and topics that are not well understood. FEIS reviews describe the location and results of individual studies to indicate their breadth of application, answering questions such as: Is a report based on a single observation or an extensive field study? Is it limited to a small geographic region or representative of a large area? Is it reported with a known level of confidence resulting from statistical analysis, or from anecdotal observation? The level of certainty conveyed in FEIS reviews may indicate to managers that a particular plant or animal response to fire is likely and chances of different results are low, or that a response is possible but uncertain, warranting post-fire monitoring and possibly an adaptive response by management.

SOME LIKE IT HOT: USING BURN INFORMATION TO BETTER PREDICT INVASIVE SPECIES POST-FIRE RESPONSES

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A growing body of literature links fire to the rapid colonization and proliferation of particular invasive plants. Despite this work, the potential for increased risk of invasion due to fire remains unknown for many exotic species at the regional level. We employed habitat suitability models (statistical models linking species responses at specific locations to environmental conditions) in order to 1) test species responses to burn variables, 2) create species habitat maps, and 3) infer relationships between fire and the species of interest based on parameter estimates. Whereas most habitat suitability models omit disturbance processes such as fire, we specifically incorporated burn characteristics (burn severity, occurrence, and time-since-fire), in addition to a standard suite of environmental variables used to predict species potential distributions (e.g., topographic, vegetative, and hydrologic data). We tested models using occurrence data for two exotic species that are currently invading the Greater Yellowstone Ecosystem: *Carduus nutans* (musk thistle) and *Linaria dalmatica* (Dalmatian toad-flax). Our results indicate that both species are influenced by burn characteristics and that for *C. nutans*, the effect of time-since-burn depends on the vegetation type. The relative odds of *C. nutans* presence continues to rise for the first decade following fires within several vegetation types, but the relative odds decreases during this range of years for other types. Each species also responded differently to burn severity (as measured through the Landsat-derived index, dNBR). Since each species responds to multiple environmental factors, habitat suitability models that include burn variables afford a greater degree of inference and potential predictive ability than either nonburn habitat suitability maps or direct burn-severity (dNBR) maps such as those used by Burned Area Emergency Rehabilitation teams. The habitat suitability maps we present can be used for demarcating areas of concern prior to prescribed fire as well as directing post-fire invasive species management at a regional to national level.

FIRE HISTORY AND CLIMATE INFLUENCES ON *PILGERODENDRON UVIFERUM* (GUAITECAS CYPRESS) IN THE COASTAL TEMPERATE RAINFORESTS OF SOUTHERN SOUTH AMERICA

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The temperate rainforests of southwestern South America (ca. 42°S) have experienced widespread wildfires in recent history. However, there is no information clarifying the natural role and scale of modern fires in this region. One of the dominant tree species in this region is *Pilgerodendron uviferum*, an endemic, slow-growing, long-lived species and the southernmost conifer worldwide. Due to a recent history of massive burning and logging, *P. uviferum* is listed under CITES (Appendix I) and IUCN (Vulnerable). What is the fire history of *P. uviferum* coastal temperate rainforests and the relative influences of climatic variability and trends, and human activities on fire occurrence on the Chiloé Island in southern Chile for the past 300 years? Fire history was reconstructed using tree cores and fire scars sampled in nine sites in Chiloé. The potential influence of low- and high-frequency climatic variability on the occurrence of fire (both extensive and small fires) was investigated using the instrumental climate record, existing and new tree-ring chronologies, and published tree-ring reconstructions of indices of broad-scale climatic anomalies. A tree-ring fire record based on two new chronologies and 90 fire scars from *P. uviferum* forests in Chiloé shows the presence of large fires prior to the European colonization period (prior to ca. 1890s). An increase in fire frequency occurred primarily during the past four decades (after ca. 1970s), and secondarily during the last decades of the European colonization period (ca. 1940s). Preliminary results show widespread fire years are negatively (positively) correlated with spring and summer precipitation (temperature) of the current fire season. These conditions are associated with interannual climatic variability, driven by broad-scale anomalies in Pacific sea-surface temperatures (ENSO). Years of high fire activity tend to follow El Niño events and were more frequent during the drier 1977–2000 period. While widespread fires are a natural, yet infrequent component of the historical fire regimes of these coastal temperate rainforests on the Chiloé Island (even prior to the widespread European settlement), higher fire activity coincides with recent, more severe, interannual droughts that have been facilitated by a decadal trend towards warmer temperatures across the region since the mid-1970s.

WHITEBARK PINE, FIRE, AND BLISTER RUST: A SENSITIVE APPROACH FOR A HARDY SPECIES

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Whitebark pine (*Pinus albicaulis*) is a keystone species supporting a variety of high-mountain flora and fauna. Although widely believed to be a fire-dependent species, observations of significant mortality of mature whitebark pine during recent fire events are common. This is occurring in the face of a nonnative blister rust disease coupled with a mountain pine beetle epidemic. Although fire can be used in many instances to restore and maintain whitebark pine, it must be applied with extreme care. Given the inherent high variability in fire regimes and stand characteristics, local resource specialists should fine-tune prescriptions with planners and managers to match site-specific environments. This presentation offers guidance for the following: 1) prioritizing stands for burning, 2) planning burns based on site-specific regimes, 3) working with pathologists to minimize fire mortality of disease-resistant trees, and 4) supporting lightning-ignited fires. The Bybee Fire Complex of 2006 at Crater Lake National Park is briefly presented as a model where fire managers worked with ecologists and pathologists in successfully reintroducing fire into a whitebark pine setting.

VEGETATION IMPACTS OF THE EAST AMARILLO COMPLEX WILDFIRES OF MARCH 2006

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On 12 March 2006, two wildĀres were ignited in extreme fuel and weather conditions in the Texas panhandle. Within 4 days the East Amarillo Complex burned >907,000 acres, making it the largest wildĀre complex in the contiguous 48 states since the 1988 Yellowstone Āres. Following the wildĀres, spring winds resulted in blowing topsoil, and rainfall was localized and minimal in most areas until August. We established plots in burned and adjacent nonburned areas to investigate the impacts to the vegetation composition, perennial grass mortality, forb frequency, herbaceous production, and plant basal area in two vegetation types: 1) shortgrass ecosystems dominated by buffalograss (*Buchloe dactyloides*) and blue grama (*Bouteloua gracilis*), and 2) mixed-grass ecosystems characterized by little bluestem (*Schyzachyrium scoparium*), sand dropseed (*Sporobolus cryptandrus*), and sand sagebrush (*Artemisia Èlifolia*). In mixed-grass types, frequency of dead perennial grass plants was 2 to 3 times higher in burned sites than in nonburned sites 1 and 2 years post-burning. In shortgrass types, frequency of dead perennial grass plants was 4 to 7 times higher in burned sites 1 year post-Āre, and 3 times higher after a second growing season. Following above-average rainfall in 2007, frequency of dead perennial grasses decreased in 2008. However, mortality was still higher in burned plots than in nonburned plots, a pattern that was observed in both mixed-grass and shortgrass ecosystems. In mixed-grass types, current year's production in 2006 was greater in burned areas than nonburned areas; in the second year, production was similar in burned and nonburned areas. In shortgrass types, there was no difference in production in either the Ārst or second growing seasons following wildĀre.

DELAYED TREE MORTALITY FOLLOWING FIRE IN WESTERN CONIFERS

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Accurately estimating tree mortality following wildĀres is an important aspect of both pre- and post-Āre forest management. In most burned areas, there are trees that initially survived the Āre but have various levels of Āre injuries. Predicting which trees will soon die is a large factor in post-Āre treatment actions, including post-Āre salvage logging. Accurately predicting tree mortality when planning prescribed burns is also crucial, in order to meet burn objectives. Managers need to know what level of Āre intensity will kill trees in order to keep Āre below or above this threshold. This presentation reports the Ānal results of an analysis of 3-year post-Āre mortality for 16 western U.S. conifer species. We pooled tree injury data from 29 Āres in California, Arizona, Idaho, Montana, and Wyoming (18,000+ trees), including data collected in the 1988 Yellowstone Āres. We used logistic regression to model tree mortality and compared the results with the current mortality model used in the First Order Fire Effects Model (FOFEM). Individual species models were created because of superior performance to a single, multispecies equation. We also developed two sets of equations, one for pre-Āre planning as currently used in FOFEM, and another for post-Āre planning, when Āre injuries are known. This new post-Āre planning tree mortality module will be added to FOFEM to expand the model's tree mortality prediction capability.

UNDERSTORY RESPONSE TO THINNING AND CHIPPING PONDEROSA PINE FORESTS IN THE BLACK HILLS

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Restoration of the fire-suppressed landscape of rapidly regenerating ponderosa pine in the Black Hills is a management challenge. High tree densities and frequent visitors to this nationally iconic area make the reintroduction of fire a difficult task. Disposal of debris piles from mechanical thinning treatments can also be difficult to accomplish because snowfall of the depth required to conduct pile burns is not a reliable occurrence. Managers in the Black Hills need an alternative method for restoration of high-density ponderosa pine stands. Broadcast chipping of mechanically thinned fuels provides an alternative to other common fuels reduction methods, such as pile burning or lop and scatter. The effects of broadcasting chips on forest ecology remain unknown. It is undetermined whether broadcast chips enhance or disrupt tree regeneration, promote or reduce exotic species, or restore suppressed understory plant communities. This study will investigate the effects of broadcast chipping on forest understory communities in the Black Hills at Mount Rushmore National Monument and Wind Cave National Park. Treatments include 1) broadcasting chips from mechanically thinned fuels; 2) removing mechanically thinned fuels; and 3) control, no treatment. Treatment implementation will begin in the fall of 2008, but pre-treatment data were collected using modified Whittaker plots during the summer of 2008. Overstory trees were sampled to determine forest structure as well as to estimate the volume of chips created from trees at a given density. The understory plant community was sampled to assess the effects of broadcast chips on ponderosa pine regeneration and understory plants. Finally, soil physical and chemical properties were sampled to further understand the mechanisms driving post-treatment responses. This project will provide fire and resource managers in the Black Hills with the information necessary to determine if broadcast chipping of thinned fuels is a viable fuels management alternative in the ponderosa pine ecosystems they manage.

EFFECTS OF HERBICIDE APPLICATIONS AND NATIVE SEEDING ON THE POST-FIRE SEEDBANK OF A *BROMUS TECTORUM*–INFECTED PINYON–JUNIPER WOODLAND

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A large wildfire occurred in Zion National Park in the summer of 2006. High pre-fire populations of *Bromus tectorum* (cheatgrass), both within the burned area and on adjacent private land, focused rehabilitation efforts on reducing the reestablishment of this invasive grass within the park. Two treatments, the aerial application of the herbicide Plateau® and the seeding of four native plant species, constituted the overall strategy in this effort. A concurrent study is being conducted to evaluate the effect of the treatments on the soil seedbank and is collaborative with research assessing the success of the treatments on the aboveground plant community. Soil samples were collected in the fall of 2006 and 2007 and will continue to be taken for two additional years. Currently, the first two years of data from this greenhouse study are available and preliminary results will be presented.

EFFECTIVENESS OF NATIVE SEEDING AND LANDSCAPE-SCALE HERBICIDE APPLICATIONS FOR CONTROLLING CHEATGRASS IN ZION NP

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The Kolob Fire started just outside Zion National Park in June 2006 and by the time of containment had burned 4,256 ha within the park. A Burned Area Emergency Rehabilitation (BAER) team was sent to evaluate the fire and formulate a rehabilitation plan. Pre-fire vegetation mapping in the park showed high amounts of cheatgrass (*Bromus tectorum*) and red brome (*Bromus rubens*) throughout the newly burned area. Controlling these invasive grasses was the primary concern of the BAER team due to their ability to dominate post-fire landscapes and the resulting shifts in fire regime caused by the creation of a continuous layer of fine fuels. The two treatments recommended by the BAER team were for aerial applications of a seed blend composed of four native perennials and Plateau™ herbicide (imazapic). These treatments were implemented in late October 2006 and resulted in 200 ha receiving seed and 3,577 ha of the burn being treated with imazapic. To our knowledge, this is the first landscape-scale aerial application of herbicide to a post-fire environment within the Park Service. Three study sites were set up within the fire perimeter to evaluate the effectiveness of these treatments on the bromes and the residual plant community. At each site, measures of plant density, cover, and biomass will be taken for five seasons along with additional measurements of soil nutrients, species richness, and shrub density. This poster will show results on bromes from the first two seasons of data collection (spring and fall 2007).

LANDSCAPE ECOLOGY AND THE 1988 FIRES

EMERGING UNDERSTORY COMMUNITY SUCCESSIONAL PATHWAYS FOLLOWING THE 1988 YELLOWSTONE FIRES

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ABSTRACT

Question: What are the patterns of understory plant succession in the subalpine zone following the '88 Āres in the Greater Yellowstone Area, and how do differences in topography and xeric and mesic moisture conditions affect the resulting seres?

Background: Ecological succession is the process by which an ecosystem recovers from either natural or anthropogenic disturbances. Within the Intermountain West of the United States, the relationship between forest Āres and ecosystem health has been well understood for >50 years, including the dynamics of subsequent conifer regeneration. However, successional dynamics of the understory plants have not been widely studied, particularly in the subalpine zone where harsher environmental conditions play a larger role in community formation than at lower elevations. The Yellowstone Āres of 1988 presented an enormous opportunity to detail temporal changes within the developing understory community in two study areas, and to study the effects of local moisture conditions on the ultimate conĀguration of the understory. The following hypotheses were tested: 1) the initial herbaceous pioneers were similar between both study areas and study sites, 2) xeric and mesic communities of both study areas had developed distinct successional trajectories by 2001, and 3) successional changes occurred rapidly after the Āre event and then slowed.

Location: 1) Mt. Washburn, Yellowstone National Park, Wyoming, USA (lat 45°82′N, long 110°45′W); 2) Henderson Mountain, Gallatin National Forest, Montana, USA (lat 45°5′N, long 109°92′W).

Methods: Tomback and colleagues sampled intermittently from 1990 to 2001, encompassing 12 years of succession. We used moist-site indicator species to distinguish between mesic and xeric sites, and established 100 circular 20-m^2 plots per study area (50 mesic, 50 xeric). Here, we only considered species presence/absence and total plot understory cover for analysis; this included species frequency of occurrence, Shannon index, coefficient of community (CC), and Morisita's index (Mhf).

Results: Regardless of study site, Āreweed (*Chamerion angustifolium*), Ross' sedge (*Carex rossii*), and grouse whortleberry (*Vaccinium scoparium*) remained the dominant species throughout the study, and maximum species richness was attained as early as 1994. Succession at both Henderson study sites was comparatively slow, as indicated by high CC values for the four years sampled. Additionally, Morisita's index values showed no appreciable difference between the xeric and mesic understory communities over the course of the study, possibly showing nearly identical successional trajectories. In contrast, both Washburn study sites initially underwent rapid succession but then slowed through 2001. From 1990 to 1994, the xeric and mesic herbaceous communities remained fairly similar (Mhf = 0.76, 0.80, 0.78), but by 2001 a 10% drop in similarity occurred (Mhf = 0.69).

Conclusions: Twelve years following the Āre event, clearly distinct understory communities have formed in the two study areas. On Mt. Washburn, whereas mesic and xeric sites demonstrated relatively high similarity early in succession, by 2001 they became more differentiated from one another. If future sampling were to verify successional divergence between the two, then this would be consistent with their distinct slope aspects and associated meso-climates. However, on Henderson Mountain, both study sites possessed highly similar communities over the four years sampled. This similarity appears to be a consequence of common slope aspects, imparting a stronger inÈuence on community formation than localized differences in moisture; this effect may be important to consider in future montane restoration efforts.

keywords: community development, forest Āre, Gallatin National Forest, sere, subalpine, succession, understory, Yellowstone National Park.

Citation: Andrade, A.J., S.M. Marvez, D.F. Tomback, S. Mellmann-Brown, and K.S. Carsey. 2009. Emerging understory community successional pathways following the 1988 Yellowstone Āres [abstract]. Page 66 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

UNDERSTORY DEVELOPMENT OF SUBALPINE FORESTS AFTER THE 1988 YELLOWSTONE FIRES

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ABSTRACT

Question: Thirteen years after stand-replacing fire, what are the characteristics of understory development in subalpine forests? How similar is the vegetation composition of sites with different fire "treatments" and moisture regimes?

Background: The 1988 Yellowstone fires burned large portions of subalpine forest previously dominated by Engelmann spruce (*Picea engelmannii*), whitebark pine (*Pinus albicaulis*), and subalpine fir (*Abies lasiocarpa*). While we have some knowledge of tree succession in subalpine forests, we know significantly less about the development of herbaceous cover after stand-replacing fire. In 2001, 13 years after the fire event, we studied the composition of the herbaceous vegetation under variable moisture regimes and fire "treatments."

Location: Henderson Mountain, Gallatin National Forest (lat 45°05′N, long 109°92′W), Montana, and Mount Washburn, Yellowstone National Park (lat 44°82′N, long 110°45′W), Wyoming, USA.

Methods: We established 275 plots, each 20 m^2 in area, in the Gallatin National Forest and in Yellowstone National Park. Elevations ranged from 2,560 to 2,745 m. Sites were classified into "ecological treatments" according to burn intensity (burned, mixed-severity burn, unburned) and moisture conditions, based on pre-fire tree composition and vegetation characteristics of adjacent unburned forest. We inventoried the cover of all vascular plant species within each plot and recorded slope, aspect, depth of the char layer, and any disturbance on the site. Altitude and potential growing season solar radiation were derived from a digital elevation model (DEM), under consideration of topographic shading. Understory composition and vegetation response along major environmental gradients were analyzed with nonmetric multidimensional scaling (NMDS) general additive models (GAMs), and nonhierarchical cluster analysis. Treatment and vegetation clusters were tested for validity with a multi-response permutation procedure (MRPP).

Results: A total of 210 species was identified on all sites, with an average of 21 species occurring on each plot. Species diversity (Shannon index H') varied from 0.38 to 3.06 depending on ecological treatment. On average, mesic sites had high diversity indices ($H' = 2.31$) and xeric unburned sites were significantly less diverse ($H' = 0.89$) than xeric burned sites ($H' = 2.10$). Total understory cover was higher on burned sites (63%) compared with the unburned controls (56%). Vegetation composition was distinctly different between both study areas and all ecological treatments. In particular, burned and unburned sites were well separated in the NMDS ordination diagram. All MRPP tests were highly significant with increasing effect size (= increasing heterogeneity between groups) from the distinction of study sites to different treatments. However, the best grouping was achieved with a nonhierarchical cluster solution, re-sorting mesic and xeric burned sites on Henderson Mountain and splitting mesic burned Washburn sites into two clusters. GAMs successfully related char depth (a surrogate for pre-fire productivity and moisture conditions) and growing-season solar radiation to trends in vegetation composition. Each factor explained between 43 and 84% of floristic variability.

Conclusions: Thirteen years after stand-replacing fire, burned and unburned sites are still considerably different in understory species composition. However, some of the differences between burned and unburned sites on Henderson may be caused by environmental variability between sites. Our initial classification of study sites into mesic and xeric sites can mostly be supported with floristic data. Furthermore, understory composition may serve as indicator for moisture conditions and improve site classification for the concurrent analysis of tree regeneration after the 1988 fires.

keywords: classification, fire, forest succession, GAM, gradient analysis, herbaceous vegetation, NMDS, Rocky Mountains, understory.

Citation: Mellmann-Brown, S., D.F. Tomback, and A.W. Schoettle. 2009. Understory development of subalpine forests after the 1988 Yellowstone fires [abstract]. Page 67 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

FUSING RADAR AND OPTICAL DATA TO MAP POST-1988 COARSE WOODY DEBRIS IN YELLOWSTONE

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ABSTRACT

Question: Can remote sensing be used to estimate coarse woody debris quantity and quality in Yellowstone?

Background: Coarse woody debris (CWD) is common in forests worldwide and is a vital component of forest ecosystems, important for forest nutrient cycling, tree regeneration, wildlife habitat, fire dynamics, and carbon dynamics. Both the quantity, defined as biomass per unit area tons/ha, and quality, defined as the proportion of standing dead logs to the total CWD quantity, are important for ecological processes. However, very few articles could be found reporting the mapping of post-fire CWD and a cost-effective and time-saving method to determine CWD availability. Remote sensing can provide a landscape view of a specific site repeatedly, remotely, and spatially. A practical, cost-effective, reliable method based on remote sensing techniques is desirable. In 1988, Yellowstone was severely burned by fires, resulting in high spatial heterogeneity of post-fire structure. The ability to use remote sensing methods to classify and map spatially explicit structural characteristics of Yellowstone post-fire ecosystem was unknown. In this study, we investigated the capability of the fusion of multi-frequency, multi-polarization Airborne Synthetic Aperture Radar (AirSAR) and optical data for estimating post-fire CWD quantity and quality in Yellowstone.

Location: Our study area comprised Yellowstone National Park (lat 44°37′N, long 110°30′W) and immediately surrounding lands in northwestern Wyoming, southwestern Montana, and southeastern Idaho, USA.

Methods: We inventoried standing and downed CWD in 186 burned forest plots. We first reduced the terrain effect to remove the interference of topography on AirSAR backscatter. We then removed the influence of regenerating saplings by quadratic polynomial fitting between Airborne Visible/Infrared Imaging Spectrometer Enhanced Vegetation Index and different channels backscatter. The quantity of CWD was derived from the channels of P-band HH polarization (Phh) and P-band HV polarization (Phv), and the quality of CWD was derived from Phh aided by the ratio of L-band HH polarization (Lhv) and Phh.

Results: The CWD quantity and quality in Yellowstone post-fire forest ecosystem were mapped. Regarding CWD quantity, the correlation coefficient between surveyed and predicted CWD is only 0.54 with root mean squared error up to 35 tons/ha. However, if the CWD quantity was discretely classified into three categories of ≤ 60, 60–120, and ≥ 120, the overall accuracy is 65.6%; if classified into two categories of ≤ 90 and ≥ 90, the overall accuracy was 73.1%; if classified into two categories of ≤ 60 and ≥ 60, the overall accuracy was 84.9%. This indicates our attempt to map CWD quantity spatially and continuously achieved partial success; however, the general and discrete categories were reasonable. Regarding CWD quality, the overall accuracy of five types (Type 1—standing CWD ratio $\geq 40\%$; Type 2—$15\% \leq$ standing CWD ratio $< 40\%$; Type 3—$7\% \leq$ standing CWD ratio $< 15\%$; Type 4—$3\% \leq$ standing CWD ratio $< 7\%$; Type 5—standing CWD ratio $< 3\%$) was only 40.3%. However, when Types 1, 2, and 3 are combined into one category and Types 4 and 5 are combined into one category, the overall accuracy is 67.74%.

Conclusions: Our results indicate partial success for our initial attempts to map CWD quality into detailed categories. The result is acceptable only if very coarse CWD quality is considered. Bias can be attributed to the complex influence of many factors, such as field survey error, sapling compensation, terrain effect reduction, surface properties, and backscatter mechanism understanding. Our study provided active and passive sensor fusion to find a variety of post-fire structural metrics, allowing a wide variety of potential applications in the areas of nutrient cycling, wildlife conservation, fire management, and invasive species intrusion. Research on the cause and consequences of the Yellowstone fires will provide insight into the spatial heterogeneity needed for ecological processes.

keywords: coarse woody debris, data fusion, forest fire, radar, remote sensing, Yellowstone.

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POST-FIRE SPATIAL AND TEMPORAL COMPLEXITY IN YELLOWSTONE: WHAT DOES IT MEAN FOR CLIMATE CHANGE FORECASTS?

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Climate change is expected to result in more severe fire seasons in mid-elevation Rocky Mountain forests. Here, we explore the challenges and opportunities of modeling the response of the post-1988 fire landscape to such climate changes. The 1988 Yellowstone fires resulted in increased heterogeneity in stand structure, and recent evidence suggests this variation in stand structure also resulted in initial variation in ecosystem function including aboveground net primary productivity and nitrogen availability. Using the Century ecosystem model, we demonstrated that following the 1988 fires, the ability of the Yellowstone landscape to store carbon to year 2100 depended on the specific global climate model used, as well as the rate of post-fire vegetative recovery. However, in the absence of fire, lodgepole pine forests were projected to be a large C sink due to positive responses of lodgepole to increased warming. This suggests the importance of incorporating post-1988 fire recovery patterns into future C projections. In addition, N availability is known to limit forest productivity in Yellowstone National Park, which may have important feedbacks to carbon cycling. The model results indicated that N availability increased following the 1988 fires, and differed based on the ratio of grasses and trees in the post-fire stand. Overall, these model results complement earlier synthesis efforts that suggest resilience of the Yellowstone landscape to fire over long time periods. For shorter-term projections (to year 2100), the model results show that projected changes in climate and the multiple trajectories of recovery representing the heterogeneous post-1988 fire landscape may be important. Ongoing work using FIRE-BGC suggests that projections in climate change must include effects of multiple disturbances, such as bark beetles and fire, to forecast realistic C change scenarios. We conclude that there are at least three important factors that must be considered in short-term (<100-year) projections of climate change in Yellowstone: 1) multiple trajectories of response from single fire events, 2) spatial and temporal heterogeneity in N–C feedback responses, and 3) multiple disturbance interactions.

BIOTIC AND ABIOTIC EFFECTS ON PLANT SPECIES RICHNESS AND COMMUNITY COMPOSITION IN POST-FIRE YELLOWSTONE FORESTS

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Landscape-scale variability in post-fire lodgepole pine seedling density has been shown to be a primary driver in the variability in aboveground net primary production and leaf area, but its effect on understory plant species composition and richness is not well understood. We measured plant species richness in 90 sites in Yellowstone National Park that burned during 1988, and varied substantially across gradients of lodgepole pine sapling density, elevation, precipitation, and substrate. We used analysis of variance (ANOVA) and canonical correspondence analysis (CCA) to test for significant treatment effects and to describe patterns of community composition within the 90 sites. ANOVA identified significant effects of both biotic (sapling density) and abiotic variables on plant species richness (model adj. $R^2 = 0.72$; $P < 0.001$). Plant species richness was significantly lower in sites with the highest sapling density ($n = 14.8$) than sites with lower sapling density ($n = 19.0$–24.8). Richness was also lower in sites located at lower elevations ($n = 16.9$) versus sites at higher elevations ($n = 22.6$). Sites that occurred on fertile andesite soils showed significantly higher species richness ($n = 33.5$) than sites found on infertile rhyolite ($n = 17.9$–19.2; $P < 0.001$). Interestingly, sites that receive the lowest annual precipitation exhibited higher species richness ($n = 25.6$) than other sites ($n = 16.1$–20.5; $P < 0.001$). CCA identified four primary groups of species assemblages, which appear to respond most strongly to gradients of precipitation and elevation. Low-elevation, dry sites were characterized by abundant graminoids and a higher proportion of nitrogen-fixing plants. High-elevation, wet sites were dominated by a ground-covering shrub, *Vaccinium scoparium*, upland sedges, and fewer species of grasses. Sites at mid-elevation that experience intermediate levels of precipitation were characterized by abundant forbs and shrubs other than *V. scoparium*. Current patterns in plant species richness and composition may change as post-fire stands mature, but long-term studies are necessary to identify such dynamics.

FIRE AND CARBON CYCLING FOR THE YELLOWSTONE NATIONAL PARK LANDSCAPE

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Understanding how stand-replacing Āres control release of carbon from forests is critical for predicting changes in carbon storage across large areas, particularly if climate change alters disturbance frequency. We used three approaches to assess how Āre changes carbon storage for a landscape. First, we measured carbon storage and carbon accumulation rates along a replicated lodgepole pine chronosequence to provide essential data for modeling and landscape-scale assessment. Second, we modeled how a change in Āre frequency from the current 200- to 300-year return interval to a 100-year return interval would change carbon stored on the landscape under equilibrium conditions. Finally, we modeled the recovery of carbon storage from the 1988 Āres. The chronosequence data show that the aboveground live carbon recovers to pre-Āre levels remarkably quickly (in 50–80 years) and total carbon stocks (including dead wood, forest Èoor, and soil carbon) also stabilize in 80 years. The dead wood in the stands burned in 1988 was substantially lower than the total of the live + dead wood in stands 80–300 years old in our chronosequence, even accounting for combustion losses. Modeling the effects of changes in Āre frequency on landscape carbon storage showed that the carbon storage is very resistant to large changes in Āre frequency. This resistance occurs because lodgepole pine regenerates proliĀcally and because carbon stocks stabilize after only 80 years. Either Āre frequency would need to be <50 years or regeneration would need to fail frequently for changes in Āre frequency to cause substantial losses of carbon from the Yellowstone landscape.

FIRE HISTORY OF OLD-GROWTH BALSAM FIR FORESTS IN NORTHEASTERN NORTH AMERICA AS EVIDENCED FROM CHARCOAL IN MINERAL SOIL

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ABSTRACT

Question: What is the fire history of old-growth balsam fir stands in northeastern North America?

Background: The balsam fir (*Abies balsamea*) forest corresponds to the southernmost zone of the boreal forest in northeastern North America. It is distributed from western Ontario to the Atlantic provinces of Canada. The fir forest is dominated by balsam fir, with white birch (*Betula papyrifera*) and white spruce (*Picea glauca*) as companion species. The main disturbances in the fir forest are spruce budworm (*Choristoneura fumiferana*) outbreaks occurring at a frequency of ca. 30 years and large wind blow-downs. In the absence of these large disturbances, old-growth stands are structured by gap dynamics. High atmospheric humidity, abundant precipitation (>1,000 mm/year), and a cold and snowy climate are the main factors reducing fire occurrence. The fir zone is bordered to the north by the fire-prone closed-crown black spruce (*Picea mariana*) forest zone characterized by monospecific stands of either black spruce or jack pine (*Pinus banksiana*). The northernmost fir stands are located in the subalpine belt of high Precambrian plateaus standing out above the fire-prone closed-canopy black spruce forests in the lowlands. Stands of the southern fir zone are restricted to a humid region, whereas the northernmost fir stands are confined to protected sites in a fire-prone area. This setting suggests the hypothesis that northernmost stands are remnants of a former fir zone that extended to the north earlier during the Holocene. Thus, contrasting fire histories would be responsible for the present distribution of fir forests. Our objective was to compare the Holocene fire histories of old-growth stands in the boreal fir zone with the northernmost fir stands. To test this hypothesis, we developed a method to evaluate the in situ fire history of stands where no known ecological fire proxies are currently available.

Location: Québec, Canada. Northernmost stands: Otish Mountains (52°23′N, 70°26′W), Blanches Mountains (51°17′N, 70°22′W). Southern Fir zone: Réserve Faunique des Laurentides (47°32′N, 71°01′W), Valin Mountains (48°35′N, 70°50′W), Gaspésie (49°00′N, 65°56′W).

Methods: Botanically identified and radiocarbon-dated charcoal macrofossils in mineral soils were used as a paleoecological tool to reconstruct the fire history. Charcoal particles (>2 mm) buried in situ in mineral soils by tree uprooting were used as a proxy of the historical composition and relative abundance of species and were radiocarbon dated by accelerated mass spectroscopy to evaluate timing of fire events.

Results: Buried charcoal particles were found in the mineral soils at all the studied northernmost stands (between 106 and 1,154 charcoal particles). Charcoal was also found between the mineral and organic layers at these sites. Half of the sites studied in the southern boreal fir forest zone included a small number of buried charcoal particles (1–27). Charcoal from the northernmost stands is currently under analysis and will not be discussed here. Soil charcoal (n = 26) from three sites of the southern fir forest zone indicates 15 fire events dated between 8195 bp and 4205 bp. All the identified charcoal particles were either spruce (black or white undistinguishable) or balsam fir, and one birch. Organic matter at the contact with mineral soil was dated at sites in the southern fir zone where no charcoal was found. Basal dates of organic matter spanned between 4540 bp and 420 bp.

Conclusions: Fire history of the northernmost stands is different from that of sites of the southern balsam fir forest zone. The abundance of charcoal at the northernmost sites confirms that fire is a major factor shaping the forest landscape in this area. The northernmost fir stands are the remains of a former extension of balsam fir forest flora surviving in an area where recurrent fires strongly shapes the vegetation mosaic in the lowlands. A former fir forest zone probably extended to the north earlier during the Holocene until fire caused the decline of the fir forest, allowing the extension of the closed-canopy black spruce forest zone. The modern southern balsam fir forest zone corresponds to a region where recurrent fires were significantly reduced since the mid-Holocene. In this area, several sites that never burned during the Holocene served as seed source, allowing the persistence of the fir zone.

keywords: balsam fir, fire history, old-growth forests, Québec, radiocarbon dating, soil charcoal analysis, subalpine forest.

Citation: de Lafontaine, G., and S. Payette. 2009. Fire history of old-growth balsam fir forests in northeastern North America as evidenced from charcoal in mineral soil [abstract]. Page 71 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

ARE OLD-GROWTH FORESTS MORE SUSCEPTIBLE TO FIRE? A CASE STUDY FROM THE EASTERN BOREAL FOREST

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ABSTRACT

Question: In the eastern boreal forest of North America, are old forests more susceptible to Āre than young or mature forests?

Background: In the boreal forest of eastern Canada, there are currently pressures to conserve more old forest and to develop forestry practices aimed at maintaining old-forest characteristics and structure. Some argue, however, that these old forests are more susceptible to insect outbreak, disease, and Āre, and that they should therefore be harvested Ārst. With regard to Āre, old forests are often perceived as potentially more susceptible to Āres because of a higher fuel load on the ground, the presence of dead snags, and the development of structural characteristics and ladder fuels that favor Āre crowning. Although old forests may be more susceptible to intense conÈagration in some ecosystems of the world, there is little empirical evidence that this is the case in the boreal forest of eastern Canada. In this study, we assessed empirically whether old resinous forests were more susceptible to burning than young and mature forests at three different spatial scales.

Location: Thir ty-Āve Āres (1992–2005) in the resinous boreal forest of Quebec, Canada (lat 50°N, long 75°W).

Methods: For each Āre, we used geo-referenced data on pre-Āre forest composition and age, and post-Āre impacts observed a few weeks afte r its occurrence. This data set allowed us to study the "preference" of Āres across a wide variety of Āre situations. Moreover, it allowed us to assess the susceptibility of older forests to burn compared with mature or younger forests at three different spatial scales: ignition points, within the perimeter of the event, and at a regional scale.

Results: At the ignition-points scale, we tested whether Āre ignited more often in the old stands, considering the availability of forests in the ignition neighborhood. Only 18% of the Āres indicated that old forests were selected, whereas 82% of the Āres showed that these forests were avoided. At the event scale, we assessed whether old stands are overrepresented in the high-impact burn class and consequently are underrepresented in the Āre skips. At this scale, the old forests were overrepresented in the high-impact class in 16% of the events, whereas they were underrepresented in 63% of the Āres. Finally, at the regional scale, we evaluated whether the proportion of old stands was higher within the Āre perimeter than it was in the surrounding landscape unit. Overall, in 37.5% of the events, we observed a higher proportion of old forests within the perimeter of the Āre as compared with its surrounding landscape, whereas in 50% of the cases, there was an "avoidance" of old forests.

Conclusions: Although old forests were selected in a few Āre events, at all scales, the majority of the events indicates either an "indifferen ce" toward or an "avoidance" of the old forest. Moreover, it appeared that in many situations mature forests were preferred. Therefore, the argument that old forests are more susceptible to Āre does not appear to hold in this forest ecosystem.

keywords: boreal forest, Āre susceptibility, old forest.

Citation: Gauthier, S., A. Leduc, Y. Bergeron, and D. Lesieur. 2009. Are old-growth forests more susceptible to Āre? A case study from the eastern boreal forest [abstract]. Page 72 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

INITIAL CONTROLS ON CONIFER REGENERATION FOLLOWING A LARGE-SCALE MIXED-SEVERITY FIRE

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ABSTRACT

Question: In a large-scale burn mosaic, how does seed source availability interact with microsite variation to control early conifer regeneration density?

Background: In many temperate forests, Āres generate and maintain ecosystem structure by regulating tree establishment. Following Āre, conifer regeneration is governed by the interaction between seed availability (top-down control) and favorable microsites for germination and survival (bottom-up). Large-scale wildĀres (>100,000 ha), which have become increasingly common and a growing management concern, may potentially lack seed sources over broad areas due to their sheer size. Thus, top-down control via seed availability may be the main limiting factor for regeneration in these burns. Surprisingly, to our knowledge no studies have quantiĀed the relative importance of top-down versus bottom-up controls on regeneration in a large-scale Āre in temperate North America.

The 2002 Biscuit Fire burned in a mosaic pattern over 200,000 ha of mixed-evergreen forest in the Klamath-Siskiyou Mountains of southwestern Oregon. Across a broad range of environmental conditions, we quantiĀed 1) regeneration of conifers (density, distribution) and associated vegetation in stand-replacement patches 2–4 years after Āre; 2) the distribution of live-tree seed sources relative to stand-replacement patches in the context of a large mixed-severity burn mosaic; and 3) the relative importance of seed source availability (top-down) and microsite variation (bottom-up) in predicting initial conifer abundance. In addition to providing basic ecological insight, increased understanding of factors controlling post-Āre conifer regeneration will aid land managers allocating limited resources to achieve reforestation objectives following large wildĀres.

Location: Biscuit Fire, Klamath-Siskiyou Mountains, southwestern Oregon, USA (lat 42°26′N, long 123°54′W).

Methods: Using intensive plots and stocking surveys, we measured regeneration in 11 discrete stand-replacement patches ($n = 60$ plots), capturing most of the variation in environmental conditions within the burn. We also performed a GIS-based analysis of conifer seed source distribution across the burn landscape. Finally, we used an information-theoretic regression analysis to assess the relative importance of distance-to-seed-source and 11 microsite variables in predicting early seedling density.

Results: Patch-scale conifer regeneration, composed of 72–80% Douglas-Ār (*Pseudotsuga menziesii*), ranged from 127 to 6,494 stems ha^{-1}. Median densities were 1,721 and 1,603 stems ha^{-1} 2 and 4 years post-Āre, respectively, approximately 12 times the pre-Āre overstory density of 134 stems ha^{-1}. Mean frequency (proportion of plots occupied within patches) was 90% (range 60–100%). Due to the complex burn-severity mosaic, approximately 58% of stand-replacement areas were ≤200 m from live-tree edge (seed source), and approximately 81% was ≤400 m. Median conifer density exceeded 1,000 stems ha^{-1} out to 400-m distance before declining rapidly at larger distances. The two most important predictors of regeneration density were distance to live trees and soil parent material, with skeletal coarse-grained igneous soils supporting lower densities (133 stems ha^{-1}) than Āne-grained soils with higher water retention (729–1,492 stems ha^{-1}). Other site factors (e.g., topography, broadleaf cover) had little association with conifer regeneration.

Conclusions: Despite the large area of the burn, we observed abundant but variable conifer regeneration in most stand-replacement areas. The mixed-severity Āre pattern strongly inÈuenced the regeneration process by providing seed sources throughout much of the burn landscape. In this way, a large mixed-severity Āre may effectively behave as a collection of smaller stand-replacement patches in a matrix of surviving canopy, rather than vice versa.

Conifer establishment is typically a management goal after large wildĀres, but often receives limited funding. These data suggest that, in mesic forest types experiencing mixed-severity Āre, natural regeneration may be a viable management option over more of a large burn than generally expected. Nevertheless, sparse regeneration was measured in areas distant from live-tree edges. Where consistent with management objectives, such areas could be prioritized for conifer planting.

keywords: Biscuit Fire, burn mosaic, Douglas-Ār, forest establishment, forest succession, landscape Āre, post-Āre reforestation, seed dispersal, seed source.

Citation: Donato, D.C., J.B. Fontaine, J.L. Campbell, W.D. Robinson, J.B. Kauffman, and B.E. Law. 2009. Initial controls on conifer regeneration following a large-scale mixed-severity Āre [abstract]. Page 73 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

GLOBAL PYROGEOGRAPHY: USING COARSE-SCALED MODELS TO UNDERSTAND GLOBAL AND REGIONAL PATTERNS OF WILDFIRE

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ABSTRACT

Question: What are the environmental conditions that determine the observed global patterns of Āre?

Background: Fire has a heterogeneous global distribution, and research exploring overarching biophysical controls of Āre at global and regional scales is only just beginning. The focus on global patterns has been primed by remotely sensed collections of Āre data that now offer relatively long snapshots of global Āre activity at a Āne resolution. In the United States, myriad forms of data have been assembled not only to estimate current Āre activity but also historical and current Āre regimes across the conterminous landmass. While it is critical to remember that Āre activity and regimes are heavily inÈuenced by human behavior, looking at maps of the global and regional distribution of Āre naturally lead to questions about how environmental variability contributes to explaining its macro-scaled patterns. Here, we provide preliminary estimates of environmental conditions, based on multiple regression modeling, that describe the niche of Āre at 1) a global scale, and 2) a regional scale, in the United States. We use global estimates from (1) to demonstrate a promising method to project the future of Āre under climate change. We use estimates from (2) to propose Āre regimes that might exist in China based on analogous conditions in the United States.

Location: The terrestrial globe, speciĀc reference to the conterminous United States and China.

Methods: For global analyses, we built generalized additive multiple regression models estimating the relationship between remotely sensed active Āre occurrence and climate, biomass, lightning, and human footprint data. We then used parameter estimates with climate change data to predict a future distribution of Āre. For regional analyses, we used the same model framework but estimated the relationship between LANDFIRE Āre regime classes and climate data in the United States and projected these to China.

Results: For the global analyses, we selected a parsimonious suite of variables to describe the current distribution of Āre. These models Āt the observed data well, and we took logical precautions to not overĀt these spatial data. Projected changes in Āre distribution were then based on one set of simulated climate change data and used to demonstrate the genre of changes that could be expected in the future. Despite an overall expected trend of global warming, the interplay of Āre–climate variables suggest there are areas of the world where Āre could increase, decrease, or not change very much at all. For regional analyses that focused on inferring the distribution of Āre regime classes in China based on the climate relations of LANDFIRE classiĀcations in the United States, we demonstrated that all Āre regime classes might be expected to occur in China, though some had relatively small or isolated distributions.

Conclusions: Here we have described two methods to use coarse-scaled Āre data to examine questions about global pyrogeography: 1) What are the environmental controls of global Āre occurrence, and how might climate change affect Āre in the future? 2) Can we use our knowledge of Āre regimes in intensively studied parts of the world, such as the United States, to infer Āre regimes in others, such as China? Te United States and China share many Èoristic and climatic characteristics, and we propose they might also share historical Āre regimes. Both of the studies described here provide an understanding of Āre as a global process and could be used to inform conservation planning.

keywords: China, climate change, Āre regimes, global pyrogeography, modeling, United States.

Citation: Krawchuk, M.A., and M.A. Moritz. 2009. Global pyrogeography: using coarse-scaled models to understand global and regional patterns of wildĀre [abstract]. Page 74 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

THE IMPACT OF CERTAIN SURFICIAL DEPOSITS ON THE OCCURRENCE AND FREQUENCY OF FIRE AT THE NORTHERN LIMIT OF THE COMMERCIAL FOREST IN QUEBEC, CANADA

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ABSTRACT

Question: Our general objectives are to characterize regional Āre cycles and identify sources of spatial variability in Āre cycle in northern Quebec.

Introduction: Fire is one of the main natural disturbances in the boreal forest, and it is generally assumed that the northern boreal forest is characterized by a short Āre cycle (i.e., the time needed to burn an area equivalent to the study area). However, the spatial variability of the Āre cycle is still poorly understood. Our ability to achieve sustainable forest management is related to Āre frequency. Our study area encompasses an isolated region on both sides of the current northern limit of commercial forest allocation. The Āre regime of this large area (140,000 km2) is not well deĀned.

Location: Northern Quebec, Canada (between lat 49–53°N and long 70–76°W).

Methods: At the stand scale, we investigated the effect of attributes such as stoniness, soil texture, and hillslope position of the deposit types on burned areas. Survival analyses are used to compute Āre cycles on predeĀned landscapes, while creating Āre maps that will subsequently be used to characterize the potential for proper forest management. The Ārst method consists of analyzing 30,000 randomized points with the parametric procedure PROC LIFEREG SAS. The second method uses a nonparametric procedure to evaluate burn rate.

Results: Our preliminary results show that at the stand scale, glacioÈuvial deposits such as esker or the proglacial deposits offer a material and a topography that tend to burn more often than the other deposit types. They are characterized by the accumulation of gravels and sands, deposited and sorted in distinct layers over a thickness of dozens of meters that are highly visible in the landscape. Second, at the Quebec territory scale, parts of the study area are distinguished by a relatively short Āre cycle between 50 and 150 years.

Conclusions: These results will be used to assess the potential for sustainable management while taking Āre into account on both sides of the current northern limit of forest attribution.

keywords: Āre cycle, GIS, northern boreal forest, surĀcial deposits, survival analysis.

Citation: Mansuy, N., S. Gauthier, and Y. Bergeron. 2009. The impact of certain surĀcial deposits on the occurrence and frequency of Āre at the northern limit of the commercial forest in Quebec, Canada [abstract]. Page 75 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

CARBON TRANSFORMATIONS FOLLOWING LANDSCAPE FIRE: MORTALITY AND ECOSYSTEM RECOVERY ACROSS THE METOLIUS WATERSHED, OREGON

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ABSTRACT

Question: How do large mixed-severity wildfires transform landscape carbon balance?

Background: Fire catalyzes ecosystem change and influences terrestrial and atmospheric carbon dynamics from local to global scales. Like other disturbances, wildfire transfers carbon from living to dead pools and exerts powerful feedbacks on photosynthesis and ecosystem respiration. Regional carbon budgets must account for pyrogenic carbon emissions and post-fire carbon storage associated with live and dead vegetation. Following a period of reduced fire activity in western North America, wildfire has recently recovered its dominant disturbance role. Since 2002, mixed-severity wildfires have burned >65,000 ha in the eastern Cascade Range near Sisters, Oregon. Ongoing analyses of carbon dynamics, climate, and disturbance in the Metolius River area provide an exceptional research platform for the assessment of fire impacts, particularly in ponderosa pine (*Pinus ponderosa*) and mixed-conifer forests. The objective of this study is to quantify carbon transformations, mortality, and ecosystem recovery across four large fires that burned approximately 35% of the Metolius River Watershed (115,000 ha) in 2002 and 2003.

Location: Metolius River watershed (lat 44°30′N, long 121°40′W), Deschutes National Forest, East Cascade Range, Oregon, USA.

Methods: We employed a stratified random factorial design across three landscape gradients: 1) forest type (ponderosa pine [PP] and mixed-conifer [MC]); 2) burn severity (unburned, low, moderate, and high overstory mortality classes from dNBR); 3) pre-fire biomass (low to high, reflecting recent disturbance history). We located 64 randomized inventory plots using Landsat-derived GIS layers and sampled these during 2007 and 2008. We used analysis of covariance and multiple regression to determine significant differences.

Results: The fires created a complex mosaic of burn severity and associated overstory and understory responses. Total aboveground mass was 75% greater in MC forests than in PP forests (mean: 10.21 vs. 5.85 kg C m^{-2}; $P < 0.001$), and tree mass dominated both live and dead C pools. Across both forest types, mean aboveground dead mass increased twofold in high-severity stands compared with low-severity stands. Basal area (BA) mortality was an effective ground-based metric of burn severity that validated the remotely sensed dNBR severity map. BA mortality ranged from 14% in low-severity PP stands to 100% in high-severity PP stands, with parallel patterns in MC stands. Additionally, fire-sensitive grand fir (*Abies grandis*) accounted for the majority of mortality in low- and moderate-severity MC stands (74 and 54% of BA mortality, respectively), whereas fire-adapted ponderosa pine and Douglas-fir (*Pseudotsuga menziesii*) tended to survive. Post-fire conifer seedling density was negatively correlated with burn severity, while live shrub cover and biomass showed the opposite trend. Conifer regeneration was patchy but generally abundant; median seedling density ranged from 10,223 seedlings ha^{-1} (low-severity MC) to 0 seedlings ha^{-1} (high-severity PP). Conversely, mean live shrub mass was highest in high-severity MC stands (0.145 kg C m^{-2}) and lowest in low-severity PP stands (0.022 kg C m^{-2}).

Conclusions: The recent wave of large wildfires across the Metolius Watershed has transformed the relative balance of live and dead biomass pools and stimulated strong ecosystem responses. The prevalent mortality of grand fir, much of which had recruited since the onset of fire suppression, represents a potential restoration of historic composition and structure in some MC stands. The opposite response of conifers and shrubs demonstrates a wide range of trajectories across the mixed-severity mosaic that, combined with overstory productivity and decomposition, will drive short- and long-term carbon loss and storage. Results from this study will be used with novel Landsat disturbance/recovery maps and the Biome-BGC process model to simulate landscape carbon balance before and after fire. Scaling these results to the East Cascades ecoregion will reduce uncertainty in the regional carbon budget and inform management across a rapidly changing and socially important landscape.

keywords: carbon balance, Cascade Range, landscape fire, Metolius River, mixed-conifer forest, mixed-severity fire regime, *Pinus ponderosa*, post-fire recovery.

Citation: Meigs, G.W., and B.E. Law. 2009. Carbon transformations following landscape fire: mortality and ecosystem recovery across the Metolius Watershed, Oregon [abstract]. Page 76 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

IMPROVING NATURAL REGENERATION OF WHITE SPRUCE BY COUPLING SILVICULTURAL TECHNIQUES WITH A MASTING EPISODE

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ABSTRACT

Question: How do we improve natural regeneration of white spruce following disturbances such as fire and harvesting?

Background: White spruce (*Picea glauca*) is one of the most important commercial tree species in North America. Its fiber properties are well suited for the production of pulp, paper, lumber, and other timber products. However, in the boreal forest of Canada and the United States, white spruce has some difficulty attaining its original stocking levels after disturbances such as fire and harvest cuts. Every 2–6 years, white spruce will mast, emitting a significant amount of seed, while little or no seeds are produced during the intermittent years. By prescribing silvicultural treatments prior to the actual masting episode, this study aimed to establish whether the natural recruitment of white spruce germinants could be improved in a seed-tree retention cut. At least five mature trees were left uncut per treatment.

Location: Lac Duparquet, Abitibi-Témiscamingue (lat 48°28′00″N, long 79°16′00″W), Québec, Canada.

Methods: Four treatments were replicated in three separate blocks: 1) control (cut; with no prescription), 2) scarification of the ground, 3) chipping of the understory, and 4) a combination of scarification and chipping.

Results: We found that a combination of scarification and chipping significantly increased the amount of mineral soil available, resulting in the highest recruitment rate of germination of the four treatments. In addition, decomposed wood proved to be a very good seed bed for recruiting white spruce germinants. Based on seed trap contents, a mast year produces the most seed rain between the months of September and December, and steadily declines afterwards. A robust amount of cones detach from the trees just before snowfall.

Conclusions: In light of the growing popularity of ecosystem management, forest managers may want to explore possibilities of better planning white spruce harvest cuts in light of masting episodes to diminish post-harvest planting costs and improve on the overall sustainability of forests today.

keywords: mast year, mineral soil, natural regeneration, *Picea glauca*, scarification, seed-tree retention cut, white spruce.

Citation: Rive, A.C., D.F. Greene, and B.D. Harvey. 2009. Improving natural regeneration of white spruce by coupling silvicultural techniques with a masting episode [abstract]. Page 77 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

EFFECT OF FUEL TREATMENTS ON FUELS AND POTENTIAL FIRE BEHAVIOR IN CALIFORNIA NATIONAL FORESTS

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ABSTRACT

Question: How do mechanical methods and prescribed Āre affect forest and fuel structure and potential Āre behavior in coniferous forests in California?

Background: Fire has been a part of California's ecosystems for thousands of years. Throughout California and the western United States, Āre exclusion, timber harvesting, and livestock grazing over the past century have altered forest structure. Forests in the western United States are currently characterized by smaller trees and larger fuel loads than in the past. The transformation of fuel conditions, coupled with a changing climate, has altered the historical Āre regime in coniferous forests of California. The increase in uncharacteristic stand-replacing crown Āres in ecosystems that historically burned as surface or mixed-severity Āre is of concern to land managers. In 2001, the PaciĀc Southwest Region of the USDA Forest Service initiated a region-wide fuel hazard reduction treatment monitoring project. The monitoring project was designed to quantify the effectiveness and effects of fuel treatments on major vegetation types across California. Monitoring plots have been established in 17 out of the 18 national forests in coniferous forests and chaparral ecosystems. Treatment types included prescribed Āre, mechanical treatments, a combination of the two, and wildĀre. To date, the majority of plots that received treatment are in coniferous forests and were treated with mechanical methods or prescribed Āre. The objective of this study was to determine how prescribed Āre and mechanical treatments affect fuel loads, forest structure, and potential Āre behavior for three forest types.

Location: Fourteen national forests in California, USA.

Methods: Pre- and post-treatment forest structure (tree density, quadratic mean diameter, canopy cover, canopy base height, and canopy bulk density) and fuel characteristics (ground and surface fuel loads and fuel bed depth) were measured and statistically compared. Fire behavior modeling was completed with NEXUS, using fuel models and forest metrics to compare pre-and post-treatment Āre type, Èame length, Āreline intensity, and rate of spread for two wind-speed scenarios.

Results: Mechanical treatments had a greater impact on forest stand characteristics than prescribed Āre. Canopy base height and quadratic mean diameter signiĀcantly increased and tree density, canopy cover, and canopy bulk density signiĀcantly decreased for all three forest types. Prescribed Āre did not alter stand characteristics as widely as mechanical treatments. Canopy base height signiĀcantly increased for both forest types. For the short-needle forest type, prescribed Āre signiĀcantly decreased canopy bulk density and increased quadratic mean diameter. Prescribed Āre reduced surface and ground fuel loads more than mechanical treatment. For the short-needle forest type, prescribed Āre signiĀcantly reduced duff, litter, 1-hour, 10-hour, and 1000-hour fuel loads, and fuel bed depth. The long-needle prescribed Āre combination had signiĀcantly reduced duff, litter, 10-hour fuel loads, and fuel bed depth. Mechanical treatments did not signiĀcantly alter fuel loads for the red Ār (*Abies magniÈca*) forest type and increased larger diameter fuel loads for the short-needle and long-needle forest types. Fire type decreased post-treatment for all forest–treatment combinations. Flame length, Āreline intensity, and rate of spread decreased post–prescribed Āre under average and gust wind speeds. Mechanical methods reduced the proportion of post-treatment potential crown Āre but had mixed effects on other Āre behavior metrics.

Conclusions: This research showed that both prescribed Āre and mechanical treatments were successful at reducing potential Āre behavior with average and gust wind speeds. However, with faster wind speed, four of the Āve forest–treatment combinations would beneĀt from further treatment based on modeled Āre type, Èame length, and Āreline intensity. Another concern with fuel treatments is the effectiveness to maintain reduced potential Āre behavior over time. The question of how frequent fuel treatments need to be re-treated and with which methods is still relatively unknown. This study presents an opportunity to continue long-term monitoring of forest and fuel changes over time. This information could be used to better understand the longevity of fuel treatment effectiveness for three coniferous forest types and two treatment options for California.

keywords: Āre behavior modeling, mechanical fuels treatment, prescribed Āre, wildĀre risk.

Citation: Vaillant, N.M., and J. Fites-Kaufman. 2009. Effect of fuel treatments on fuels and potential Āre behavior in California national forests [abstract]. Page 78 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

PRECIPITATION VARIABILITY IN THE UPPER SNAKE RIVER WATERSHED: CLIMATE SCIENCE MEETS EDUCATION

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ABSTRACT

Question: What is the natural range of precipitation variability in the Upper Snake River watershed? How does the current dry period compare to previous dry cycles?

Background: Recent drought and increasing demands on the water supply emphasize the need to account for climatic variability in all aspects of natural resource management. In particular, moisture variability can influence fire occurrence, with hotter, drier periods resulting in more frequent, more intense burns. Tree rings provide a window into past precipitation regimes, yielding critical information on decadal and multi-decadal trends in water resources. Tree growth can be used as a precipitation proxy because moisture availability influences annual growth, especially on well-drained slopes. Variation in moisture-related metrics, such as precipitation and streamflow, is captured in annual ring widths. Trees growing on steep, dry sites are particularly well suited for hydrologic reconstructions. Data on historic precipitation cycles can help guide planning efforts for water resources, forest management, and conservation of ecosystem processes. Application of historic climate data is dependent, however, on ensuring that data are shared with appropriate user groups. Little is achieved by archiving rigorously generated results on dusty bookshelves. Interactive workshops and experiential-based learning tools enhance both the understanding and incorporation of climate science in resource management.

Location: Upper Snake River watershed near Jackson Hole, Wyoming (lat 43.48°N, long 110.761°W), USA.

Methods: We developed a streamflow reconstruction of the Upper Snake River watershed (USRW) to better understand historic precipitation patterns in the region. We sampled Douglas-fir (*Pseudotsuga menziesii*) and limber pine (*Pinus flexilis*) at five sites in USRW in 2006 and 2007. Tree-ring data were calibrated with naturalized flows from the Jackson Lake dam. The best regression-based model was applied to the full length of the tree-ring data (analysis by the Laboratory of Tree Ring Research).

Results: The best models of tree-ring data included 7 chronologies from the Laboratory of Tree Ring Research, 4 chronologies from the Jackson area, and 33 additional chronologies from the International Tree Ring Data Bank and fellow dendrochronology researchers. The best performing model explained 38% of the variance in the gauge record. This model was used to reconstruct Snake River annual streamflow from 1587 to 2006. The lowest flow year in the reconstructed record was 2001. At longer time scales, however, the recent drought (2000–2004) does not rank among the 10 most extreme dry periods because it is bracketed by relatively wet years (1996–1999; 2005–2006). Overall, dry periods in the early to mid-1600s were more severe than recent droughts. Streamflow during 1626–1659 was below median in 25 of 34 years, including 8 consecutive years. We shared our work with interested publics through informational sessions, targeted presentations to water-user groups, workshops for public and private school teachers, and through hands-on learning tools for K–12 students.

All data analysis is courtesy of E. Wise and the Laboratory of Tree Ring Research.

Conclusions: While the most recent drought (2001–2004) was severe, it is exceeded in both duration and magnitude by earlier dry periods. Overall, the 20th century was relatively wet compared with the climatic conditions this region experienced in the past. Prolonged dry periods are a natural part of the historic climate record. Dry conditions will likely lead to hotter, more severe fires. Ecologists should incorporate historic precipitation variability in long-term resource management scenarios, especially in the arid West where fire plays an important role in ecosystem function. Human-caused changes in the climate system notwithstanding, the natural resources community should be prepared for long-duration dry cycles in the future. Responsible resource stewardship begins with consideration of useful information. We will continue to disseminate our findings to targeted resource managers through a series of science-based workshops in winter 2008–2009.

keywords: climate variability, dendroclimatology, education, hydrologic reconstruction, tree ring, Upper Snake River watershed.

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POPULATION GENETIC STRUCTURE OF ASPEN IN YELLOWSTONE AND ROCKY MOUNTAIN NATIONAL PARKS

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Aspen populations often have high levels of clonality due to widespread vegetative reproduction. This has implications for genetic diversity at all scales, from the individual tree, to the stand, and up to the entire landscape. Clonality of individual stands is expected to increase over time due to competitive exclusion of genotypes. Fire resets this process by destroying adult clones and creating establishment opportunities for new seedlings. We are studying seedling populations that became established following the 1988 fires and quantifying levels of genetic diversity within populations and differentiation among populations. We have generated multi-locus microsatellite genotypes for >200 seedlings and 400 adult trees collected from across Yellowstone and Grand Teton national parks. We have used these data to identify levels of clonality 20 years after establishment, thereby shedding light on stand development processes following post-fire recruitment. Furthermore, genetic diversity in parental trees is providing clues to the origin of the seedlings and insights into potential stand development trajectories for the seedling populations. We are also integrating geographic analysis with patterns of genetic diversity to infer landscape drivers of the genetic composition of aspen stands. Finally, we are comparing adult trees' genetic diversity between Yellowstone and Rocky Mountain national parks to gain insights into the impact of different stand development histories on genetic diversity. These analysis will lead to enhanced understanding of the forces shaping current, past, and future aspen populations in Yellowstone and other ecosystems in the western United States.

DO BARK BEETLE OUTBREAKS INCREASE FIRE RISK IN THE WESTERN U.S.? A SYNTHESIS OF CURRENT KNOWLEDGE AND FUEL DYNAMICS IN THE GREATER YELLOWSTONE ECOSYSTEM

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In the western United States, forest fires and native bark beetle outbreaks have increased in extent and frequency during the recent decades. It is often assumed that widespread bark beetle outbreaks set the stage for catastrophic wildfires because they create great quantities of dead and ladder fuels. Although this idea has dominated since the early 20th century, it is only beginning to receive rigorous testing. We first review the state of the science on beetle–fire interactions across several western forest types, then present surface and canopy fuel data from the Greater Yellowstone Ecosystem. Fuels were sampled in 2007 in lodgepole pine (*Pinus contorta* var. *latifolia*) stands ($n = 25$) that were attacked by the mountain pine beetle (MPB; *Dendroctonus ponderosae*) at different times in the past (undamaged and 1- to ~35-year-old attacks). This time-since-beetle chronosequence is compared with another chronosequence sampled in 1981 ($n = 10$ stands, 0 to ~15 years post-beetle), allowing a more robust estimate of bark beetle effects on fuel dynamics. Review of peer-reviewed empirical studies revealed that beetle–fire interactions varied with time-since-beetle attack and between host–beetle pairs. There is increasing evidence that spruce beetle (*Dendroctonus rufipennis*) outbreaks have no effect on the occurrence and severity of stand-replacing fires in spruce–fir (*Picea engelmanii–Abies lasiocarpa*) forests. The effect of MPB infestations on fire occurrence and severity in lodgepole pine forests are variable and influenced by time since beetle outbreak. Effect of bark beetle outbreaks on fire in other forest types are unknown (ponderosa pine [*Pinus ponderosa*], pinyon–juniper [*Pinus edulis–Juniperus* spp.]) or need more research (Douglas-fir [*Pseudotsuga menziesii*]). Chronosequence data from the Yellowstone area showed that immediately after the outbreak (2–4 years post-beetle), the most significant changes in fuels were a decrease in canopy bulk density and an increase in needle litter depth. Over longer periods of time (10–30 years post-beetle), biomass of large dead surface fuels and understory vegetation increased. Dead surface woody fuels <8 cm in diameter (1-hour to 100-hour fuels) showed high variability throughout the chronosequence. These results illustrate the complex changes in the quantity and distribution of dead and live fuels following bark beetle outbreak, and underscore the need to consider both canopy and surface fuels. Time since beetle outbreak is an important factor to consider in the relationship between bark beetle outbreaks and fire risk because fuels change over time.

A COMPARISON OF SEVERE FIRE AND BARK BEETLE DISTURBANCE EFFECTS ON SOIL NITROGEN DYNAMICS OF THE GREATER YELLOWSTONE ECOSYSTEM

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The dominant components of the disturbance regime within western subalpine forest landscapes are Āres and bark beetle (*Dendroctonus* spp.) outbreaks. Together, these disturbance types have affected approximately 80% of Yellowstone National Park over the past four decades, as well as large areas of the Greater Yellowstone Ecosystem (GYE). In addition to large changes in seral stage, stand structure, and spatial heterogeneity induced by these disturbance types, there are also signiĀcant alterations to soil nutrient dynamics. Fire and beetle disturbances differentially affect ecosystem pools such as foliar litter, organic soil, and aboveground biomass, which in turn create the potential for unique responses in soil nitrogen cycling following disturbance. To characterize these differences, we Ārst describe the unique effects of each disturbance type on a suite of ecosystem pools important to the nitrogen cycle within lodgepole pine (*Pinus contorta* var. *latifolia*) forests. Then, we examine soil nitrogen data from a post-Āre time series and a post–mountain pine beetle (*Dendroctonus ponderosae*) chronosequence to compare the responses of the lodgepole pine ecosystem to these different disturbance types. We Ānd that despite differing and even sometimes opposite effects on tree mortality, litter depth, and organic soil mass, there are qualitatively similar responses of soil N availability following each disturbance type, namely a sharp increase in available ammonium following disturbance. However, the magnitude and duration of this response differs by disturbance type, being much larger and shorter-lived following Āre, and smaller but longer-lived following bark beetle outbreak. Understanding how post-disturbance soil N dynamics are altered in this system has important consequences for regeneration, nutrient retention, and other ecosystem services.

THE EFFECTS OF MOUNTAIN PINE BEETLE DISTURBANCES ON UNDERSTORY VEGETATION PATTERNS IN LODGEPOLE PINE FORESTS OF ROCKY MOUNTAIN NATIONAL PARK

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Colorado is in the middle of a severe mountain pine beetle outbreak that has caused widespread lodgepole pine mortality in 1.5 million forested acres since 1996. How these forests will respond to this epidemic is not known, and is of great concern to residents, visitors, and land managers. Although mountain pine beetle disturbances have historically been a part of these ecosystems, the present circumstances are unique; global climate change and invasive species have the potential to signiĀcantly alter the composition and structure of post-epidemic forest communities. More generally, there is a lack of detailed information about how understory vegetation responds to bark beetle outbreaks. The purpose of our study is to describe the response of the understory plant community to a recent and ongoing mountain pine beetle epidemic in Rocky Mountain National Park (ROMO). To meet this goal, we are surveying understory vegetation composition and structure in ROMO's lodgepole pine forests. Data collection began in 2008 and will extend over two Āeld seasons. Environmental differences and non-uniform mortality across our study sites in ROMO have resulted in varied patterns in the understory vegetation and tree regeneration. Understory vegetation growth and establishment is likely to depend on the interaction with future Āres, especially in areas where lodgepole pine trees have serotinous cones. This information is important for alerting land managers about potential consequences of the mountain pine beetle epidemic, such as habitat type conversion and nonnative species invasion. It is our hope that not only will our study satisfy these practical management needs, but that it will also help clarify the ecological processes and factors that inÈuence vegetation patterns following disturbances.

MOUNTAIN PINE BEETLE MORTALITY AND SCALE: PATTERNS IN ROCKY MOUNTAIN NATIONAL PARK

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The current mountain pine beetle (MPB; *Dendroctonus ponderosae*) epidemic affecting the southern Rocky Mountains has caused extensive mortality to mature lodgepole pine stands at varying spatial scales. This has raised questions related to the resiliency of forests with regard to disturbance agents. Our research investigates the severity and spatial pattern of the MPB epidemic in Rocky Mountain National Park, Colorado. We used field sampling and spatial modeling to examine the overall percentage of lodgepole pine mortality and the effects of increasing spatial scale (grain size) on percent mortality. Field plots were located in the lodgepole pine cover type using a spatially balanced, random design. We found that, although some patches of lodgepole pine forest have experienced 100% mortality, lesser degrees of mortality also exist across the landscape. Consequently, as one's observational spatial grain size increases, overall percent mortality decreases. These results are particularly applicable to fire managers who have widespread MBP mortality within their jurisdiction and need help framing the scale at which to implement preventative MPB and fuels reduction treatments on the ground. By measuring to what extent and how severely MPBs have affected the current landscape, this research helps establish a more accurate perspective that will guide future lodgepole pine and MPB management strategies.

EFFECTIVENESS OF IMAZAPIC HERBICIDE IN REDUCING POST-FIRE CHEATGRASS INVASION IN ZION NATIONAL PARK

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The Dakota Hill Complex Fires burned approximately 2,400 ha in Zion National Park during June 2007. In response to the fires, a Burned Area Emergency Rehabilitation (BAER) Team assessed the impacts of the fires and recommended a landscape-level application of imazapic (trade name Plateau®) herbicide in order to reduce cheatgrass (*Bromus tectorum*) occurrence in the park. Approximately 1,273 ha of the high-severity burned landscape were sprayed by helicopter at an application rate of 8 oz. per acre during September 2007. The implications of such a large-scale application of imazapic herbicide to burned landscapes are not fully understood. This project will monitor the effectiveness of this landscape-scale aerial application of imazapic herbicide in suppressing the post-fire invasion of cheatgrass over the next 3 years. The effects of the herbicide on the native understory plant community will also be evaluated in order to discern any potential negative impacts. Additionally, the viability of cheatgrass for 2 years post-application will be assessed, as the treatment would be considered ineffective if the biomass of individual cheatgrass plants is reduced but the seed production and viability remain constant. The monitoring is being conducted using a paired plot study (treated and untreated) in both piñon (*Pinus monophylla*)–juniper (*Juniperus osteosperma*) and Gambel oak (*Quercus gambelii*) vegetation types within the high-severity burned areas. Density, cover, and biomass will be measured by species to reach a conclusion about the effect of the herbicide on the understory plant community. Cheatgrass viability will be evaluated through germination tests carried out in a germination chamber. Preliminary results for the effectiveness of imazapic at reducing cheatgrass occurrence as well as any potential reduction in cheatgrass viability rates in Zion National Park will be presented at the conference.

TWENTY-TWO-YEAR TRENDS FIRE EXTENT AND SEVERITY TRENDS IN NORTHERN ROCKY MOUNTAIN FORESTS RELATIVE TO CLIMATE AND VEGETATION

Zack Holden, Penny Morgan, Michael Crimmins, Charlie Luce, and Emily Heyerdahl

The Monitoring Trends in Burn Severity Program (MTBS) has recently made available databases describing the extent and severity of most major wildfires across the Northern Rocky Mountains from 1984 to 2005. Derived from pre- and post-fire Landsat-derived normalized burn ratio images, these data allow us for the first time to examine short-term trends in wildfire severity, a critical but poorly understood aspect of fire regimes. Using data for >1,200 fires, we describe the extent and severity of wildfires in Washington, Oregon, Idaho, Montana, western Wyoming, and northern Utah relative to climate, vegetation, and topography. We contrast these patterns with data for Yellowstone National Park, including the 1988 Yellowstone fires.

THE EFFECTS OF CHARCOAL REMOVAL ON SHORT-TERM SOIL NUTRIENT DYNAMICS AFTER EXPERIMENTAL BURNING IN THE *BETULA PLATYPHYLLA* FORESTS, NORTHERN JAPAN

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Hokkaido University

In Far Eastern Eurasia, the frequency of surface fires in forests has been drastically increasing in recent decades. The charcoal generated is well known to affect soil conditions and, therefore, changes in fire regime should affect the forest function by changing the amount of charcoal in the ecosystem. To clarify this hypothesis, we need to understand the role of charcoal in post-fire forests in detail. In previous studies, the effects of charcoal on soil nutrients were mainly studied by charcoal addition and/or mixing experiments with the unburned forest soils in the lab or those in the agro-environment. However, charcoal tends to stay on the surface and does not immediately mix with soils after the fire. Furthermore, fire does not only generate charcoal but also deposits ash and consumes the humus layer in forests. To understand the accurate effect of charcoal in the ecosystems, we should investigate accurately how charcoal affects the soil under the multiple changes occurring in post-fire forests. In this study, we conducted charcoal removal treatment after a experimental burnings to duplicate fire-induced changes without charcoal. The experimental burning was conducted in July 2007 in the northern part of Japan. The dominant woody species is *Betula platyphylla*. To simulate the frequent surface fires in Far Eastern Eurasia, only the forest floor with dwarf bamboo was burned. In each of four sites, we established three plots: control (unburned), burned, and burned plus charcoal removal. Charcoal was carefully removed by hand-sorting. Soil sampling was conducted just before fire, 1 week, and 1, 2, and 4 months after burning. Separate samples were taken for the organic layer, and for the 0- to 5-cm and 5- to 10-cm mineral soil layers. In the burned plots, nutrient dynamics in the soil, NH_4^+, available P, exchangeable Ca, Mg, K, and Na, and extractable Al, Fe, Mn, and Ni were affected compared with the control. Charcoal removal only affected the nutrient dynamics of available P, exchangeable Mg and Ca, extractable Al, and Fe in the organic layer compared with the burn-only plots. Other nutrition in the organic layer and nutrition in the deeper layers were not significantly affected. This study suggests that, even over the short term, changes in the amount of charcoal affect the specific nutrient dynamics in the organic layer in the post-fire forest ecosystem.

COMPARATIVE ANALYSIS OF FOREST FIRE DANGER RATING ON FOREST CHARACTERISTICS OF THINNING AREA AND NON-THINNING AREA ON FOREST FIRE BURNT AREA IN KOREA

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We selected 18 plots for study on Gangneung, Samcheok, and Uljin areas, Korea, where forest fires occurred after thinning in 2007. We compared the relationship between forest fire damage and thinning. Many factors, such as tree species damaged, thinned or non-thinned, direction of headfire, DBH, tree height, tree mortality, leeward scorching ratio, crown damage ratio, forest tree density, crown base height, thinning slash presence, plot location (GPS), elevation, slope aspect, slope angle, and topography, were measured. Leeward scorching ratio was 24.7% on the thinned area, compared to 60.2% on the non-thinned area; therefore, leeward scorching ratio on the thinned area was 35.5% more than on the non-thinned area. We found that overall pine forests were damaged more than oak forests. Tree mortality was increased by about 41.4% on non-thinned areas. Ladder fuel presence should influence forest fire spread rate because the clear length of tree boles on non-thinned areas was lower than on thinned areas by 2.6 m. As a result, leeward scorching ratio and crown damage ratio on non-thinned areas was higher than on thinned areas. Stands with slash from thinning were damaged 10–20% more than other stands as a result of higher fuel loads. Because the potential for reignition increases with more accumulated slash from thinning, it will be important to require a method for periodic removal or practical utilization of slash. This study was carried out with the support of Forest Science & Technology Projects (Project No. S210808L0101004) provided by Korea Forest Service.

LONG-TERM FIRE EFFECTS AND FIRE REGIMES

ADAPTING LANDFIRE VEGETATION MODELS FOR RESTORATION PLANNING

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ABSTRACT

Question: How can LANDFIRE vegetation models be adapted to assist restoration planning efforts?

Background: LANDFIRE vegetation models are used to estimate the historic fire regime of different biophysical settings (BpS) as a benchmark against which to assess the current departure from historic conditions. Models are developed using the Vegetation Dynamics Development Tool (VDDT). VDDT is easy to use and rapid to simulate due to the simplicity of the data requirements and the algorithms for nonspatial state and transition models. However, the implications of assuming non–spatially explicit dynamics are not well understood. Furthermore, the vegetation models developed under LANDFIRE do not include any of the uncharacteristic states and transitions that were absent historically but are occurring today. Our objectives were twofold: 1) to determine the implications of assuming non–spatially explicit dynamics on the inferences drawn from the LANDFIRE vegetation models about the historic range of variability in fire regimes, and 2) to adapt the LANDFIRE vegetation models to current conditions by adding noncharacteristic states and transitions and then determine their utility for restoration planning.

Location: Grouse Creek and Raft River Mountains (lat 41°46′N, long 113°35′W), Utah, USA.

Methods: We used a collaborative workshop approach with ecologists, managers, and stakeholders to add states and transitions to reference condition models as well as to define alternative management scenarios. Scenarios address interagency cooperation, BpS priorities, fuel breaks, and spatial configuration of treatments. Simulations used either nonspatial (VDDT) or spatially explicit algorithms (TELSA). We evaluated scenario outputs using ecological departure and habitat diversity indices.

Results: For the landscape as a whole, ecological departure measurements for reference simulations using spatially explicit and nonspatial algorithms were similar. Most biophysical settings also demonstrated similar results using either nonspatial or spatially explicit algorithms. Biophysical settings that had longer fire return intervals and had a high perimeter-to-area ratio demonstrated statistically different results when using spatially explicit versus nonspatial algorithms. Management scenarios that were not constrained by ownership boundaries for restoration and that used fuel breaks demonstrated lower levels of ecological departure and higher levels of habitat diversity for wildlife.

Conclusions: Our results suggest that for large landscapes, using less expensive nonspatial models to determine reference conditions is adequate. However, differences between spatial and nonspatial results suggest that the spatial configuration of BpS in any one particular landscape is important in defining reference conditions. Results of nonspatial reference condition models should be interpreted cautiously at smaller scales. Our management models for the Grouse Creek Mountains and Raft River Mountains of northwestern Utah suggest that the constraints placed on restoration by the configuration of ownership boundaries on the landscape is an important barrier to improving the ecological condition of the landscape over the next 50 years. Our models also show that investing in fuel breaks to reduce the size of uncharacteristic fires may be effective at improving the ecological condition of the landscape.

keywords: ecological departure, habitat diversity, LANDFIRE, landscape, restoration, simulation, spatially explicit, state and transition, TELSA, VDDT.

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LINKING FIRE ENVIRONMENT DATA TO LONG-TERM FIRE EFFECTS

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This presentation will describe a method to graphically display fire environment data to compare on-site fire environment conditions with long-term fire effects, thus linking management objectives to the fire environment, a critical step in predicting the success of a fire in meeting long-term objectives. Perhaps the most common quantifiable data collected during wildland fire and prescribed fire events is information about the conditions in fire environment. During fire incidents, these data aid in predicting short-term fire behavior and weather during the event. This methodology utilizes fire environment conditions (temperature, relative humidity, fine fuel moisture, and winds) collected during fire events to link those environmental conditions to fire effects (severity, regeneration, species composition, etc.). Similarly, this methodology may be used to graphically display prescription parameters described in prescribed burn plans compared with actual conditions during the event to determine the effectiveness of prescriptions in meeting project objectives. Data groupings of environmental conditions from historical fires may be produced and compared with fire effects that have been observed since the event. These groupings are then used to benchmark environmental conditions on prescribed fires against those conditions on wildland fire. This comparison links long-term fire effects with environmental conditions experienced. The link is applied to other events of prescribed or wildland fire to more accurately predict the long-term fire effects that would be expected to develop following the fire. Managers use this link to refine prescriptions, determine trigger points, and better understand the potential for system changes in vegetation communities in response to fire. This methodology is also useful in public education/information forums for displaying current and expected fire site conditions, especially in relation to benchmark fire events.

LOW- AND MIXED-SEVERITY FIRE REGIMES IN LODGEPOLE PINE/DOUGLAS-FIR FORESTS IN CENTRAL BRITISH COLUMBIA

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A study was initiated in 2002 to characterize the range in natural variability in historical fire regimes and stand structures in the Fraser variant of the dry cool Interior Douglas-fir biogeoclimatic subzone (IDFdk3) on the Fraser Plateau of the Cariboo region of south-central British Columbia. The plateau is gently sloping from south to north and contains three broad forest types: pure lodgepole pine at high elevations (Pl High), a lodgepole pine/Douglas-fir mix within an intermediate elevation band (FdPl Mod), and pure Douglas-fir at low elevations (Fd Low). We hypothesized that there were fire regime and stand structure distinctions between these three broad forest types. At each of 44 unharvested sample sites, we collected six to ten fire-scar samples within a 20-ha area centered on the plot. We collected a total of 265 useable fire-scar samples that were cross-dated to determine fire dates for a total of 537 fire scars. We used existing stand structure data, tallied the number of downed trees, and aged five trees in each diameter class cohort and 10 trees in the oldest cohort at each plot. Historical fire frequency was similar among all three strata with a median mean fire interval (MFI) of 22 years for all strata combined. Median fire frequency at individual plots ranged from 5 to 49 years. The average MFI for the Pl High stratum (26 years) was longer than for the FdPl Mod stratum (21 years) and Fd Low stratum (19 years), but was not statistically significant. The Pl High stratum showed the most evidence for a component of high-severity events in the disturbance regime with four of the eight plots sampled being relatively even-aged. Mean historical stand densities (540 stems per ha [sph] established prior to 1900) were about half that of current plots (1,186 sph for trees >5 cm DBH). The majority of plots in the FdPl Mod stratum were multi-aged (25 of 29 plots), and exhibited significant density increases between the pre-settlement period and today (421 sph established prior to 1900 versus 1,758 sph today). All plots in the Fd Low stratum were multi-aged, dominated by Douglas-fir, and often showed a significant regeneration pulse in the late 1800s. Average historical stand density in 1860 was 499 sph; in 1900 it had jumped to 1,582 sph, and was 2,487 sph in 2002. We identified two historical fire regimes: a predominantly frequent, low-severity fire regime in the Fd Low stratum and a frequent, mixed-severity fire regime in the FdPl Mod and Pl High strata. Our results have pertinent implications for both forest management and understanding of the current epidemic of mountain pine beetle infestation that the study area lies within.

REMOTE SENSING OF BURN SEVERITY IN ALASKA: CHALLENGES IN THE LAST FRONTIER

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By the end of 2011, all large fires (>400 ha) in the United States will have been mapped from 1982 to the present, utilizing Landsat remotely sensed data as part of the USGS Monitoring Trends in Burn Severity (MTBS) program. The MTBS program applies the differenced Normalized Burn Ratio index to map fire perimeters and stratified burn severity, creating a multi-decadal data set that will open research doors to understanding how hierarchical processes both impact and are constrained by burn-severity patterns. To complete this mapping process, however, a host of challenges must be met and overcome in various regions. One of the most difficult regions to map burn severity is Alaska, where the remote access, short growing season, summer cloud cover, high latitude, diversity of cover types, and complex topography provide limited opportunities for optimum mapping. This work addresses the challenges faced in mapping burn severity in this region and highlights the research undertaken to overcome them. It describes linear spectral unmixing of MODIS pixels to produce burn fraction maps, calibration of Landsat MSS to Landsat TM for mapping burn severity, and the use of classification trees to explore contributing factors to burn-severity intensity. It also identifies how long time-series maps of burn severity in the region are being used to describe climate change impacts on burn severity.

FIRE AND AQUATIC SYSTEMS

THE FIRE PULSE: MID-TERM EFFECTS OF WILDFIRE ON STREAM–RIPARIAN LINKAGES IN WILDERNESS WATERSHEDS OF CENTRAL IDAHO

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WildĀre has the potential to alter many land–water linkages, yet relatively few studies have addressed its inÈuences on stream ecosystems or the vectors of aquatic–terrestrial connectivity. Through a combination of studies, we have investigated the mid-term effects of wildĀre (5 years post-Āre) on several key land–water linkages in the Big Creek Watershed, located in the Frank Church "River of No Return" Wilderness of central Idaho. We hypothesized that wildĀre ampliĀes aquatic–terrestrial connectivity via a number of direct and indirect mechanisms. Through comparison of unburned stream–riparian systems to those that experienced low- and high-severity wildĀre, we investigated inÈuences of Āre on the Èow of energy from aquatic to terrestrial habitats via the emergence of adult insects from streams, the effects of Āre on plant and invertebrate inputs from land to water, and the inÈuences on the export of invertebrate prey from burned versus unburned tributaries to downstream reaches. We also evaluated potential effects on riparian predators of aquatic insects like birds, bats, and spiders, as well as aquatic consumers like invertebrates and Āsh. We observed that stream reaches that experienced high-severity Āre exported the greatest Èuxes of adult aquatic insects, and these also had the highest abundance of riparian spiders, Èy-catching birds, and foraging bats. Though inputs of terrestrial arthropods and plant matter did not differ in magnitude among burn categories, they did vary in composition. High-severity-burned stream reaches also had the greatest benthic insect biomass, including that of productive, disturbance-adapted consumers and predatory insects. Similarly, we observed that burned tributaries of the Big Creek basin exported the greatest numbers of invertebrate prey to the mainstem of Big Creek, and that these tributary junctions were used by larger numbers of cutthroat trout than were those junctions with unburned tributaries. When combined with perspectives from long-term monitoring data (including pre- and post-Āre observations of some of these stream systems), our observations suggest that wildĀre may drive a pulse of productivity that extends into the mid-term time period, that may be characterized by ampliĀed Èuxes from stream to riparian systems and increases in some groups of terrestrial predators, but may also propagate effects on aquatic consumers downstream of the Āre disturbance.

WILDFIRE-MEDIATED CHANGES IN NUTRIENT CYCLING BETWEEN AQUATIC AND TERRESTRIAL ECOSYSTEMS

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Terrestrial ecosystems tightly cycle nutrients restraining availability to aquatic ecosystems. Nitrogen cycling is disrupted following wildĀre, commonly increasing soil availability and subsequent release to aquatic ecosystems. Mechanisms controlling soil nitrogen (N) availability post-Āre were explored on three wildĀres in central Idaho to further understand the impacts of wildĀre on the exchange of N between soil and stream water. Soil ammonium (NH_4^+) concentrations increased about 10-fold and nitrate (NO_3^-) concentrations increased from below detection limits to 9.4 ± 5.4 mg NO_3–N kg^{-1} in burned relative to unburned watersheds in the Ārst year post-Āre. We investigated gross inorganic N Èuxes in mineral soil 2 years after three wildĀres in central Idaho coniferous forests to determine the causes of the elevated soil NO_3^-. We found that there were no signiĀcant differences in NO_3^- production rates between burned and control soils. However, NO_3^- consumption rates were signiĀcantly lower in burned soils compared with control soils. The decoupling of supply and demand of NO_3^- in burned soils almost certainly caused elevated soil NO_3^- contents in burned soils relative to controls. This increase in soil NO_3^- post-Āre resulted in streamwater NO_3^- concentrations that were about two orders of magnitude higher ($P < 0.05$) in burned than in unburned watersheds during spring runoff without a decreasing trend 3 years after the Āre. Increased soil and streamwater inorganic N concentrations post-Āre were not temporally coupled. Increased soil N represented the net effect of microbial and plant activity over the growing season, whereas the streamwater N was due to Èushing of winter and early spring mineralization products before the onset of the growing season. Changes in N isotope ratios associated with wildĀre allowed us to track the fate of this newly available N as it was utilized by the terrestrial and aquatic systems. The increases in available N post-Āre led to signiĀcantly increased ($P < 0.05$) foliar N concentrations in all terrestrial upland species (0.8%) and in-stream moss (0.9%). Higher foliar N concentrations in terrestrial plants and in-stream moss represent analogous and important N retention mechanisms. The simultaneous study of many components of watershed ecosystems revealed the importance of complex interactions between biotic, abiotic, and hydrological factors inÈuencing post-Āre N retention and redistribution after wildĀre. The temporal disconnect between major losses of available N from the soil during snowmelt and the onset of the growing season highlighted the importance of aquatic N retention.

EFFECTS OF WILDFIRE ON HYDROLOGIC AND GEOMORPHIC PROCESSES AFFECTING FISH

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Fires yield important changes in hydrology and geomorphology of mountain basins. Impacts range from the dramatic debris flows resulting from thunderstorms on water-repellent soils to changes in stream temperature driven by changes in stream shading. While the impacts to individual fish are often clear and commonly fatal, the effects on populations are more ambiguous because fires also have beneficial effects. For example, additions of gravel, soil nutrients, large wood, and solar irradiance after fire are important to renewal and maintenance of habitats. To understand the impacts to fish populations, the impacts to stream reaches need to be considered in the context of the larger habitat patch and network of connected patches and migratory habitats where the impacts of fire can be temporarily escaped. Two principal features of physical process emerge as critical descriptors of disturbance: the spatial scale, how much area is disturbed synchronously; and the temporal scale, how long impacts and risks persist. We review some of the important effects of fires and discuss temporal and spatial scaling of the effects and implications for conservation strategies and priorities.

STREAM/RIPARIAN ECOSYSTEM RESPONSES TO THE 1988 WILDFIRES—A 20-YEAR PERSPECTIVE

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Stream/riparian ecosystems studied over the first 10 years following the 1988 fires in Yellowstone were reexamined in 2008 to determine their present status and infer response pathways over the previous decade. Marked differences in physical and biological conditions, that initially were evident in burned relative to unburned streams, diminished rapidly during the first decade but were still evident after 20 years. Changes during the second decade were much less pronounced than during the first and are attributable to further channel stabilization and development of riparian vegetation that provided the template for biotic metrics to shift further toward pre-fire conditions. The results are compared with those from two comparable studies in central Idaho to extend the findings beyond Yellowstone and together are used to revise and refine a conceptual model of the long-term responses of stream/riparian ecosystems to fire, first published in *BioScience* in 1989. The results generally support and amplify our original hypotheses and provide insights into the possible effects of climate change on stream/riparian ecosystem response to fire.

LANDSCAPE-SCALE EFFECTS OF DISTURBANCE ON GENETIC STRUCTURE OF SALMONID POPULATIONS IN HEADWATER STREAMS

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Fire is a natural process that has been occurring for millions of years, and in aquatic systems with adequate connectivity and sufficient species pool, fire-mediated perturbations generally do not lead to reduced persistence in most groups of organisms. Current evidence suggests that local extirpation of fishes following fires is patchy, recolonization is rapid, and lasting detrimental effects on fish populations have been limited to areas where native populations have declined and become increasingly isolated because of anthropogenic activities. However, most observations of fire effects to date have been relatively localized and on shorter time frames (i.e., one to several generations). To examine how this type of perturbation may affect populations across landscapes and at longer time scales, we examined genetic data from three regions of the western United States and assessed relationships among landscape structure, stochastic disturbance, anthropogenic alterations, and genetic diversity. Data were collected from 27 barrier-isolated populations of coastal cutthroat trout (*Oncorhynchus clarkii clarkii*) from western Oregon, native rainbow trout (*Oncorhynchus mykiss*) from 55 sites in the Boise and Payette River basins, Idaho, and Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*) from 16 sites in a complex stream network in the Great Basin desert. Genetic diversity of coastal cutthroat trout coincided with indices of regional within-watershed complexity and connectivity, and it appears that physical landscape features have influenced genetic patterns in these populations. In the Idaho study areas, wildfire-related disturbance did not reduce genetic diversity, and human influences such as barriers to dispersal and introductions of nonnative fish may actually pose greater threats to populations of native trout than wildfire. Although the effects of fire were not evaluated directly, Lahontan cutthroat trout populations appeared to be influenced by a combination of landscape and metapopulation processes in a dynamic stream network, and there were significant genetic bottlenecks in populations that were isolated, recently founded, or that inhabited streams that frequently became desiccated. Together, these data provide additional support for the theoretical connection between population persistence and effective population size, stream network connectivity, and watershed complexity.

WILDFIRE AND NATIVE FISH: SCALING OF DISTURBANCE AND POPULATION STRUCTURE AS CONTEXT FOR RESTORATION AND CONSERVATION

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WildĀre has been a focal issue in public land management in the West for fully a century. Recent efforts to mitigate the effects of long-term Āre suppression, changing climate, and other habitat disruption have reinvigorated a political and scientiĀc debate over the last two decades. The controversy and attendant challenges have been particularly apparent at the interface of aquatic (Āshes and Āsheries) conservation and terrestrial forest and fuels management on federal lands in the West. It is clear that wildĀre can have a profound inÈuence on watersheds and streams and the aquatic organisms associated with them. It is also clear that aggressive management can lead to disruption of watershed processes and the quality of habitats for those same species. The immediate effects of a severe Āre may be perceived as a catastrophic event (e.g., the local extinction of a rare species), or as one of the necessary costs associated with longer-term restoration or maintenance of a diverse and productive system. Aggressive fuels management can be painted in the same terms. These are essentially elements of a basic tension in applied ecology characterized on one hand by "restoration ecology," intent on re-creation of more natural forests and sustained ecological services, and on the other by "conservation biology," focused on threatened, endangered, or sensitive species and remnant, native biological diversity. The association between these two is not simply coincidental, but tied, in part, to past land management activities which disrupted both terrestrial and aquatic ecosystems and the linkages between them. In this paper, we consider the processes that link forests, wildĀre, and aquatic systems across watersheds of central Idaho and explore the potential opportunities for more integrated management among them. We conclude that a native Āsh conservation perspective for Āre and fuels management depends on the joint scaling of disturbance and the species population structure. We argue that common ground in Āre, fuels, and aquatic management will emerge from broad perspectives where diverse management objectives may conÈict or converge in complex ways across landscapes of forests, watersheds, semi-urban development, and the structure of populations that are the focus of conservation efforts.

CHANGES IN NATIVE AND NONNATIVE FISH ASSEMBLAGES AND HABITAT FOLLOWING WILDFIRE IN THE BITTERROOT RIVER BASIN, MONTANA

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WildĀre frequency and severity have increased over the past decade, but few studies have assessed the effects of large, intense Āres on mixed native/nonnative salmonid assemblages in the Intermountain West. A unique data set with 1–11 years of pre-Āre population data in 24 small streams in the Bitterroot River basin in western Montana was utilized to determine if habitat changes caused by a large (1,108 km^2) wildĀre and associated debris Èows favored nonnative brook trout (*Salvelinus fontinalis*) over native west slope cutthroat trout (*Oncorhynchus clarkii lewisii*) and bull trout (*S. confluentus*). Before–after control–impact (BACI) and extensive post-treatment study designs were used to determine whether changes in species abundance and habitat increased with increasing burn severity and debris Èows. Species abundance was estimated pre- and post-Āre with mark–recapture electro-Āshing, and habitat conditions post-Āre were assessed by measuring substrate, temperature, large woody debris, and habitat type. Stream temperature and sedimentation generally increased with burn severity, whereas habitat complexity decreased with increasing burn severity and presence of debris Èows. However, recovery of native trout populations was rapid, with populations approaching or surpassing predisturbance levels within 3 years. In contrast, brook trout recovery was less apparent especially in debris Èow reaches as the proportion of brook trout to the total salmonid assemblage decreased each year post-Āre. However, one notable exception occurred in a high-burn-severity reach on Rye Creek, where brook trout increased by 499% and apparently replaced bull trout. Model results indicated that brook trout abundance was negatively related to stream gradient, elevation, and the proportion of a basin that was burned and positively related to watershed area, water temperature, and pool frequency. Spread of nonnative species to reaches where they were undetected pre-Āre ($n = 7$) occurred irrespective of wildĀre disturbance with brown trout (*Salmo trutta*) being the primary invading species ($n = 5$) and only one occurrence of brook trout and rainbow trout (*Oncorhynchus mykiss*) invasion. Although changes in aquatic habitat following wildĀre have the potential to favor nonnative Āshes, connected cutthroat trout and bull trout populations in the Bitterroot River basin were resilient to disturbance and generally recovered more rapidly than nonnative brook trout.

AMPHIBIANS AND FIRE IN THE NORTHERN ROCKIES

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The effects of fire on amphibians in the West received relatively little attention until several large fires in the northern Rocky Mountains recently provided us with unique opportunities to investigate this topic. In Glacier National Park, fires in 2001 and 2003 burned through areas where we had previously sampled both pond- and stream-breeding amphibians, allowing us to return to those sites and contrast occurrence or abundance before and after the fires. Among pond-breeding species, fire had no effect on occurrence of long-toed salamanders or Columbia spotted frogs, but boreal toad breeding sites increased the year after both fires. The causes of this increase in occurrence are puzzling. The distribution of toads was not related to water temperature or water chemistry. We did find that telemetered adult toads preferentially used severely burned forests, which provided more optimum thermal conditions for growth. Further confounding any attempt to explain this result, the occurrence of boreal toads declined to pre-fire levels within 3 years after both fires but have begun to increase again in the area burned in 2001. In headwater streams in Glacier, abundance of Rocky Mountain tailed frog tadpoles was reduced in watersheds burned in the 2001 fire, compared with unburned streams. Elsewhere in western Montana and central Idaho, fires in 2000 burned across many watersheds containing tailed frogs. Using a retrospective approach, we found the density of tadpoles was lower in burned streams relative to unburned streams and density tended to decrease linearly with increasing burn severity of a watershed. In contrast, tailed frog reproduction was not affected by prescribed fire in an Idaho stream studied 3 years before and 3 years after broadcast burning. The difference in responses of tailed frogs to wildland and prescribed fire appears to be associated with burn severity; prescribed fires are generally less severe than what we often consider low-severity wildland fires.

QUANTIFYING POST-FIRE BOREAL TOAD HABITAT CONNECTIVITY USING LANDSCAPE GENETICS

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Amphibian species may be ecological indicators, with many in decline around the world. As such, they are a focal group in the Inventory & Monitoring Program for Yellowstone National Park. However, ecological effects of fire on amphibian species are just beginning to be explored. The boreal toad (*Bufo boreas*) is a locally abundant, patchily distributed species thought to be in decline throughout most of its range. In addition, studies suggest increased dispersal and colonization of unoccupied habitats 1–2 years post-fire. We use a landscape genetics approach to quantify the effect of fire history on population connectivity and recent population bottlenecks using multi-locus genotypes (15 loci, 805 samples). We used a novel algorithmic approach (in Random Forests) to conduct multiple-scale analysis of boreal toad connectivity. We explain 74% of variation in genetic distance as function of three landscape processes: habitat permeability (including fire history), topographic morphology, and temperature–moisture regimes. Metrics operating at finer spatial and temporal scales drive connectivity within a genetic cluster (growing-season precipitation, fire history, impervious surfaces, and cover), while metrics operating at coarser spatial and temporal scales drive connectivity between genetic clusters (hot–dry slopes, ridges, and mean annual precipitation). Impervious surfaces (roads and development) and recent drought conditions are major limiting factors for boreal toad dispersal, while fire is positively associated with habitat connectivity. In addition, we find genetic signatures of recent population bottlenecks associated with high-severity fire. Our study suggests that fire results in direct mortality of boreal toads, followed by a pulse of increased habitat connectivity. Finally, we propose that boreal toads are a fire-adapted species. Changes in fire regime may have resulted in genetic fragmentation due to loss of post-fire habitat connectivity.

CLIMATE, FIRE, AND EMISSIONS

RECENT WILDLAND FIRE ACTIVITY IN BOREAL AND TROPICAL REGIONS UNDER RAPID CLIMATE CHANGE

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ABSTRACT

Question: What types of weather conditions control recent wildfire activity in Alaska, Sakha (Siberia), Mongolia, and Indonesia under rapid climate change?

Background: In this paper, recent wildfire activity in Alaska, Sakha (Siberia), Mongolia, and Indonesia was characterized by considering recent weather conditions during a period of rapid climate change. Forest fire data from various government forest agencies, hot-spot data obtained from satellite, and weather records were analyzed to clarify the relationship between fire activity and weather. Results showed that level of wildfire activity in all four locations was strongly affected by lower precipitation and increased temperatures. Thus, weather conditions coincident with rapid climate change may allow occurrence of large-scale fires and create a positive feedback loop to climate warming by the release of greenhouse gasses from forest fires. It is notable that increased temperature and lower precipitation led to increases in wildfire in four widely different ecosystems from the boreal to the tropical. Wildland fires in boreal and tropical forests are important as potential carbon sources because they accumulate large amounts of carbon in their forest floors and emit large amounts of not only carbon dioxide (CO_2) but also other greenhouse gases such as methane (CH_4) after large-scale fires and clearcutting. Recent large-scale wildland fires in these four regions should be considered one of the most important ecological disasters caused mainly by human activity or man-made climate change. Analysis of the four regions and level of wildfire activity under rapid climate condition are described briefly below.

Location: Alaska, USA (lat 71–59°N, long 141–167°W); Sakha, Siberia (lat 70–56°N, long 106–160°E); Indonesia (lat 7°N–9°S, long 95–120°E); Mongolia (lat 52–42°N, long 88–120°E).

Methods: To characterize recent wildfire activity in Alaska, Sakha (Siberia), Mongolia, and Indonesia, forest fire data from various government forest agencies, hot-spot data obtained from satellite, and weather records were analyzed. Analysis results clarified not only the relationship among fire activity, weather, and recent weather conditions but also important weather factors influencing fire activity for the four different areas.

Results: 1) Wildland fires in boreal regions: In 2002, many large-scale forest fires occurred near Yakutsk, the capital of the Sakha Republic in Siberia, burning a total area estimated at >23,000 km^2. In 2004 and 2005, many large-scale forest fires occurred in Alaska. The total burned area in 2004 and 2005 was 26,000 and 19,000 km^2, respectively. Precise analysis of forest fires and weather data clearly shows that key indicators are precipitation in June for Sakha and temperature in June for Alaska. Drought in August led to fatal fires in both regions. 2) Wildland fires in tropical regions: Peat fires in Kalimantan and Sumatra, Indonesia, have become very widespread, especially since 2002, and are no longer El Niño events. To clarify this recent incendiary trend, we mainly focused on fire trends in the Mega Rice Project area in Central Kalimantan. Analysis results using sea surface temperature (SST) data clearly showed that there is a strong relationship between fire occurrence and positive values of SST anomalies even in non–El Niño years. 3) Wildland fires in forest and steppe regions: In Mongolia, fires have become prevalent since the 1990s. The worst fires during the seven years (2001–2007) occurred in 2002 when the annual number of hot spots totaled 7,295 and many fires occurred under long-term drought. Analytical results using hot-spot and weather data indicate that higher temperature and lower precipitation in summer cause large wildland fires.

Conclusions: We showed that wildland fires in four different regions apparently have increased as a result of climate change. Important weather factors influencing fire activity for four different geographic areas were temperature in June for Alaska, precipitation in June for Sakha, and precipitation in August and September for Kalimantan and Mongolia. Except in Alaska, the main factor was precipitation. This implies that more attention should be paid to the occurrence of drought due to El Niño and regional weather anomalies under rapid climate change. In Alaska, lightning activity is an important factor for forest fire ignition. But precipitation in August, not only for Alaska but also for Sakha, was the second most important weather factor influencing forest fire activities. Finally, more attention should be paid to recent weather changes due to rapid climate change.

We thank Randi Jandt (Alaska Fire Service) for assistance on this project.

keywords: boreal forest, effective humidity, El Niño, global warming, peat fire.

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INTERMODEL COMPARISON OF PROJECTED CLIMATE-INDUCED CHANGES IN EXTREME FIRE DANGER FOR THE NORTHERN ROCKIES

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ABSTRACT

Question: Given the full spectrum of global climate models from the Intergovernmental Panel on Climate Change Fourth Assessment report, what level of confidence is there of future changes in extreme fire danger for the Northern Rockies?

Background: Over the past three decades, the size and number of number of large wildfires have dramatically increased across the western United States. While increases in both the number of large fires and area burned have been linked in part to wildfire management, land-use changes, and data quality, mounting evidence suggests that observed changes in climate over the past half century have also played a contributing role.

Climate change influences wildfire regimes through the fuel and weather sides of the so-called "Fire Behavior Triangle" that identifies topography, fuels, and weather as the determinants of fire behavior. Prior assessments of climate change on the weather side of the fire behavior triangle have projected increases in fire danger and area burned in a doubled-CO_2 world.

A fundamental scientific gap in prior studies is reliance on a single or limited set of global climate models (GCMs) in projecting and modeling future fire danger and area burned. While GCMs simulating future climate in an enhanced greenhouse planet show a great deal of confidence with respect to global, or even regional, changes in temperatures, GCMs show a great deal of uncertainty with respect to other variables that are relevant in projecting future fire danger (e.g., relative humidity and precipitation). Projections of future fire danger using the output of a single GCM provide a single depiction of change; however, projections of future fire danger using the output of all available GCMs provide fire management with a much richer depiction of projected change. The upshot of an intermodel comparison study is to provide decision makers with an envelope of projected changes. A first effort is presented here to assess how the frequency of extreme fire danger over the Northern Rockies is projected to change over the 21st century using 15 GCMs.

Location: The study area encompasses the Northern Rockies Geographic Area Coordinate Center with a detailed analysis for Yellowstone National Park (NP).

Methods: Monthly climate change output from 15 GCMs forced with the SRES-A1B emission scenario are combined with 32-km observed weather streams from the National Centers for Environmental Prediction's North American Regional Reanalysis using inverse distance weighting to create future weather streams. Both observed and future weather streams are ingested into the National Fire Danger Rating System using fuel model G. Observed and future fire danger are quantified through the Energy Release Component (ERC), a hybrid climate–weather metric that is not as reliant on using direct daily weather fields from GCMs.

Results: This intermodel comparison study examines how climate change is expected to alter extreme fire danger frequency (EFD) across the Northern Rockies, as quantified by the observed 97th percentile ERC value, as much of area burned occurs during such conditions (e.g., the 1988 fires in Yellowstone NP). The multimodel ensemble mean (MMEM), thought to simulate projected changes in future climate better than any single model, shows pronounced increases in the annual frequency of EFD over the region by the late 21st century. Results indicate that climate change may double the likelihood of experiencing the extended duration of EFD as was experienced during the summer of 1988.

Changes in EFD frequency show considerable spatial differences across the Northern Rockies. Across much of North Dakota and western Montana–Idaho panhandle, the MMEM projects increases in EFD frequency (>60%), with a majority of individual GCMs confirming significant increases. However, results show a great deal of uncertainty in eastern Montana, reflecting large intermodel variability of projected changes in precipitation and relative humidity.

For Yellowstone NP, the MMEM projects EFD frequency to increase 75% by the late 21st century. However, the full intermodel comparison shows that a few GCMs indicate relatively little change (or even decreases), while others show increases in excess of 120%. The fallacy of relying on a single model is clearly shown in the substantial intermodel spread.

Conclusions: Intermodel comparisons are a necessary step forward in communicating projected changes in climate for impact assessment. While projections are shown to vary across models, in general, the models suggest an increase in EFD frequency over the 21st century. Results also demonstrate that the manifestation of climate change on fire danger varies spatially across the Northern Rockies. As demonstrated for Yellowstone NP, projections of changes in EFD vary dramatically among GCMs. However, by incorporating projections from multiple models we can begin to state potential changes with a level of confidence (e.g., 12 of the 15 models show increases exceeding 30%). Finally, analysis herein suggests that intermodel climate change projections be used jointly with site-specific weather, fuel (and projected changes in fuel types), and topographic information to make climate change projections relevant to fire management.

keywords: climate change, climate models, energy release component, fire danger, Northern Rockies, Yellowstone National Park.

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MODELING FIRE REGIMES UNDER CLIMATE CHANGE: FROM SOUTHEASTERN AUSTRALIA TO THE ROCKY MOUNTAINS

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ABSTRACT

Question: What will be the impact of climate change on fire interval and season in Glacier National Park, Montana?

Background: Most studies of climate change effects on fire regimes are conducted independently of other models and involve a single landscape fire model implemented on a single landscape. For example, predicted climate change (2°C increase in temperature, a small decrease in relative humidity, and precipitation that is unchanged but shifts toward early summer) resulted in the average interval between simulated fires decreasing from around 40 to 20 years in a FIRESCAPE model simulation of the Australian Capital Territory region, southeastern Australia. This increase in the probability of pixels burning, due to enhanced levels of drought in the model system, resulted in a greater likelihood of active fire when severe fire weather occurred. While important, these single-model studies generate results that are highly provincial and may be influenced by the design of the model.

Alternatively, multiple-model studies demonstrate the extent to which there is consensus, regarding modeled fire dynamics, among a range of individual models. An earlier model comparison of the sensitivity of simulated area burned to variation in climate, weather variability, terrain, and fuel pattern was conducted across five landscape fire models (EMBYR, FIRESCAPE, LAMOS-DS, LANDSUM, SEMLAND). Changes in climate (observed climate, warmer and wetter climate, warmer and drier climate) and weather variability were observed to be generally more important in explaining variation in area burned compared with terrain relief and fuel pattern.

This demonstrates that the climate change response in area burned is not necessarily model specific, and there is justification in applying models from one part of the world to other locations to generate hypotheses about the possible effects of climate change on area burned. Given this, we applied the Australian landscape fire model FIRESCAPE to Glacier National Park (NP) to explore the possible implications of climate change on fire interval and season of fire occurrence.

Location: Glacier National Park (lat 48°42′N, long 113°48′W), Montana, USA.

Methods: FIRESCAPE was implemented and calibrated for a 430,000-ha area of Glacier NP and surrounding vicinity. Predictions about likely climate change effects on fire regimes by 2050 were generated by introducing a 3°C increase in temperature and a 10% increase in precipitation by 2050. This was consistent with Hall and Fagre, who modeled glacier retreat and changes to vegetation distribution in the Blackfoot–Jackson Glacier Basin of Glacier NP in 2003.

Results: Simulations with the calibrated model using unchanged climate produced an average fire interval of 145 years across the study area and 170 years in the Lake McDonald catchment, which is within Barrett, Arno, and Key's estimate of 140–340 years. Shorter intervals were simulated for the North Fork Flathead Valley, also consistent with estimates for drier areas with gentler terrain. The climate change scenario resulted in an average fire interval of 85 years across the study area and a greater likelihood of fires in summer, with less fire in autumn. Areas likely to burn with an interval of <50 years were predicted to increase >10-fold, from 2 to 23% of the study area. Areas likely to burn at intervals of >200 years were predicted to decrease by around 70% from 13 to <4% of the study area. These predicted changes in fire interval and season resulted from the direct effect of changes in fire weather only. Hall and Fagre predicted that under global warming, considerable areas of glaciers would disappear and that herbaceous and forest vegetation would invade the formerly barren areas. These effects have not been included in the current modeling experiment and are likely to have further significant effects on fire regimes in Glacier NP.

Conclusions: Intervals between fires in Glacier NP are predicted to decrease with climate change, consistent with findings from similar studies in southeastern Australia. These findings, based on the FIRESCAPE fire regime simulation model originally developed for southeastern Australia, are not an artifact of model selection because FIRESCAPE has been shown to respond to changes in climate in a fashion similar to a range of other models. A predicted increase in the proportion of fires occurring in summer in Glacier NP is offset by a reduction in the proportion of fires occurring in autumn. The predicted changes in fire regimes has implications for park management, including aspects of vegetation and fauna dynamics, and fire management in general. Further studies incorporating the direct effects of climate change on vegetation distribution, which determines spatial patterns of fuel loads, would enhance confidence in the results presented here. The next phase of this work is to directly compare fire regimes generated by the Australian model and models specifically designed for the northern Rocky Mountains.

keywords: climate change, fire interval, fire modeling, fire regime, FIRESCAPE, fire season.

Citation: Cary, G.J., R.E. Keane, and M.D. Flannigan. 2009. Modeling fire regimes under climate change: from southeastern Australia to the Rocky Mountains [abstract]. Page 92 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA

IMPACT OF FIRE EMISSIONS FROM WILDLAND AND PRESCRIBED FIRES ON REGIONAL AIR QUALITY

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ABSTRACT

Question: How does forest Āre emission affect regional and local air quality?

Background: Emissions from forest Āres and prescribed Āres play an important role in regional and local air quality. Wildland Āres release large amounts of particulate matter (PM), carbon monoxide (CO), oxides of nitrogen (NO_x), and volatile organic carbon (VOC), which are the primary pollutants or precursors of ozone (O_3), one of the principal air pollutants. Proper characterizations of wildland Āres and forecasting their effects are crucial for decision makers and Āre managers, especially as related to state implementation plans and management of prescribed Āres.

In order to assess the impact of wildĀre, we used the Āfth-generation National Center for Atmospheric Research (NCAR) Penn State Mesoscale Model (MM5) and the Community Multiscale Air Quality (CMAQ) model, developed by the U.S. Environmental Protection Agency (EPA) for meteorology and chemistry simulations, respectively. The 2002 National Emissions Inventory (NEI2002) was used as the base emissions input. We also utilized the Hazard Mapping System (HMS) forest Āre data, archived by the National Environmental Satellite Data and Information Service and available by National Oceanic and Atmospheric Administration (NOAA)'s Air Resources Laboratory, to retrieve the detected forest Āre locations and burn times by various observatory satellites, such as Geostationary Operational Environmental Satellite, Moderate Resolution Imaging Spectroradiometer (MODIS, onboard Aqua and Terra), and the Advanced Very High Resolution Radiometer.

Comparisons with measurements were done using the Texas Commission on Environmental Quality Continuous Ambient Monitoring Stations data, EPA's Air Quality System (AQS) data, and the MODIS Aerosol Optional Depth (AOD) data.

Location: Contiguous United States (CONUS) for 36-km simulation; Texas region for 12-km simulation.

Methods: Fire emissions were estimated using the method developed by NOAA and NCAR. Emission rates for the trace species are functions of area burned, fuel loading, combustion efficiency, and the emission factors for different species. The Global Land Cover data set 2000, and the Fuel Characteristic ClassiĀcation System are used for the fuel loading and the land cover type. In vertical allocation, we assumed that 80% of emissions are well distributed within the planetary boundary layer and 20% goes up to 5 km.

Results: We performed CMAQ simulations in multi-domains, 36-km grid simulation in the CONUS, and 12-km grid simulation in the Texas region, during a 3-wk period (20 August–10 September 2006). In 36-km simulation, we have two notable changes in the northwestern and south-central United States due to the addition of forest Āre emissions. During the study period, many Āre events were detected in the states of Washington, Oregon, and Indiana. Surface measurements from the AQS and satellite measurements from the MODIS AOD also conĀrm increased PM in the nearby locations. The base simulation (without addition of forest Āre emissions) could not simulate enhanced PM. Although the NEI2002 already includes forest Āre emission as the yearly base, it was incapable of simulating daily variation of Āre emission inputs. By adding Āre emissions, we could simulate enhanced PM levels in the northwestern region. Fires in Texas, Louisiana, and Arkansas (1–4 September) were also shown to contribute to the continental haze, which affected PM concentration of eastern Texas and Louisiana. The 12-km simulations are used to study rural and urban differences and changes in the diurnal characteristics of the PM and ozone due to the Āre emissions impacts.

Conclusions: Using the CMAQ chemistry model, we have simulated enhanced PM variations, which could not be produced by basic emission inventory. The impact of additional Āre emissions on $PM_{2.5}$ concentration is direct and localized because $PM_{2.5}$ is largely determined by the primary inputs. On the other hand, the impact on ozone concentration is more complicated. The addition of Āre emissions increases both NO_x and VOC-related species. The impact on the NO_x change is clearly seen during the nighttime, especially in urban areas. Usually, there is a decrease of the ozone levels by titration, due to the NO_x emission. During the daytime, the addition of reactive VOCs enhances ozone formation, so the ozone levels increase signiĀcantly in the downwind areas of the Āres.

keywords: CMAQ, emission inventory, forest Āre, ozone, PM.

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EVALUATION OF THE BLUESKY SMOKE MODELING FRAMEWORK USING THE OCTOBER 2007 SOUTHERN CALIFORNIA WILDLAND FIRE EVENT

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ABSTRACT

Question: Does the BlueSky smoke modeling framework provide reliable information on the location and movement of smoke produced by wildfires?

Background: In October 2007, a series of wildfires broke out across southern California. These wildfires destroyed 1,500 homes, burned >500,000 forested acres, caused 9 deaths and 85 injuries, and forced >900,000 people to be evacuated. In addition to the direct threats wildfires create, secondary threats such as reduced visibility and increased air pollution also exist. In California at the height of the fire activity, 17 separate fires were burning, causing 10- and 2.5-micron particulate matter (PM) concentrations to reach and maintain unhealthy levels for several hours. Air quality and wildfire managers need to be able to make fast and accurate decisions about impending risks current fires and their accompanying smoke release may cause. Modeling of aerosol dispersion over the western United States is complicated by the mountainous terrain, which greatly affects the meteorology of the region. Further, the long-term effects of smoke are dependent upon the fire environment and the fire's characteristics, increasing the complexity of modeling smoke dispersion. In early 2000, the USDA Forest Service AirFire team launched a modeling system, coined BlueSky, that integrates meteorology, emissions, dispersion, and trajectory models to predict smoke trajectories and ground concentrations from wildland fires. Results from previous evaluation efforts show that while BlueSky can predict smoke trajectories and the timing of smoke impacts reasonably well, predictions of ground concentrations are poor. This project presents evaluation results of the performance of the BlueSky modeling framework by applying the model to the October 2007 wildfire outbreaks. Spanning more than seven counties and the fires raging for >19 days, this case study is larger in spatial and time scales than any other previous case studies involving BlueSky. The availability of an extensive observational network within the region allowed for more detailed evaluation of both the modeled meteorological fields and ground PM concentrations.

Location: Southern California (lat 33°32′N, long 116°43′W), USA.

Methods: Meteorological inputs for BlueSky were produced using the Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model (MM5), initialized with both National Center for Environmental Prediction 40-km Eta and 32-km North American Regional Reanalysis (NARR) forecasts. Fire inputs were obtained from the SMARTFIRE network. Model hourly meteorological and PM concentrations were compared with observed values collected from the National Climatic Data Center (meteorological parameters) and the AIRNow ($PM_{2.5}$ concentrations) database. BlueSky imagery was compared with satellite imagery from both the MODIS Hazard Mapping System (HMS) and GOES Aerosol and Smoke Product (GASP) databases.

Results: Both meteorological simulations were able to predict the trend and day-to-day variation that occurred due to changes in synoptic conditions. MM5-NARR surface temperatures were slightly warmer than MM5-Eta, and both runs produced a smaller overall diurnal temperature range than what was actually observed. Both simulations tended to underpredict surface wind speeds, but the predicted wind directions agreed with the observed. Comparisons at upper levels indicated both model runs were able to capture the observed changes in wind directions with height. The predicted smoke plumes using both meteorological fields appeared to be in agreement with HMS satellite images, in both smoke plume shape and orientation. On days when the simulated smoke plume did not match the satellite images, upper-level observed and simulated wind directions were in disagreement. Comparisons between BlueSky and MODIS/GASP Aerosol Optical Depth images show BlueSky captures the peaks and locations of large aerosol concentrations but tends to predict a smaller aerial coverage and spatial variation when compared to the satellite observations. A natural variability of about $\pm 10\ \mu g\ m^{-3}$ was apparent in the observed $PM_{2.5}$ concentrations. The timing and magnitude of BlueSky-predicted increases in surface $PM_{2.5}$ concentrations were comparable to the observations when BlueSky did predict an increase. However, BlueSky failed to capture all of the observed sudden increases in the $PM_{2.5}$ concentrations.

Conclusions: Overall, BlueSky proved to be a good tool for predicting long-range location of wildfire smoke plumes and their subsequent increases of surface $PM_{2.5}$ concentrations but had difficulty in predicting the overall magnitude of $PM_{2.5}$ increases. BlueSky was found to be sensitive to the input meteorology used, with slight differences in upper-level wind patterns creating larger differences in the predicted and observed smoke impacts. While improvements to the emissions model and fire characteristic inputs are necessary for accurate predictions of the magnitudes of smoke impacts, BlueSky is still a useful tool for obtaining the overall location, size, and path of a smoke plume and indicating the areas of possible large impacts. With this information, warnings can be issued to those regions within the smoke plume's path and cautionary steps can be taken to ensure the safety of the community.

keywords: BlueSky, California fire, model validation, smoke modeling, wildland fire.

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ASSESSING THE IMPACT OF FIRE MANAGEMENT ON BURNED AREA IN THE BOREAL FOREST UNDER CURRENT AND CHANGING CLIMATES

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We describe the development of a statistical model of the spatial variation in the area burned by forest fires across the province of Ontario, Canada. We partitioned Ontario's fire region into a number of compartments, each of which is relatively homogeneous with respect to its vegetation, weather, and fire management strategies and tactics. We then developed a linear regression model that relates the average annual area burned in a compartment to its vegetation, weather, and fire management attributes. This model was then coupled with climate projections to predict how burned area may vary as the climate warms and the extent to which changes in fire management strategies and tactics might mitigate the impact of climate change on burned area in Ontario.

SMOKE, EMISSION, AND FUEL LOAD MODELING IN NC COASTAL PLAIN FORESTS

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The management of prescribed and wildland fire on federal and state lands with deep organic soils pose critical challenges for ecosystem management, smoke dispersion, and the protection of private property and human life. Several regions in the United States contain significant areas of deep organic soils: the black and white spruce boreal forest of Alaska and the northeastern United States, the peat bogs in the glaciated Northeast and Great Lakes, and the pocosins in the southeastern and Gulf coasts. The USDA Forest Service BlueSky smoke prediction system and the BlueSky Rapid Access Information System were implemented for North Carolina for prescribed burns over a 3-year period. Pre- and post-burn below- and aboveground biomass was determined to estimate fuel consumption for fine and coarse woody material, shrub, herbs, litter, and duff, and assess fire effects on plant communities. Field data were collected to determine the relationships between meteorology, litter/duff moisture, and fire behavior in flaming and smoldering combustion stages. Smoke and photochemically/radiatively important trace gases during flaming and smoldering stages of prescribed burns were collected to estimate emission fluxes and validate BlueSky. Prescribed fire emission factors for $PM_{2.5}$ and PM_{10} were shown to be lower than values previously reported for open biomass burning studies.

CARBON FLUXES IN ECOSYSTEMS OF THE GREATER YELLOWSTONE AREA PREDICTED FROM REMOTE SENSING DATA AND SIMULATION MODELING

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A simulation model based on remote sensing data for spatial vegetation properties is being used to estimate ecosystem carbon fluxes across the Greater Yellowstone Area (GYA). The model, called CASA (Carnegie Ames Stanford Approach), applied at a regional level across the GYA can estimate seasonal and annual carbon fluxes as net primary production and soil respiration components. Predicted net ecosystem production flux of CO_2 is estimated from the model for carbon sinks and sources over multiyear periods that vary in climate and disturbance histories. Long-term storage of carbon in biomass pools (vegetation and soils) of all ecosystems is also predicted by the NASA-CASA model. Enhanced Vegetation Index (EVI) image coverages from the NASA Moderate Resolution Imaging Spectroradiometer instrument (2000 to the present) are direct inputs to the NASA-CASA model. EVI represents an optimized vegetation index, whereby the red and near-infrared spectral bands are designed to approximate sunlight capture relationships by vegetated cover types. Initial modeling results will be presented on the capacity of the NASA-CASA model to predict seasonal uptake rates of CO_2 in unburned forests, shrublands, and grasslands of the GYA. New approaches will be presented for adding airborne remote sensing data products and dynamic carbon simulations for areas burned by wildfires over the past several decades in the GYA.

THE EFFECTS OF ELEVATED CO_2 ON FIRE BEHAVIOR: IMPLICATIONS FOR FIRES OF THE FUTURE

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The effect of global climate change on fire regimes has received increasing attention. No work to date, however, has evaluated the potential for changes in fuel particles and fuel beds to changes in response to elevated atmospheric CO_2. We investigated the effects of elevated CO_2 (ambient + 200 ppm and ambient + 300 ppm) on fire behavior and fuel loading in two field studies in southeastern U.S. pine forests. To assess changes in fire behavior, we burned litter samples of three dominant tree species: *Pinus palustris*, *P. taeda*, and *Quercus margaretta*. In a combustion chamber, we measured percent combusted, maximum flame height, flame time, ember time, total burn time, and mean weight loss rate. There were changes in fire behavior between elevated and ambient CO_2 concentrations. Maximum flame height was significantly greater ($P = 0.098$) for *P. taeda* litter. Smoldering time was longer for *Q. margaretta* and *P. palustris* and reduced for *P. taeda*. At one site (Duke FACTS-1) dominated by *P. taeda*, we measured surface fuel loads subjected to 11 years of elevated CO_2. Litter, woody 1-hour, and 10-hour fuel loading increased in stands by 11, 22, and 24% respectively. When changes in fuel load and fuel particles are combined, fire behavior changes. Flame height, flame time, and smoldering time all changed significantly when fuel loads were modified to meet field fuel mass values observed at site FACTS-1. Future work will focus on elucidating the mechanisms for changed fuel properties to facilitate our understanding of future fires.

SMOKE TRAINING AND CHANGING REGULATIONS—AN UPDATE FROM THE FIRE AIR COORDINATION TEAM (FACT)

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Fire has the greatest potential to affect human health of any other source on public and private lands. Changes in air quality regulations are changing the way the fire programs operate and will affect how land management objectives are met. Tightening of air quality standards to protect public health will result in more non-attainment areas across the United States (all regions). Current approaches to smoke management and prescribed fire have resulted in local and interstate exceedances of existing public health standards. A clear understanding of these issues and changes will be important to minimizing future impacts. The Fire Air Coordination Team (FACT) has been developing training for line officers and fire management staff. Online training for line officers consists of a half-hour overview of regulation changes with more in-depth modules on key topics. Training to help fire managers meet potential challenges on a national scale with state-level implementation, using a proactive approach, ensuring timely decisions and greater efficiency, all in the interest of public and ecosystem health, is critical for the success of fire programs. Training for fire staff emphasizes creating or rejuvenating state-level smoke coordination groups. By creating and participating in state-level groups, the specialized staff can represent agency policy with respect to the Clean Air Act and implementing regulations, the ecological need for fire, the trade-offs between wildfire and prescribed fire emissions, and potential basic smoke management practices. Because federal air quality standards are implemented by state, tribal, or local regulators, fire managers must work at these local/state levels. Federal activities are subject to the Clean Air Act as implemented by state, tribal, and local authorities.

FIRE HISTORY AT MULTI-CENTENNIAL TO MILLENIAL TIMESCALES

FIRE HISTORY AT MULTI-CENTENNIAL TO MILLENNIAL TIME SCALES: RELEVANCE TO FIRE ECOLOGY AND LAND MANAGEMENT IN A CHANGING WORLD

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Area burned in boreal forests is projected to increase with climatic warming over the next century. This projection is based upon observational data of the past several decades showing that fire occurrence is controlled primarily by mean summer temperatures and precipitation. However, the climate–fire–vegetation relationships during this period may not capture the range of variability that has occurred over longer time periods and that may occur in the future. We conducted paleoecological analyses and computer simulations to assess Holocene fire-regime responses to vegetation and climatic variations in Alaskan boreal ecosystems. Most of our data are from two regions: the south-central Brooks Range (BR) and the Copper River basin (CRB). Consistent with historical data, fire frequency has been substantially higher in BR than in CRB since ca. 7,000 bp (years before present). Both regions experienced a steady increase in fire frequency during the middle Holocene. In BR, mean fire-return intervals (FRIs) reached a sustained low of approximately 125 years between 2,000 and 3,000 bp and then increased over the past 2,000 years. In CRB, FRIs were at minimal values of approximately 250 years/fire over the past 2,500 bp. Preliminary comparison of the CRB fire-frequency data with an independent summer-temperature reconstruction shows a generally inverse relationship. Statistical analyses of these fire records reveal little to no synchrony in fire occurrence across individual sites. Thus, fires were patchy throughout the Holocene, and local factors (e.g., firebreaks) may have exerted important controls over the spatial patterns of fire occurrence. A prominent feature in our paleoecological records is an increase in fire occurrence with the establishment of boreal forests dominated by *Picea mariana*; estimated FRIs decreased from approximately 300 years to as low as approximately 80 years at some sites. Computer simulations using ALFRESCO, a spatially explicit ecosystem model of boreal forests, were applied to evaluate alternative explanations that the mid-Holocene decrease in FRIs was caused by climatic change, changes in vegetation flammability, or a combination of climatic and vegetation effects. Results clearly indicate the overriding effects of vegetation, as none of the climate-alone scenarios resembled the paleorecords. Thus, species composition appears to have played a key role in modifying the impacts of Holocene climatic change on boreal forest fire regimes. Recent warming has led to vegetation changes across northern high latitudes. Our results imply that in these regions, vegetation variables may greatly alter the direct effects of climate. This possibility highlights the need for improved understanding of vegetation–climate–fire interactions in northern high latitudes.

AREA BURNED IN KOOTENAY NATIONAL PARK, BRITISH COLUMBIA, SINCE AD 1000

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High-resolution charcoal analysis of lake sediments and stand age information were used to reconstruct a 1,000-year fire history around Dog Lake in Kootenay National Park, which is located in the montane spruce zone of southeastern British Columbia, Canada. Macroscopic charcoal (>125 µm) accumulation rates (CHAR) from lake sediment were compared with a modern stand-origin map and fire-scar dates in the Kootenay Valley to determine the relative area and proximity of fires recorded as CHAR peaks. This information reinforces previous findings where CHAR peaks represent a complex spatial aggregation of local to extra-local fires around a lake site. CHAR peaks indicate frequent stand-destroying fires during the Medieval Warm Period (ca. ad 1000–1300), and other large fires at ad 1360, 1500, 1610, and 1800. Fire return interval reconstructions show a continuously changing crown fire regime in this montane valley. The 2003 fire season seemed to reset the formally stalled area-burned statistics for Kootenay National Park and suggests that paleo-fire records can help managers better predict large infrequent disturbances with a comprehensive distribution of charcoal sites.

MULTI-SEASON CLIMATE-SYNCHRONIZED WIDESPREAD FIRES (1650–2003) ACROSS THE U.S. NORTHERN ROCKIES

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Predicting the climate drivers of regional-fire years (e.g., 1910, 1919, 1988, and 2000) is ecologically and socially important because fire in such years affects ecosystem dynamics regionally, and fire's threat to people and property is highest when fires are synchronous and widespread. We inferred the climate drivers of years with regionally synchronous forest fires in Idaho and western Montana, both in the past (1650–1900, from tree rings) and the present (1900–2003, from digital polygon fire atlases). We reconstructed past fires in dry forests from 9,245 crossdated fire scars on 576 trees (mostly ponderosa pine) at 21 sites and identified 32 past regional-fire years as those with ~5 sites with fire. We derived annual fire extent across all forest types from a digital polygon fire atlas we developed from 5,038 fire polygons recorded from 12,070,086 ha, or 71% of the forested land in Idaho and western Montana. The 11 regional-fire years we identified, i.e., those exceeding the 90th percentile in annual fire extent from 1900 to 2003 (>102,314 ha or ~1% of the fire atlas recording area), were concentrated early and late in the century (six from 1900 to 1934 and five from 1988 to 2003). We compared past fires to existing tree-ring reconstructions of climate (temperature and the Palmer Drought Severity Index) and large-scale climate patterns that affect modern spring climate in this region (El Niño–Southern Oscillation [ENSO] and the Pacific Decadal Oscillation [PDO]). We compared modern fires to instrumental records of climate (temperature and precipitation), ENSO and PDO. During regional-fire years from 1650 to 2003, spring–summers were significantly warm and summers were significantly warm–dry. Climate in prior years was not significantly associated with regional-fire years. ENSO was not a significant driver of regional-fire years either in the past or the present, consistent with the relatively weak influence of ENSO on spring climate in this region. PDO was not a significant driver of past regional-fire years, despite being a strong driver of modern spring climate and modern regional-fire years in the U.S. Northern Rockies. Climate continues to be a major driver of widespread, synchronous fires in this region despite intensive fire suppression, logging, domestic livestock grazing, and other land uses. Although we cannot identify their relative contributions with our data, climatic variability, fire suppression, and land use likely all played a role in regional fire activity in the past and will continue to do so in the future.

TUNDRA FIRE REGIMES IN THE NOATAK NATIONAL PRESERVE, NORTHWESTERN ALASKA, SINCE 6000 BP

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Fire and fuels management initiatives in Alaska are hindered by a limited understanding of fire history and the controls of fire regimes. This is especially true for tundra ecosystems that cover nearly one-third of the state. More than 4.1 million acres of Alaskan tundra have burned over the past 50 years, indicating the highly flammable nature of these ecosystems under warm and dry conditions. Land managers working within the tundra face decisions on fuels management, suppression tactics, and pre-suppression staffing. However, these decisions are currently made in the absence of long-term fire history records and limited empirical knowledge on the relationships between fire, climate, and vegetation. Current and future climatic change also challenge land managers as they consider the impacts of increasing temperatures on tundra fire regimes and the potential cascading effects on other ecosystem processes. We are utilizing macroscopic charcoal from lake-sediment cores to characterize the frequency component of fire regimes in shrub-dominated and herb-dominated tundra ecosystems in northwestern Alaska over the past 6000 years. Fire-history records will provide context for resource management and serve to refine the tundra component of an ecosystem model designed to aid Alaskan land managers in assessing fuels and fire hazards. We present the first long-term records of fire history in the Alaskan tundra from lakes in the Noatak National Preserve, a region encompassing some of the most flammable tundra in Alaska. Preliminary results from one lake indicate that fire has been a consistent process in tundra ecosystems, with fire return intervals (FRIs) ranging from 40 to 500+ years over the past 6000 years. This record also suggests significant changes in historic FRIs at millennial time scales, likely related to climatic changes in the region. For example, from 1500 bp to present FRIs averaged 260 years (SD 170), while FRIs from 6000 to 4500 bp, a period of lower effective moisture and higher summer temperatures, averaged 120 (SD 81) years. In addition to providing some of the first estimates of long-term fire occurrence in modern tundra ecosystems, our results indicate that tundra fire regimes are sensitive to past, and by inference, future climate change.

MILLENNIAL-SCALE CHANGES IN BIOMASS BURNING: INSIGHTS FROM CHARCOAL RECORDS

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Rapidly changing Āre regimes are having dramatic consequences on people, ecosystems, and the global climate system. Fire-history research provides critical long-term context for these changes. It can also help us answer important questions about their nature: How unusual are the current levels of Āre activity? Are they unprecedented in the historic and prehistoric records? If similar changes occurred in the past, where, when, and why did they occur? This study uses Āre-history records based on charcoal data along with pollen-based records of vegetation change to analyze patterns of biomass burning on millennial time scales. Climatic changes on this time scale exceed those of the past several centuries, and therefore provide a long-term context in which potential future climate changes, and the response of Āre to them, can be placed. We examine gradual trends in climate, vegetation, and Āre as well as extreme Āre events in charcoal records that describe the response of biomass burning and of individual Āres to 1) the abrupt climate changes that occurred during the last deglaciation; 2) regional-scale patterns of Holocene drought in North America; and 3) centennial-scale variations and abrupt changes of climate during the past two millennia, both globally and in North America. For example, widespread increases in Āre activity occurred in response to the abrupt climate changes associated with both the beginning and end of the Younger Dryas interval, at 12.9 and 11.6 calendar years ago. Furthermore, the largest swings in Āre activity during the past 2,000 years have been caused by human alteration of vegetation (fuels) and Āre regimes since ad 1800. Ou r results reveal a tight coupling between climate change, vegetation change, and biomass burning on multiple spatial and temporal scales, although the mechanisms by which climate and vegetation changes drive Āre activity are varied and complex.

TWO MILLENNIA OF VEGETATION AND BIOGEOCHEMICAL RESPONSES TO CLIMATE CHANGE AND DISTURBANCE IN A COLORADO WATERSHED

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Climate changes in the western United States are causing drought-induced forest dieback and frequent stand-replacing Āres. These changes are likely to have important consequences for ecosystem services such as clean water and carbon storage, but the long-term ecosystem consequences are unclear. Paleoecological studies demonstrate the responsiveness of ecosystem composition to both climate and disturbance, but new studies are needed to demonstrate how climate and disturbance interact to jointly reorganize ecosystem structure and function. Here, we present a novel lake sediment record of climate, disturbance, vegetation composition, and biogeochemical Èuxes from a single watershed in Colorado over the past 2,000 years. The record tracks successional dynamics in a 94-ha watershed of lodgepole pine (*Pinus contorta* var. *latifolia*) forest at the edge of a >2,600-km^2 intra-montane steppe, and shows responses to repeated stand-replacing Āres in the context of long-term moisture trends. Like recent decades, dry periods during the past are associated with frequent severe Āres. Elemental Èuxes after the Āres are consistent with biomass-related Èuxes documented by watershed manipulations and chronosequences. The Èuxes show that aridity-induced Āre regimes signiÃcantly altered the patterns of biomass accumulation by favoring large, young (<125 years) forest stands. The Āres also led to episodes of lake eutrophication under certain climate regimes. Paradoxically, the forest–steppe ecotone shifted during only one of two dry periods, possibly because a reduction in Āre severity between ad 950 and 1260 i ncreased forest pathogen populations and thus encouraged forest dieback during a multi-century drought and severe Āre episode from ad 1260 to 1495.

EXAMINING HUMAN–FIRE LINKAGES DURING THE LAST MILLENNIUM ON NEW ZEALAND'S SOUTH ISLAND

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Late-Holocene pollen records from South Island, New Zealand, provide evidence that the arrival of the Maori (700–800 calendar years ago) dramatically altered the landscape. Forests of podocarp and beech were abruptly converted to shrub and grasslands over 50% of the island. This transformation has largely been attributed to Maori use of Āre, yet the duration and pattern of burning and the environmental consequences resulting from this burning are still poorly understood. High-resolution charcoal and pollen analyses were conducted on sediment cores from Āve lakes on the eastern side of the Southern Alps to document the Āre history of the last 1,000 years and the response of vegetation and watersheds to burning. Data indicate that initially one to three high-severity crown Āres occurred within a few decades and these "events" resulted in the majority of forest loss and erosion. Bracken fern was then maintained through frequent, low-severity surface Āres at some sites. Changes in sedimentation rates, soil chemistry, and magnetic susceptibility accompanied this period, suggesting that Āres and deforestation shortly after Maori arrival led to substantial changes to watershed vegetation, soil, and biochemistry. Fire activity increased again with European settlement. Understanding the Āne-scale structure and timing of burning and consequent vegetation response is providing important new information on the rates and mechanisms of deforestation through the use of Āre, the natural resilience of mesophytic forest to the introduction of a new disturbance, and perhaps a better understanding of Polynesian motivation for what initial data suggest was widespread, intensive, and repeated burning.

RECONSTRUCTING THE LAST 1,000 YEARS OF FIRE HISTORY IN THE WILLAMETTE VALLEY OF OREGON AND WASHINGTON USING HIGH-RESOLUTION MACROSCOPIC CHARCOAL AND POLLEN ANALYSIS

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Fire is a natural and necessary component of the ecosystems in the Willamette Valley of northwest Oregon and southwest Washington. However, the role Āre played in creating and maintaining the vegetation patterns of the valley prior to Euro-American settlement (ca. ad 1850) is poorly understood. Over the past 150 years, the vegetation of the valley has changed dramatically. As described by early explorers and land surveys, presettlement vegetation was dominated by wet prairie and oak savannah, but today very little of those ecosystems remain. Although much of the landscape alteration was a result of direct land conversion, the vegetation has also been greatly altered by the elimination of Āre. In the absence of regular burning, either by lightning or human-set Āres, open plant communities have converted to riparian woodlands and closed oak or oak–conifer forests. Management of the Willamette Valley's ecosystems, especially in light of rapid population growth and human development of the wildland–urban interface, requires information on Āre history. Knowledge of historical Āre activity (e.g., frequency and severity) can contribute to management strategies that use prescribed burning to recreate native vegetation and open up areas that are becoming densely forested, as well as enable more informed and knowledgeable management decisions regarding wildĀre threats and other wildland–urban interface hazards. In this study, we reconstructed the last ~1,000 years of Āre and vegetation history in the Willamette Valley based on high-resolution macroscopic charcoal and pollen analysis of lake sediments from Āve study sites. These records have been evaluated and compared with local tree-ring records, regional climate records, and local and regional archaeological–cultural records in order to assess the role that both climate variability and human activities had in creating the valley's prehistoric Āre regimes. Our results show that changes in Āre activity occurred in response to centennial-scale climatic variations (e.g., the Medieval Climate Anomaly and the Little Ice Age), as well as major anthropogenic shifts in the valley (e.g., Native American population decline, Euro-American settlement, and 20th-century Āre suppression), but the patterns vary both spatial and temporally. It is our hope that the information provided by this study will aid future management decisions regarding the Willamette Valley's ecosystems.

TETON INTERAGENCY FIRE: A MODEL FOR INTERAGENCY COOPERATION

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ABSTRACT

Question: How do agencies and counties cooperate in the area surrounding Grand Teton National Park?

Background: Teton Interagency Fire is a true example of interagency cooperation, from shared firefighting resources to administrative-level decisions. While Grand Teton National Park and the Bridger-Teton National Forest are the primary federal agencies involved, the interagency cooperation extends to the National Elk Refuge and Teton, Lincoln, and Sublette counties.

Location: Grand Teton National Park and Bridger-Teton National Forest, covering Teton, Lincoln, and Sublette counties (centered on approximately lat 43°40′N, long 110°50′W), in northwest Wyoming, USA.

Methods: Agencies coordinate through frequent meetings, combined training, and planning.

Results: Park and Forest resources coordinate initial attack by responding to fires regardless of land ownership to ensure the most cost-effective and -efficient action. Shared resources include engines, helicopters, fuels management crew, fire effects crew, and fire-use monitors. These resources are funded by both agencies and Jackson Hole Fire & EMS and are often staffed by interagency personnel. Funding for two Type III helicopter rappel modules provides an integral part of fire management. The partnership has broken new ground through management consolidation and shared fire-related positions, including an interagency fire planner, GIS coordinator, fuels management specialist, and fire education and information specialist. Coordinated interagency fire management planning is ongoing with the goal of making objectives more compatible across agency boundaries. This cooperative planning allows agencies to manage fires and resources more efficiently, plan and monitor fire activity more effectively, and study the effects of fires through a monitoring team. Teton Interagency Fire formed a working relationship with the Wyoming Fire Action Team to prioritize, fund, and complete fuels reduction projects for urban interface communities. The Teton Interagency Dispatch Center is managed jointly by the Forest and Park, dispatching law enforcement, and fire incidents for the two agencies.

Conclusions: While the Bridger-Teton National Forest and Grand Teton National Park primarily comprise Teton Interagency Fire, the agencies work closely with fire departments from Teton, Lincoln, and Sublette counties, Wyoming State Forestry, Wyoming Game and Fish, and the National Elk Refuge.

keywords: cooperation, fire effects, fire management, fuels reduction, interagency, shared resources, wildland fire.

Citation: Elenz, L., R. Dykehouse, R. Palmer, and T. Weaver. 2009. Teton Interagency Fire: a model for interagency cooperation [abstract]. Page 101 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

GREATER YELLOWSTONE AREA FIRE MANAGEMENT: YESTERDAY, TODAY, AND TOMORROW

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ABSTRACT

Question: How did fire management in the Greater Yellowstone Area evolve during and as a result of the 1988 fires?

Background: This panel discussion will provide the history of the Greater Yellowstone Area (GYA) Fire Management. Dialogue will include coordination prior to the 1988 fires, personal perspectives during the fires, the development of the Fire Management Advisory Group (FMAG), and a lead-in to today's management. Since their establishment, national forests, refuges, and parks have operated under different management mandates. In the 1960s, national forest and park managers in the GYA recognized the need to coordinate issues and programs that crossed jurisdictional boundaries. This prompted agency administrators to establish the Greater Yellowstone Coordinating Committee (GYCC) in 1964, which includes the Beaverhead-Deerlodge, Custer, Gallatin, Shoshone, Caribou-Targhee, and Bridger-Teton national forests, and Grand Teton, John D. Rockefeller, Jr. Memorial Parkway, and Yellowstone national parks. In 1999 Red Rock Lakes and the National Elk Refuge also joined. One FMAG member serves as a liaison with the GYCC.

Fire has been a major force in shaping soil, physiographic, vegetation, and wildlife distribution patterns with much of the area affected by large and widespread fires. In 1988 the GYA experienced large, fast-moving fires never seen before in the post-European settlement history of the area. The 1988 fire season led to a nationwide debate about fire management policy on federal lands and about National Park Service and Forest Service policy, which allowed some fires to burn as prescribed natural fires. Debate included discussion on conflicting agency mandates and coordination among the GYA. In September 1988 the Secretaries of Agriculture and Interior appointed a Fire Management Policy Review Team, which ultimately provided 15 recommendations for improving federal fire management programs, which the Secretaries approved. They serve as the framework for the GYA Interagency Fire Management Planning and Coordination Guide.

Location: The Greater Yellowstone Area (centered on approximately lat 44°47′N, long 109°4′W), Wyoming, USA, which includes parts of six national forests, two national wildlife refuges, and two national parks. Contiguous portions of these lands encompass roughly 14.0 million acres.

Methods: The panel includes Phil Perkins, retired Fire Management Officer for Yellowstone National Park; Bill Breedlove, former Fire Management Officer for Gallatin National Forest; John Chapman, retired Forest Fire Management Officer for Bridger-Teton National Forest; and Keith Birch, former Forest Fire Management Officer for the Caribou-Targhee National Forest. They will discuss their first-hand experiences, expectations, policies, decision factors, mobilization challenges, and other issues from 1988.

Results and Conclusions: Previous and current Fire Management Officer perspectives demonstrate how fire management has evolved with policy changes, new technology, coordination, and cooperation. The 1988 fires prompted policy and local changes that have led to a more cohesive interagency partnership and management of fire in the GYA today.

keywords: cooperation, coordination, fire management, fire policy, GYA, interagency, partnerships.

Citation: Gagen, M., J. Krish, and T. Weaver. 2009. Greater Yellowstone Area fire management: yesterday, today, and tomorrow [abstract]. Page 102 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

FIRE MANAGEMENT PROGRAMS TODAY AND TOMORROW IN THE GYA

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ABSTRACT

Question: How have Āre management programs evolved over the last 20 years in the Greater Yellowstone Area?

Background: The national forests, refuges, and parks were established with different management mandates; consequently, in the 1960s, managers recognized the need to coordinate issues and programs that crossed jurisdictional boundaries.

Following the 1988 Āres, the Greater Yellowstone Coordinating Committee created the Fire Management Advisory Group (FMAG), which includes representatives from all of the agencies within the Greater Yellowstone Area (GYA). The FMAG coordinates Āre management planning, provides for speciĀc operating principles and procedures, and articulates the role of national forest, refuge, and park managers in Āre management. The FMAG also developed the "Green Book," which includes guidance on Āre management throughout the area. The FMAG meets biannually and maintains a conference call schedule throughout the season to share intelligence and coordinate resources and public information. Public outreach and education efforts by the FMAG have led to a greater understanding and support by the public in the GYA.

Location: The Greater Yellowstone Area (centered on approximately lat 44°47′N, long 109°4′W), Wyoming, USA, which includes parts of six national forests, two national wildlife refuges, and two national parks. This area encompasses 14.0 million acres in Wyoming, Idaho, and Montana.

Methods: The FMAG has the ability to easily share resources not only on wildland Āres but on a variety of projects, including prescribed Āres and fuels reduction. Data sharing includes Āre-severity mapping and Āre effects monitoring results. The efforts have culminated in the annual Teton Interagency Fire Effects Symposium, which has evolved to include research throughout the GYA.

Results: Long-term planning and strategies are being reĀned to ensure agency interests are considered in advance. Creation of a continuous fuels layer to model Āres in areas of concern or Āre starts is underway. As policy and implementation strategies change, this coordination and preplanning is imperative to the success of managing Āres on the landscape.

Conclusions: It is important for all agencies in the GYA to work together to accomplish similar goals and projects to beneĀt the area's wildlife and plant communities. By sharing information and resources by working together, the agencies will be more productive and more successful in managing Āres on the landscape.

keywords: Āre, Fire Management Advisory Group, Green Book, Greater Yellowstone Area, GYA, interagency, management, wildĀres.

Citation: Norman, A., L. Elenz, and T. Weaver. 2009. Fire management programs today and tomorrow in the GYA [abstract]. Page 103 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

FIRE MANAGEMENT "DOWN UNDER": INCORPORATING ECOLOGY INTO FIRE MANAGEMENT IN NSW, AUSTRALIA

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ABSTRACT

Question: How can ecological fire science be incorporated into fire management and planning across multiple land tenures?

Background: Most of the natural ecosystems in southeastern Australia are fire prone, and the vegetation of the rugged east coast and ranges surrounding the cities of Sydney, Canberra, and Melbourne is particularly flammable. The wildland–urban interface in these regions is extensive and growing, with large numbers of people and assets. These ecosystems are also diverse and have high levels of endemism, so fire management in natural areas needs to take into account the needs of many species and vegetation communities with a broad range of fire regime requirements.

Historic fire frequency information is unavailable for most places in New South Wales (NSW), and Australia, because 1) the lack of strongly pronounced summer–winter temperature and rainfall differences mean that tree growth is highly variable and that dendrochronology is unreliable; and 2) the aridity of the continent means that sedimentary records are unavailable in most places at appropriate spatial and temporal scales to reconstruct historic fire regimes.

Location: The state of New South Wales (lat 28–37°S, long 141–153°E), southeastern Australia.

Methods: This paper describes four key aspects of fire management in NSW: 1) use of fire frequency thresholds for biodiversity conservation; 2) zoning to prioritize for different fire management objectives in different parts of the landscape; 3) routine interagency collaboration in fire planning and firefighting; and 4) use of a risk management framework to prioritize actions and determine responses.

Results: A plant fire response spreadsheet was compiled with entries for >2,700 plant species in NSW, using the functional response types of Noble and Slatyer (1980. Vegetatio 43:2–21) and Noble and Gitay (1996. J. Veg. Sci. 7:329–336), including their identification of groups particularly vulnerable to high-frequency fire (slow-maturing serotinous obligate seeders) and low-frequency fire (short-lived species with fire-cued seed germination or flowering). From this spreadsheet, species lists were assembled for each of the 14 broad vegetation types in NSW. For each vegetation type, we generated a suggested lower interval (i.e., most frequent fire) based on the time needed by the slowest maturing obligate seeding species and an upper interval (i.e., least frequent fire) based on the longevity of the shortest lived species that depends on fire to regenerate. This information was (and is) applied in NSW national parks using a GIS to compare the guidelines against actual frequencies derived from routine fire mapping. Park managers then exclude fires or introduce fire as necessary (as modified by additional considerations) to maintain at least 50% of each vegetation type within these suggested intervals.

Because protection of human life and property and reducing fuel loads have to take precedence in certain parts of the landscape (e.g., around built areas), which generally requires a higher fire frequency than is appropriate for biodiversity conservation, a zoning approach is implemented. Areas are mapped as either an Asset Protection, Strategic Fire Advantage, Land Management, or Fire Exclusion Zone, and appropriate fire and fuel management implemented accordingly.

Routine interagency fire planning is carried out by Bush Fire Management Committees (BFMCs), as required by NSW legislation (Rural Fires Act 1997) for all local government areas in NSW that have a risk of wildfires. BFMCs comprise a representative from each of the agencies and organizations with land or authority relating to land management in the area, representatives for the rural landholders, conservation interests. local volunteer firefighters, the Local Aboriginal Land Council, and any other interested party. Each BFMC compiles and implements a Bush Fire Risk Management Plan that covers all land tenures.

Because it is not possible to carry out all the actions necessary to protect all assets from all fires, and—even if it were—the costs involved may far outweigh the likelihood or severity of the risk, NSW has adapted the Australian Risk Management Standard (AS/NZS 4360:1999, Risk Manag. Stand. Assoc. of Australia, Sydney) as a framework to manage bushfire risk across all land tenures. This involves: 1) identifying the assets, their location, and importance; 2) identifying the risks to these assets; 3) analyzing the risks to each asset, in terms of the likelihood of the event and its consequences or seriousness; 4) evaluating and comparing the level of risks between assets and ranking them; and 5) treating the risks for those assets where the level of risk is considered unacceptably high.

Conclusions: NSW has high levels of diversity, endemism, and sensitivity to fire frequency among its plants. It is also fire prone and has highly flammable vegetation adjacent to highly populated urban areas, and a large area of wildland–urban interface. These potentially conflicting needs are integrated and resolved by the use of biodiversity thresholds, zoning, cooperative interagency planning, and an agreed risk management framework, making NSW a world leader in ecologically sustainable wildland fire management.

keywords: biodiversity thresholds, ecological fire planning, fire frequency guidelines, fire management, floristic composition, life-history attributes.

Citation: Tasker, E.M. 2009. Fire management "Down Under": incorporating ecology into fire management in NSW, Australia [abstract]. Page 104 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

MANAGING FIRE WITH FIRE IN CANADA'S NATIONAL PARKS—THE KOOTENAY COMPLEX 2003

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ABSTRACT

Question: This paper utilized events of the 2003 Kootenay Complex wildfires to illustrate Parks Canada Agency fire management policy and practice related to firing operations to meet fire management objectives.

Background: The events of the summer of 2003 were significant in the history of wildland fire in western Canada. A period of prolonged fire danger coupled with ignition resulted in several high-profile fires in southern British Columbia and Alberta.

The fire season of 2003 was arguably the most significant fire season in Canadian National Parks history. While the 152,000 ha burned in the Canadian National Park system was not the most area burned in a single season, it was the first time the organization had managed multiple fires that threatened significant values-at-risk. In August 2003, large wildland fires were ongoing in Jasper, Banff, Wood Buffalo, and Kootenay national parks. Many other national parks had elevated fire danger and several smaller fires with serious potential were managed during this same time frame.

This presentation explored the 6 weeks of the Kootenay Complex Fire and presented the backdrop to the fire scenario. We then focused on the operational aspects of the Kootenay Complex that primarily comprised two wildfires that eventually merged. Values-at-risk that were threatened included a roadside bungalow camp, a major inter-provincial highway, several park facilities and, indirectly, major values in the adjacent Bow Valley. We examined the extensive burning operations that were utilized to manage fire spread with an overriding objective of minimizing impact on values-at-risk. The operation included a large-scale burn out from a constructed heavy equipment line supported by a high-volume sprinkler system.

Parks Canada Agency policy dictates natural processes such as fire may be manipulated when there is a serious threat to facilities or public safety. When a process is manipulated, it is to be done so using techniques that mimic the natural process as closely as possible. This policy background has led fire managers to routinely utilize firing operations in fire management scenarios.

Location: Vermillion Valley, Kootenay National Park (lat 51°03′N, long 116°00′W), British Columbia, Canada.

Methods: A review of the Kootenay Complex was undertaken to ascertain the elements that enabled the successful management of this wildland fire. The challenges and issues that presented themselves during these operations will be highlighted. Parks Canada policy and program direction will be included in this discussion.

Results: Burning operations were carried out during the core period of the Kootenay Complex 1 August–1 September 2003. These operations were conducted with a variety of specific objectives but were all generally aimed at minimizing fire growth toward values-at-risk. Given observed fire behavior, options were very limited in terms of minimizing fire impact on values-at-risk. Due to the observed fire behavior, limited access, safety considerations, and ecological issues, burning operations were the primary holding option utilized. Aerial ignition operations were favored due to safety considerations and included aerial ignition device ignition and helitorch ignition. Burning operations were conducted utilizing limited personnel and logistics. Burning operations were often supported by follow-up suppression action primarily focused on helicopter bucketing.

It was evident early in the operation that fire behavior was going to challenge traditionally successful holding actions. Traditional anchoring features were not holding fires in August 2003. These observations and the nature of the two primary fires that comprised the Kootenay Complex led Incident Command Team personnel to consider developing an anchor well in advance of the established fire fronts. The Vermillion Containment Line consisted of dozer guard backed up by a high-volume sprinkler system and the strategic application of long-term retardant. The key elements of this anchor were established well in advance of the fire front.

Conclusions: Burning operations during the Kootenay Complex formed a critical tool that enabled Parks Canada Agency fire managers to minimize impacts to values-at-risk. Burning operations were conducted safely and efficiently. A key element to the success of the operation was the ability to stay ahead of the fire situation by establishing the Vermillion Containment Line well ahead of the established fire fronts. This action allowed the development of an effective anchor in a safe and efficient manner.

Although these indirect suppression efforts proved successful in this instance, this situation highlights the need for proactive fire management to limit the spread potential of future forest fires and adequately protect values-at-risk. These proactive measures include landscape-scale hazard-reduction strategies (mechanical manipulation of fuels or prescribed burning) that can be safely undertaken under controlled circumstances.

keywords: fire management policy, fire management practice, firing operations, Kootenay National Park, Parks Canada Agency.

Citation: Kubian, R.J., R.C. Walker, and J.M.H. Weir. 2009. Managing fire with fire in Canada's national parks—the Kootenay Complex 2003 [abstract]. Page 105 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

REGULATION TO REDUCE HOME LOSSES DUE TO WILDFIRE

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ABSTRACT

Question: What regulatory mechanisms are in use to motivate homeowners to modify their homes and yards to reduce their vulnerability to wildfire?

Background: As the wildland–urban interface grows, the challenge of protecting homes from wildfire also grows. Fire science research shows that modifying the "home ignition zone," the home itself and the 100–200 feet of land around the home, provides the best opportunity to reduce the likelihood of a home burning in a wildfire. These modifications include replacing flammable building components, such as roofs, siding, decks, and eaves, with noncombustible construction materials and reducing vegetative fuels surrounding the house. The question that fire managers struggle with is, "How do we get people to make the necessary changes to their homes and yards?" The choices are to have voluntary programs which emphasize individual responsibility, such as Firewise and education programs, or homeowner assistance programs which provide technical advice and/or monetary assistance, or regulatory programs which require compliance. Researchers for the Forest Service Web site, www.wildfireprograms.usda.gov, the National Database of State and Local Wildfire Mitigation Programs, have found that many states employ a combination of these program types. There is a growing awareness that regulations may be the only method that can get full community participation.

Location: The study area is the United States. The National Database of State and Local Wildfire Mitigation Programs catalogs programs to reduce fuels and educate homeowners in 35 states with wildfire risk.

Methods: The researchers interviewed state and local wildfire risk-reduction program managers between October 2001 and August 2008, posting 250 descriptions of programs to reduce hazardous fuels on private land on the National Wildfire Programs Database Web site. Programs described on www.wildfireprograms.usda.gov represent exemplary programs throughout the country. The Web site does not try to list every program in every state.

Results: Regulation for wildfire mitigation can occur at the state or local level, or at both levels using compatible ordinances. Local ordinances can stand alone or work together to enact standards for land development and construction. Regulatory approaches include zoning ordinances, development standards, building codes, and fire codes. These types of codes are most effective in areas not yet developed. As developers seek permits for new homes, they are required to build to fire-safe standards. For older areas, individual responsibility to reduce fuels and replace flammable building components is more effective because few new homes will be constructed in these areas. However, additions to existing structures and substantial remodels of a certain square footage, and roof replacements are usually included in the ordinances. At the subdivision level, covenants, conditions, and restrictions are regulatory mechanisms that can be used to require and enforce firewise practices in both new and established developments. Model fire codes, such as NFPA 1144 (*Standard for Reducing Structure Ignition Hazards from Wildland Fire*, 2008 ed.; Natl. Fire Protection Assoc., Quincy, MA) and NFPA 1141 (*Standard for Fire Protection Infrastructure for Land Development in Suburban and Rural Areas*, 2008 ed.; Natl. Fire Protection Assoc., Quincy, MA), and the ICC's *Wildland–Urban Interface Code* (2006; Int. Code Counc., Country Club Hills, IL) take a comprehensive approach, dealing with structural elements of buildings and community facilities in one ordinance.

Conclusions: There are many types of ordinances in use that have the same result: requiring defensible space around structures and noncombustible building materials. Participants will learn where to look for model ordinances that might be beneficial to their communities.

keywords: reducing structural ignitability, wildfire risk reduction, wildfire regulations, wildfire zoning, wildland–urban interface (WUI) ordinances.

Citation: Renner, C.R., T.K. Haines, and M.A. Reams. 2009. Regulation to reduce home losses due to wildfire [abstract]. Page 106 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

EVIDENCE-BASED COMMUNITY BEST PRACTICE FIRE MANAGEMENT FOR THE CONSERVATION OF BIODIVERSITY IN SOUTH EAST QUEENSLAND

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ABSTRACT

Question: What is the Southeast Queensland Fire and Biodiversity Consortium's role in educating the community on fire and biodiversity issues?

Background: The South East Queensland (SEQ) region is recognized as one of the fastest population growth areas in Australia, with a substantial proportion of new residents moving into the urban–bushland fringes. Population growth in the region is expected to double by 2026 to approximately 4.3 million, and it is envisaged that around 575,000 new dwellings and 425,000 new jobs as well as supporting infrastructure and services will be generated. This growth will impose significant social, economic, and environmental pressures on the region's 11 city and regional councils (SEQ Regional Plan Amendment 2006).

Population growth issues have been recognized in the region since 1998, and a number of local authorities approached Griffith University's School of Environmental and Applied Sciences for assistance and guidance in formulating appropriate fire and biodiversity management strategies for their open-space land acquisitions.

Location: Queensland, Australia.

Southeast Queensland Fire and Biodiversity Consortium's (SEQFABC) goals: The Consortium's aim has always been one of education, and the input from our members, who provide a multidisciplinary approach, has been instrumental in forming working groups and producing fact sheets, guidelines, and manuals. The working groups cover research, monitoring, fire management planning, and education. The multitiered fact sheets, guidelines, and manuals cover such diverse issues as 1) ecological guidelines, 2) a strategic fire management manual, 3) an operational fire management manual, 4) fire management for protected vegetation, 5) bushfire safety for home and garden, and 6) how Australian animals find food after bushfires (flame-grilled specials).

Fire management workshops: One of our most successful activities are our community fire workshops, which are held on a regular basis throughout the region: landowners are assisted by rural fire service and forestry personnel to complete a property fire management plan, and the plan can then be submitted to their local fire station. The plans are then digitized and kept for fire brigade response purposes for the property.

Key messages in products/documents: Throughout all of the documents and products, we have maintained consistency in our messages. As the following section (from Watson 1999) explains: "fire management is complex, and options often limited, particularly for private landholders in a fragmented, multi-use landscape. We convey a few key points which landholders and managers can keep in mind" and these include (from Tran 2004): 1) that fire plays a vital role in renewing many SEQ ecosystems; 2) that both too frequent, and too infrequent, burning can cause species to become locally extinct; 3) that different vegetation types are adapted to different fire frequencies; 4) that variability in the intervals between fires is important; 5) that a mosaic of vegetation in different stages of post-fire development will help provide habitat for a range of fauna species; 6) that fire should be considered in a landscape context; and 7) that there are ways to minimize risk to both life and property, and biodiversity (from Watson 1999).

Other achievements: The Consortium successfully organized and hosted the 10th Biennial Australasian Bushfire Conference, "Bushfire 2006—Life in a Fire Prone Environment … Translating Science into Practice," in Brisbane, Australia.

Key factors behind the success of the SEQFABC (Tran 2004): Clearly, we have touched a nerve within the community in relation to the issues surrounding fire and biodiversity in SEQ. The ongoing interest in our products—workshops—and the interest generated from outside our "operational" borders continue to exceed our expectations of the project. The main reasons we have been able to succeed in the implementation of this project include 1) a dedicated project coordinator who can act as the central foci for all matters concerning fire and biodiversity issues; 2) in-kind support from the supporting organizations involved in the project (conservative estimates suggest this level of support equates to many hundreds of thousands of dollars in the time spent assisting the project); 3) an open and supportive structure. This facilitates constructive discussion on a variety of topics and, importantly, achieves a consensus on any particular issue; 4) our reputation within the community and across government as an independent expert panel; 5) regular reporting and information provided to the community; and 6) education as the main aim.

Conclusions: The SEQFABC supports the wider community to increase its awareness of the complex issues surrounding fire and biodiversity issues. We continue to develop and form long-lasting partnerships with land managers and provide consistency in our messages. Our main role in translating research findings to useful on-the-ground applications and the facilitation of research projects that further assists adaptive management procedures leads to better refined management options for the region. For additional information on the Consortium, visit the Web site: www.fireandbiodiversity.org.au/.

keywords: Australia, biodiversity, community, education, Fire and Biodiversity Consortium, fire management.

Citation: Wattz, H. 2009. Evidence-based community best practice fire management for the conservation of biodiversity in South East Queensland [abstract]. Page 107 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

A FIREFIGHTER'S VIEW OF THE HUCK FIRE OF 1988: FIRE POLICY COLLIDES WITH FIRELINE REALITY

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ABSTRACT

Question: On the Huck Fire did fire policy and strategy match the realities of actual and predicted fire behavior and on-the-ground conditions?

Background: The Huck Fire started on 20 August 1988 and spread with high winds to the north and east, growing to 4,000 acres in the first burning period. The Huck Fire spread rapidly with the very dry fuels and drought conditions and eventually burned 121,000 acres. The Huck Fire burned into the Snake River Complex in Yellowstone Park and nearly merged with the Mink Fire on its southeast side. On 10 September, about 0.10 inch of moisture was received over the fire area. On 12 September, about 0.25 inch of rain was received over the fire area, which effectively ended fire movement. From the first week of July, for the Burro Hill weather station, the Energy Release Component (ERC) for fuel model (G) set record highs in 1988 (data from 1982 to 1988). The ERC did not return to average conditions until after the rains of 10 September and 12 September. Firefighting resources were assigned to the Huck Fire on its west and south edges. Fire crews were partly successful in suppression of the Huck Fire, but the actual fire behavior and fire spread rates overwhelmed attempts to suppress the fire on most of its south side. The fuels in the fire area were dominated by conifers with scattered grassy meadows. Fuels in the Pilgrim Creek area where crews were successful in suppression efforts were mostly a Fuel Model 8 with some Fuel Model 10. The predominate tree species were lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), and subalpine fir (*Abies lasiocarpa*). The lodgepole pine stands varied in condition and structure. The fuels were much thinner on ridgetops, which were very open with scattered copses of subalpine fir and a great deal of rock. Grassy meadows did not always carry fire due to the sparseness of vegetation or the greenness. The terrain in the fire area was very mountainous with steep glaciated peaks and deep canyons. Elevations varied within the fire area from 6,700 feet to nearly 10,000 feet.

Location: The Huck Fire started in northeastern Wyoming in Teton National Park and spread into the Bridger-Teton National Forest and Yellowstone National Park (lat 44.092103°N, long 110.516416°W).

Methods: The background, results, and conclusions are based upon personal observations while on the fire and from studying the Huck Fire from the perspective of a fire behavior analyst. Appropriate historical documents and imagery were reviewed. I was assigned to a Division as a Strike Team Leader on the Huck Fire and stationed in a remote spike camp, in the Teton Wilderness called Pilgrim Creek, with approximately 200 firefighters and support staff.

Results: The Huck Fire displayed active fire behavior for a total of 25 days and spread to the east and north 25 miles. On nine different days, the fire made runs of a mile or more and on the most active day the fire ran 6 miles. Extreme fire behavior with spotting was very common during higher winds. On 16 separate days, the Huck Fire burned >1,000 acres, with the largest gain on 7 September at 29,250 acres. The largest acreage gains coincided with the highest ERC values of the summer of 1988. The Huck Fire stalled on its east side as it neared Mink Creek, and this area was an effective barrier to fire spread because the fuels were much sparser and there were some meadows that did not carry fire. The Huck Fire eventually ground to a halt on its north side when it merged with the Snake River Complex (SRC). If the SRC fires had never occurred, the Huck Fire would have had about one more burn period to push farther into Yellowstone Park but more than likely would not have spread more than another 3 miles. Efforts to suppress the Huck Fire were effective in the southwest quadrant, but the other sides burned with impunity until the fire reached natural barriers. Fire suppression was difficult due to extremely dry heavy fuels, torching, and spotting. Safety was a major concern due to the remoteness of this fire and the ruggedness of the terrain. Fire crews were widely spread apart in an attempt to contain the fire, and air support was usually not available.

Conclusions: The Huck Fire was very difficult to suppress because fuels, weather, and topography combined to create erratic and extreme fire behavior from 20 August to 13 September. The Huck Fire was stopped only when it reached natural barriers and by a change in the weather with higher humidity and rain on 10 and 12 September. Even moderate fire behavior created problems for fire crews because of the resistance to control and fire spread rates and the remoteness and ruggedness of this area. Maintaining safety of fire crews was very hard on the Huck Fire because of the fire behavior, limited air support, and the span of control. The importance of planning, fire behavior predictions, using natural fire breaks on large fires, a robust system of gathering of information on fuels and weather, and matching strategies and tactics with actual conditions cannot be overemphasized. Suppression of the Huck Fire with higher than normal fire indices was impossible.

keywords: ERC, fire behavior, fuels, Huck Fire, safety, suppression, tactics.

Citation: McCrea, R.C. 2009. A firefighter's view of the Huck Fire of 1988: fire policy collides with fireline reality [abstract]. Page 108 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

THE FAILURE OF WILDLAND FIRE MANAGEMENT TO MEET THE TENETS OF *TRUE* WILDERNESS PRESERVATION

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ABSTRACT

Question: Does the current use or ideal of wildland fire management meet the core caveats of *true* wilderness preservation?

Background: A review of wilderness research and management practices supports the concept of *true* wilderness preservation, which is a combination of wilderness philosophy and an interpretation of the Wilderness Act. There are five main components within *true* wilderness preservation. First, the "symbolic values need to be legitimized" (Cole. 2005. Int. J. Wilderness 11(2):10, 23–27). Wilderness classification has to portray the values of humility and restraint, epitomizing the intended original symbolism as an area untrammeled by man. Second, wilderness preservation does not include ecological restoration or other manipulations in line with conservation management. Anything but pure preservation for the key components will degrade the quality of the wilderness and its associated values. Third, *true* wilderness preservation needs to be implemented through a diachronic lens which supports symbolic value. A diachronic path would recognize land that needs to be preserved, whether it is highly affected or not at all by humans, and designate it wilderness because of its potential to regain all the qualifying factors: "wilderness character," "untrammeled," and "natural conditions." Fourth, "wilderness character" needs to be the second priority of preservation. It embodies the overall objective definition of wilderness and contains its keystone qualifiers such as "natural conditions" and "untrammeled." Each of these qualifiers will need to be fully realized; otherwise, "wilderness character" will be corrupt. *True* wilderness preservation defines "natural" as any processes and components of the wilderness ecosystem that are left after the removal of human-dependant components. Lastly, in order to practically implement the concepts, a formal baseline needs to be declared involving the five tenets of *true* wilderness preservation, especially the new definition of "natural." Afterward, the manager's job will be to maintain the highest level of wilderness character and symbolic value through hands-off management.

Methods: The question was explored through research of peer-reviewed literature.

Results: The current designation of "natural" is an arbitrarily desired social distinction with significant limitations. First, managers "recognize the importance of understanding historical conditions and natural variability," but there is still a well-deserved debate over how applied historical ecology should be used for widespread land management (Landres et al. 1999. Ecol. Applic. 9:1279–1288). Next, Swetnam (1999. Ecol. Applic. 9:1189–1206) explains that 1) our understanding of the range of natural variation is still assumption laden and incomplete, 2) several well-documented cases have shown that assumptions can highly distort the quality and accuracy of the data, and 3) that "ultimately, decisions about 'desired' conditions, and what is 'natural' are inherently subjective and value laden." Third, many fire management agencies experience limitations to available knowledge for decision-making processes (Miller & Landres. 2004. Gen. Tech. Rep. RMRS-GTR-127. USDA For. Serv., Missoula, MT; Miller & Parsons. 2004. Final Rep. to Joint Fire Sci. Prog. 01-1-1-05. USDA For. Serv., Missoula, MT). Lastly, "natural" does not include historical anthropogenic ignitions (Arno et al. 1997. Res. Pap. 495. USDA For. Serv., Ogden, UT). So far, federal agencies have been "largely unsuccessful" at restoring fire regimes within the accepted definition of "natural conditions" (Parsons & Landres. 1998. Proc. Tall Timbers Fire Ecol. Conf. 20:366–373), including progressive fire management programs within the United States, e.g., Sequoia-Kings National Park and Grand Canyon National Park (Caprio & Graber. 2000. Proc. RMRS-P-15-VOL-5. USDA For. Serv., Missoula, MT; Sackett et al. 1996. Gen. Tech. Rep. RM-GTR-278. USDA For. Serv., Fort Collins, CO). Finally, it is impossible to reestablish fire as a process with widespread fire suppression in wilderness (Parsons et al. 2003. Tall Timbers Misc. Publ. 13:19–26).

Conclusions: Due to both the limitations of applied historical ecology and the available scientific and historical data concerning natural fire regimes, the currently desired natural state is arbitrary and possibly outright wrong in some areas. The solution to this dilemma is to adopt a *true* wilderness preservation management strategy. By redefining the desired conditions to be the potential in the future rather than an arbitrary point in the past we need to begin a hands-off approach to maximize the symbolic value and "wilderness character," wilderness management will once again begin to make positive progress in preserving the areas that we have deemed special enough to call wilderness. This will lead to other issues such as ecosystem changes and possible loss of biodiversity, but the core caveats of *true* wilderness preservation—which are closely intertwined and extremely similar to the original intent of the legislation—will be allowed to be maximized through untrammeled natural processes.

keywords: failure, natural, true wilderness preservation, wilderness management, wildland fire management.

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IS A WELLSITE OPENING A SAFETY ZONE FOR A WILDLAND FIREFIGHTER OR A SURVIVAL ZONE OR NEITHER?

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ABSTRACT

The Wildland Fire Operations Research Group (WFORG) of FPInnovations – Feric Division in collaboration with the University of Alberta initiated a project in late 2007 at the request of its stakeholders to examine and define the limits of wildland firefighter safety and survival zones. This partnership combines research and practical expertise in wildland fire suppression, fire behavior, heat transfer, and fire-resistant clothing evaluation.

What constitutes a safety zone has been shown to vary widely among individuals, irrespective of experience. Based on analytical work involving theoretical considerations of radiative heating, it has been suggested that the diameter or separation distance of a safety zone should be as a minimum at least four times the maximum expected flame height. In such cases, it is assumed that a wildland firefighter clothed in personal protective clothing is standing upright and receives no burn injuries.

Given the propensity for high-intensity crown fire behavior in the boreal forest and the general scarcity of suitable natural openings in the continuous overstory tree canopy, it has been suggested that wellsite openings could possibly serve as safety zones or alternatively as survival zones (G. Dakin, personal communication). In northern Alberta, these man-made clearings are quite common in some regions. They generally vary from 100 × 100 m to 120 × 120 m in area. The ground cover at active wellsites is typically maintained in a nonflammable state, which make them a potentially ideal safety or survival zone.

Based on fire behavior knowledge obtained from experimental fires, prescribed fires, and wildfire observations, we can say with some degree of certainty that the maximum flame heights in grasslands, shrublands, and hardwood stands (e.g., trembling aspen [*Populus tremuloides*]) varies from about 2 to 10 m. Thus, a separation distance of 40 m is easily met by a wellsite opening in these fuel types based on previously described criteria.

The average flame height of crown fires in conifer forests is generally 2–2.5 times the stand height. Thus, a 100 × 100-m wellsite opening with conifer trees greater than ~10 m in height bordering its edge would not be adequate as a safety zone. However, perhaps such an opening might serve as a survival zone (i.e., a firefighter is lying face down as opposed to standing upright but still does not experience any burn injuries).

The derivation of the "four times the maximum flame height" guideline for safety zone size was based on the geometry of a planar flame front at some distance from the firefighter. The present work extends this approach in that the blockage or shielding effects from the unburned vegetation or fuel between the advancing flames and the receiving surface are modeled in addition to the flame front wrapping around and passing along the wellsite opening, thereby more closely resembling real-world fire behavior.

Simulations were undertaken of the radiant heat energy emitted from the flames of an advancing crown fire to a person clothed in personal protective equipment (PPE) while lying prone in a wellsite opening, assuming a 200-m-wide × 20-m-high flame front directly approaching a 100 × 100-m wellsite opening. Given a nominal rate of fire spread of 40 m/minute and a flame front residence time of 45 seconds, this equates to a 30-m flame depth or thickness. Given this residence time, the critical radiant heat flux to avoid any burn injuries was judged for present purposes to be ~7.5 kW/m^2 based on existing information regarding the effectiveness of PPE from the literature.

The heat transfer simulations consisted of "snapshots" in time of the radiant heat fluxes or "isotherms" at ground level as the flame front approached and then passed along the sides of the wellsite opening. Based on an examination of the temporal and spatial extent of radiant heat fluxes found in these preliminary simulations, it appears that a wellsite opening could very well serve as a survival zone. However, it must be emphasized that these simulations have only considered thermal radiation (i.e., other mechanisms of heat transfer have not been considered such as flame impingement or horizontal reach into the wellsite opening, fire whirls, or any allowance for convection).

We have deduced that the suitability of a wellsite opening as a safety zone or as a survival zone depends on the characteristics of the surrounding fuel/vegetation types (i.e., height and species composition). The idealized simulations performed to date will serve as a guide in the designing of field experiments. Plans are being formulated to verify these types of simulations using experimental fires to be carried out in Alberta and the Northwest Territories in the near future. A more in-depth review of the literature on the effectiveness of PPE and of burn injuries and survival will also be undertaken. Wildfire case studies involving firefighter fatalities and near-miss incidents will also be examined in relation to simulations of the thermal environment associated with safety and survival zones in wildland fires. For further updates on this project, visit the WFORG Web site (http://fire.feric.ca).

keywords: crown fire, fire behavior, fire behavior simulation modeling, firefighter safety, flame front residence time, flame height, heat transfer, personal protective equipment, thermal radiation.

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AN EXAMINATION OF WILDFIRE FATALITIES IN AUSTRALIA AND THE IMPLICATIONS FOR EVACUATION POLICY

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ABSTRACT

Question: What are the trends in Australian wildfire fatalities and who are the vulnerable groups?

Background: Australian wildfire policy for community safety is unique. Rather than attempting to evacuate all those that may be in the path of a wildfire, fire authorities in all states allow the public to make a choice: either get out of the area early, or prepare to stay and defend your home and property from the fire. However, apart from a handful of post-fire investigations, no detailed research has ever been carried out into the circumstances of all recorded wildfire deaths in Australia. This paper will cover the main trends emerging from an analysis of Australian wildfire fatalities over the past 100 years. Attention will be paid to the deaths over the last 50 years and, in particular, deaths during the 1967 fires in Tasmania and the 1983 Ash Wednesday fires in South Australia and Victoria. The implications of these findings for wildfire management and the limitations of this study will be discussed. This work is funded by the Australian Bushfire Cooperative Research Centre.

Location: Tasmania, South Australia, and Victoria, Australia.

Methods: The database was produced over two stages. First, information was compiled from information listed in the print media from 1901. Unlike most other fatality data sets, this enabled the names, ages, and some limited information concerning the fatality to be recorded. Second, detailed information has been recorded through a thorough documentary analysis of forensic, witness, and police statements within coronial inquest reports. The database includes the details of 552 civilian fatalities and provides a unique opportunity to assess the circumstances in which people perished and the suitability of the Australian "stay and defend or leave early policy." The information pertaining to professional firefighter fatalities has been removed in order to concentrate on civilian deaths.

The analysis of the data was directed by relevance to informing the implementation of the "stay and defend or leave early policy." The data were grouped into four broad groups: demographics, medical cause of death, activity, and decision making prior to death, location, and transport. Where possible, the decisions leading to fatalities have been examined based on people's awareness of the fires and warnings and the effectiveness of the actions that they took to reduce their risk.

Results: The results of this analysis clearly show the dangers of being caught outside during a wildfire, with the majority of fatalities occurring when victims flee the flames during late evacuations or are defending wider property outside. The minority of deaths that occurred inside buildings were due to the inhabitants sheltering in place and not defending from ember attack. In addition to substantiating the "prepare, stay and defend or leave early policy," the analysis has demonstrated the heightened vulnerability of women, children, and the elderly. This is due to their propensity to evacuate late and their greater reliance on others for assistance. In particular, there is evidence of a gendered division of roles and responsibilities during wildfires that contribute to these vulnerabilities. While men are most often killed outside, while at work or attempting to protect assets, most female fatalities occur while sheltering in the house or attempting to flee. Although men are still the dominant group killed during wildfires, this number has decreased steadily over time. This is not the case for women and children, who in recent years have died in relatively high numbers.

Conclusions: It is clear that translating the "stay and defend or leave early" message into practice is complex, with a great deal of ambiguity in the "leave early" advice. Many people still consider late evacuation as a valid last resort: waiting to see how the fire develops and then fleeing at the last minute. In other cases, people expect emergency services to provide warning, help, and assistance.

Given the speed and erratic nature of wildfires (particularly in urban interface areas), there is a need for communication that prepares people mentally and physically for a situation in which they may have no choice but to stay and defend their homes. Of most importance, however, is the need to recognize and target vulnerable women and children who die fleeing or sheltering in an undefended home and men who risk their lives defending assets outside.

keywords: Australia, bushfire, evacuation, fatalities, policy, wildfire.

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STRESS AND INCIDENT MANAGEMENT TEAMS

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ABSTRACT

Question: What role, if any, does stress play among members of American Incident Management Teams?

Background: At the present time, >50 Type I and Type II Incident Management Teams (IMTs) are in existence in the United States, collectively comprising hundreds upon hundreds of individuals with unique skills and abilities. In a high-risk environment such as wildland fire, it is likely and highly probable that the external environment will present a multitude of complex factors and situations to those individuals who have been tasked with managing and/or suppressing them, such as an IMT (Gebert et al. 2007. p. 96–97 *in* S. McCaffrey et al. *Extended abstracts from the Human Dimensions of Wildland Fire Conference*. Int. Assoc. of Wildland Fire, Hot Springs, SD). Although Phase III of the *Wildland Firefighter Safety Awareness Study* conducted by Tri-Data Systems in 1998 highlighted the importance of training IMT members on how to cope with stressors during fire assignments, very little empirical research has been undertaken in the ensuing decade to learn more about these teams and the various occupational stressors they face (Sharkey et al. 2008. Wildfire 33[1 Mar.]:10–15). Lazarus and Folkman (1984. *Stress, appraisal, and coping*. Springer, New York) have proposed that stress represents a transaction between an individual and the external environment. Stress occurs when the demands of the environment are perceived by the individual as exceeding their resources to respond. Coping behaviors are all those things individuals do to reestablish a balance between the demands of their environment and their personal resources. While ample anecdotal reports suggest that IMT members experience considerable levels of stress, more empirical evidence is needed to clarify and quantify the role that stress plays among these teams. The University of Montana (UM) Human Performance Laboratory, in conjunction with the Missoula Technology and Development Center, have spent the last two field seasons (2007 and 2008) gathering data from members of various Type I and Type II IMTs in an effort to learn what role, if any, stress plays among IMTs and how they cope with it.

Location: Type I and Type II incidents in Montana and California, USA, during the 2007 and 2008 fire seasons.

Methods: Data from a variety of sources have been gathered in an effort to obtain as complete a picture as possible of IMT members: physical activity levels at fire camp during work and rest, measured aerobic fitness, the presence of risk factors for coronary artery disease and inflammatory markers in blood samples, stress and coping questionnaires, sleep logs, salivary cortisol levels, and qualitative interviews.

Results: Data from 2007 suggest the need for stress-reduction interventions, both in fire camp and elsewhere, especially for individuals whose IMT job duties require little or no physical activity. About 30% of the IMT members sampled reported above average or severe stress in their position on the team, and IMT members appear to mirror national demographics in terms of coronary artery disease risk factors relative to their age (overweight, hypertension, low VO_2 maximum values, family history of heart disease, high blood glucose, and high cholesterol). Research data gathered during the 2008 field season are presently being analyzed to further clarify the role and degree to which stress impacts IMT members.

Conclusions: Once data gathered during the 2008 field season are analyzed, the UM Human Performance Laboratory and the Missoula Technology and Development Center will be in a better position to make appropriate recommendations. The next logical step would appear to be identifying and evaluating effective coping strategies to assist IMT members in addressing and mitigating possible sources of stress.

keywords: incident management teams, stress.

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ASSESSING POST-FIRE BURN SEVERITY ON THE GROUND AND FROM SATELLITES: A REVIEW OF TECHNOLOGICAL ADVANCES

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ABSTRACT

Question: Burn severity mapping and post-fire assessment has changed dramatically over the past two decades—what changes do the future hold?

Background: For >30 years, USDA Forest Service and USDOI Burned Area Emergency Response (BAER) teams have been among the first specialists on-site after a wildfire to assess and map fire effects. The primary task is to determine the burn severity, with an emphasis on the fire's effect on the soil, which is used in turn to help identify areas at increased risk for post-fire soil erosion, flooding, or debris flows. Large fires near the wildland–urban interface in recent years have been the target of increased public scrutiny of federal land management practices. This has prompted a renewed focus on developing objective, repeatable methodologies for creating accurate post-fire maps.

Immediately after the 1988 Yellowstone wildfires, fire perimeter and tree mortality mapping was completed using aerial photography and sketch mapping from fixed-wing aircraft and helicopters. These preliminary maps were deemed adequate for emergency use, but more detailed data were necessary for long-term scientific evaluation. Satellite images were used to create post-fire burn-severity maps in the early years following the 1988 Yellowstone Fires. These maps emphasized spatial patterns of burn severity, patch sizes, and tree mortality, and were used to estimate potential vegetation recovery.

Currently, high-resolution burn-severity maps (30-m pixels) are rapidly produced from satellite imagery within days of fire containment. These maps are verified in the field and adjusted to reflect the effects of the fire on the soil, which impact post-fire soil hydrological functions. The field-validated maps highlight areas where increased runoff and peakflows, flooding, erosion, and sediment delivery to streams threaten values-at-risk. The maps are so quickly produced and highly utilized because of years of fine-tuning and standardizing the process by the USFS Remote Sensing Applications Center and the USDOI Earth Resources Observation and Science groups.

Location: Large wildfires in the western United States, especially those near the wildland–urban interface and other downstream values-at-risk.

Methods: Traditionally, BAER burn-severity maps were created by sketch mapping from a helicopter or road-accessible overlook. Accuracy and complete fire coverage were difficult to obtain with these early methods. In 1996, color infrared digital imagery was first tested for creating post-fire maps, which segued into the first use of remotely sensed satellite imagery in 2000. Since 2001, primarily Landsat satellite imagery has been used to create post-fire burn-severity maps used in post-fire assessments.

Results: Advances in GIS and remote sensing have provided tools that greatly improve the speed, precision, and accuracy of fire mapping efforts, particularly on large and inaccessible fires. The post-fire burn-severity map is also used by other resource specialists to identify potential impacts to road, structures, aquatic and terrestrial habitat, cultural resources, and resources downstream from the burned area. Examples of using GIS to derive fire effects information include overlaying the burn-severity map with steep slopes, soils, or ownership, for use in modeling post-fire slope stability or measuring acres of burn severity by ownership or by watershed. New remote sensing tools are increasingly being used to identify direct wildfire effects that predict potential secondary effects, such as increased runoff and erosion. Higher-resolution airborne hyperspectral images (4-m pixels) have been used to create post-fire maps of green and charred vegetation, exposed mineral soil, and ash. A map of these erosion-related ground-cover components provides information relevant to potential watershed response. Quickbird and IKONOS satellites provide the highest spatial resolution multispectral imagery (2-m pixels) that has been successfully used to create burn-severity maps at an even finer scale than is possible with Landsat.

Conclusions: A better understanding of fire's role in healthy ecosystems has generated great interest in the applications of burn-severity mapping, especially in relation to longer-term effects such as invasive species, vegetation recovery, and productivity. With the future of Landsat uncertain, other data sources and mapping methods are being investigated, many of which have greater spatial and spectral resolution than Landsat. These new data products hint at the future of burn-severity mapping and may allow land managers to more confidently prescribe post-fire rehabilitation only to the areas where they are most needed. Time, money, and resources will be saved if treatments are only used where they have the potential to reduce the risk to downstream values-at-risk.

keywords: burn-severity mapping, Landsat, remote sensing.

Citation: Robichaud, P.R., A. Parsons, S.A. Lewis, A.T. Hudak, and J. Clark. 2009. Assessing post-fire burn severity on the ground and from satellites: a review of technological advances [abstract]. Page 113 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

USING LANDSAT SATELLITE IMAGERY TO MAP POST-FIRE FOREST CANOPY MORTALITY CLASSES IN NORTHWEST WYOMING

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PURPOSE: Binary classification tree models were used to create predictive maps of canopy mortality in burned areas of Yellowstone National Park, Grand Teton National Park, and the Bridger-Teton National Forest of northwest Wyoming. APPROACH: Canopy mortality represented a measure of burn severity that could be easily detected using overhead sensors, is quantifiable, and important for fire and resource managers to document. Composite burn index (CBI) field plots and digital orthophotography were used to collect 694 observations of percent mortality, which were used as model training data. A suite of Landsat (TM and ETM+) indices widely used for burn severity mapping were employed as predictor variables to determine the best model combinations. Additionally, ancillary geospatial data from pre-fire images, digital elevation models, vegetation maps, drought indices, and fire locations were also used. SUMMARY: According to results from an array of spatial model comparisons and independent tests using new observations, it is possible to produce reasonably accurate maps of three canopy mortality categories in burned areas (68.5% overall, kappa = 0.45). An alternative model using only the differenced normalized burn ratio provided by the Monitoring Trends in Burn Severity program was 60.3% accurate (kappa = 0.33). Photo- and field-based canopy mortality estimates performed comparably in model development. The 80–100% canopy mortality category was most accurately mapped, followed by the 0–20% class. The middle category (25–75% mortality) was poorly predicted. Canopy mortality maps have applications for vegetation and fuels management, hydrologic assessments, wildlife habitat conservation, and updating maps post-fire. CONCLUSION: While Landsat TM and ETM+ products can be used to map the patterns of canopy mortality resulting from crown fires, the smaller-scale heterogeneity of mixed lethal burns is not well captured. Map users must be aware of this limitation in order to avoid misconceptions about the true nature of fire disturbances.

DEVELOPMENT OF THE WILDFIRE RISK MANAGEMENT SYSTEM AT A WATERSHED (VICTORIA, BRITISH COLUMBIA) AND LANDSCAPE (ALASKA) SCALE FOR APPLICATION TO THE MANAGEMENT OF WILDLIFE REFUGES AND THE PROTECTION OF DRINKING WATER QUALITY

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The Wildfire Risk Management System (WRMS) developed in 2003 (Ohlson et al. 2003) has been applied at varying scales with differing management objectives. This paper describes two unique applications to wildfire management and demonstrates how the system can be designed and used to meet the needs of managers in diverse fire environments and at varying scales of management. The dynamic WRMS interface provides unique features that allow managers to turn on, or off, various subcomponents or components in the model. This allows the quick and efficient exploration of model interdependencies and the ability to analyze individual spatial ratings of probability and consequence and the combined wildfire risk profile of a specific area. The model provides the ability to enter and test various combinations of weights at both the component and subcomponent level, which allows for the exploration of specific fire management questions (e.g., what if we increase our suppression resources) and the systematic sensitivity testing of underlying professional judgments that went into the model structure. Managers can “game” with individual or combined data layers, and are able to explore various scenarios and assumptions. The application has been designed to output maps of any scenario as high-resolution JPEGs or save them as ESRI shapefiles. Key assumptions and parameters are displayed as part of the map legend but are also stored in a separate text file. This allows for quick and efficient development of a portfolio of maps, in both digital and hardcopy format, reflecting various scenarios and assumptions. The latest version of the WRMS application includes the capability to map and track the wildfire risk on a daily basis (this assumes that daily fire weather indices are readily available). Of specific interest to fire managers, and to local, regional, and national governments, is the ability to identify the wildfire threat risk to the urban interface. This paper describes the unique application of the WRMS model in two contrasting fire environments: 1) the watersheds of the Capital Regional District in Victoria, British Columbia, Canada, and 2) the Wildlife Refuge System in the state of Alaska, USA. The two applications are compared and contrasted in both their development and application within these two jurisdictions. The outputs of the spatial risk assessment help to guide managers in priorizing fire management expenditures and strategies in protecting valuable resource values.

WILDLAND FIRE DECISION SUPPORT SYSTEM AND THE RAPID ASSESSMENT OF VALUES-AT-RISK (WFDSS–RAVAR)

David Calkin
Research Forester, USFS

This presentation will provide background, results from recent fires, and future direction of the Rapid Assessment of Values-At-Risk (RAVAR) model; the economic impact module of the Wildland Fire Decision Support System (WFDSS). The National Fire & Aviation Executive Board chartered the WFDSS Project in June of 2005 "to develop a scaleable decision support system for agency administrators that utilizes appropriate fire behavior modeling, economic principles, and information technology to support effective wildland fire decisions consistent with Resource and Fire Management Plans." The WFDSS is scheduled to replace existing Wildland Fire Situation Assessments and Wildland Fire Implementation Plans by the 2009 fire season. During the initial Web-based release during the 2007 fire season, the primary WFDSS modules included the Fire Spread Probability (FSPro) model, the RAVAR economic impacts model, and an average fire cost projection model, the Stratified Cost Index. The WFDSS was heavily utilized during the 2007 fire season, with several hundred FSPro runs completed and >100 RAVAR reports delivered to support management of ongoing wildfire events. Additional modules are being incorporated into the WFDSS for the 2008 season, and several prototype areas have been identified that will test new applications scheduled for the 2009 full release. RAVAR integrates spatial resource value data with fire spread probability contours identified by FSPro to map and report private assets, public infrastructure, and natural resource values-at-risk from ongoing wildfires. The WFDSS was a key component in supporting management efficiencies and improve large-fire oversight for the 2007 fire season. The role of the RAVAR in supporting risk-informed decision making under Appropriate Management Response framework will be demonstrated, and future applications in areas such as off-season fire planning, burned area emergency response, and monitoring will be discussed.

DECISION-MAKING PROCESSES, DECISION SUPPORT SYSTEMS, AND STANDARD OPERATING GUIDELINES

Patrick Withen
Flamologist, USFS, McCall Smokejumpers

Because decision making is perhaps the critical component when one is considering human factors on the fireline, it is explored in many wildland firefighting courses and firefighting aids, a.k.a. decision support systems (DSS), such as the *Incident Response Pocket Guide*. It is proposed that the "building blocks," the very decisions and actions that compose the firefighting effort are not the DSS themselves nor the decisions, but rather they are the standard procedures which compose routine, and in some cases nonroutine action on the fireline, i.e., the standard operating procedures. To a large extent, while the DSS and training about decision making guide us toward making standard decisions and taking standardized actions, the truth of the matter is that we have few standard operating guidelines. The present analysis examines the DSS and extracts those rules, guidelines, caveats, examples, etc. and divides them into categories such as safety rules, operations guidelines, rules of thumb, etc. The final task of this analysis is to take these operations guidelines and begin to establish a set of standard operation guidelines (SOGs) that are safe, and yet are not safety rules. These SOGs may be used in tactical operations that complement the DSS and clearly delineate where planning is to be done, where decisions are to be made, and where guidelines are to be followed.

FLORIDA'S USE OF THE ALTERNATE GATEWAY INTO THE WIMS DATABASE

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This presentation will describe the long road that Florida has been on to utilize the WIMS database without the traditional RAWS weather stations. Florida has been working closely with FENWT and the Missoula Fire Lab to upload data from 67 National Weather Service Stations into WIMS through the alternate gateway. The reason behind the push from Florida to accomplish this task was driven by the local burning community. The burning community no longer feels that the subjective system used by the Florida Division of Forestry (DOF) to make decisions concerning the issuance of burning authorizations meets their needs. They are requiring that the DOF move to a more objective system. The DOF plans to use the NFDRS to set the specific conditions for the go/no go decision-making process. The forecasts developed by the National Weather Service based on the WIMS data will supply the necessary information to make the process more objective. This ground-breaking process has been made possible through the cooperative efforts of Larry Bradshaw, Scott Goodrick, Deborah Hanley, and Jim Brenner.

FIRESCAPE: A PLATFORM FOR ON-DEMAND, BROWSER-BASED INCIDENT COMMAND

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HyPerspectives has developed a Web-based mapping and visualization application, FIRESCAPE, for end-users in wildland fire management communities. This service will uniquely combine remotely sensed NASA data products, a leading-edge weather model, and permanent/temporary meteorological station information, and deliver the resulting data to fire decision makers visually via the Internet. By partnering with Anasphere, Inc. and Cisco Systems, Inc., we have developed the FIRESCAPE application to offer not only advanced remote-sensing data products and customized reports, but on-site, real-time weather data, GPS tracking, and full data transfer and communications networks (including audio and video). FIRESCAPE will provide end-users access to a complete team of expert analysts and engineers to gather, merge, and analyze fire-related data products through satellite communications networking. Our experts then consolidate and simplify all the available data into custom, real-time data reports with geospatial context and deliver it to end-users to expedite high-level decision making, which will save valuable assets and lives. By expanding the tools available and utilizing Cisco's secure, integrated database management and internetworking solutions for data transfer and delivery, we are streamlining the decision process for end-users. The ability to quickly and efficie ntly collect, analyze, and share geospatial data (in particular, time-sensitive environmental data) across the World Wide Web is the cornerstone value proposition for the FIRESCAPE service. These combined abilities provide a critical and as-yet unavailable tool for the fire management community. FIRESCAPE has both economic and human benefits in that confinement strategies decided upon and applied during the early stages of fires can significantly reduce the cost of fire suppression by several millions of dollars. This increased information will also allow decisions to be made that keep firefighters as safe as possible. FIRESCAPE will offer advanced data products in formats designed specifically to address the aspects that influence these decisions. The FIRESCAPE Web browser interface is a flexible architecture, based on open standards; therefore, the solution is agile, dynamically configurable, and interoperable, holding significant value for applications such as natural disasters, pandemics, or homeland security. The overlay and visualization of that data through FIRESCAPE will provide analyses of critical importance for decision and policy makers, as well as regular citizens, all seeking the best geospatial information possible and in a form they can use.

POPULATION PROTECTION—THEN AND NOW

Bob Fry
Firewarden, Park County, Montana

I provide a look back at population protection during the Yellowstone fires surrounding Cooke City and Silvergate and compare it to today's population protection challenges. I was the Park County, Montana, Emergency Management Coordinator and assigned as the Population Protection Planner for the IMTs. I'm currently an IC on an IMT facing similar situations yearly. My most memorable moments of my stay in Cooke City in 1988, and there were many, included two evacuations, people who couldn't evacuate due to medical problems, people who refused to evacuate, one deputy to evacuate and provide security on the night before evacuation, road closures, a media circus, telephone lines that weren't suppose to fail but did, bears in town, a fire camp evacuation, a fire truck rolling on its side, safety zones that were in question, CNN doing an interview on the morning of one evacuation, and political posturing. The problems surrounding an evacuation request, and people refusing, reminds me of current discussions surrounding the Prepare, Stay and Defend philosophy. The idea of evacuating the populations didn't make a lot of sense when we had more media staying than residents leaving. Who's really at risk, you had to ask? The '88 population protection in Park County, Montana, mirrored what I've been experiencing as an OSC2 and IC on an IMT since then and seems to be more prevalent even today. The public needs to be prepared for long-term fires both mentally and physically. They need to understand property owner responsibilities and the risks associated with staying. They also need to understand the risk with evacuating a threatened area. We need to become more familiar with the philosophy we have been using to protect the public. Is it Prepare, Stay and Defend or be ready to run? We need to educate the public to what real preparedness looks like. We need to understand the implications of allowing residents to stay and defend their property. We need to understand our responsibilities during emerging fires and what impact they have on late evacuations. We need to better understand methods of informing the public, early and often. We need to discuss the impact of long-term fires on affected populations. We need to understand security of an affected area and what the residential risks are when the repopulation happens. In closing, I would address the real issue of population protection at the local government level and the challenges ahead.

PUBLIC ACCOUNTABILITY AND THE APPROPRIATE MANAGEMENT RESPONSE: MAKING AMR A TOOLBOX, NOT A TAUTOLOGY

Timothy Ingalsbee
Executive Director, Firefighters United for Safety, Ethics, and Ecology (FUSEE)

According to a recent change in the federal fire policy, wildland fires can now be managed for multiple objectives. (e.g., both community protection and ecosystem restoration). The concept of appropriate management response (AMR) is integral to this new policy provision. AMR expands the strategic and tactical options for fire managers so they can choose from a full spectrum of potential actions—everything from aerial monitoring to aggressive suppression can be used—and all of these tactics can be combined on the same incident. Moreover, objectives can change according to the time, place, and conditions of a fire. This is a huge improvement from the days of the Yellowstone Fires when managers had to decide shortly after detection whether a fire could be managed as a prescribed natural fire (PNF) or aggressively suppressed as a wildfire, but could not manage individual fires for both objectives simultaneously. The AMR concept provides managers with maximum flexibility and discretion, offering new options and opportunities to improve firefighter safety, control costs, and reduce the environmental impacts of traditional wildfire suppression operations. While fire managers are supposed to draw guidance from Forest Plans and Fire Management Plans in deciding operational objectives, strategies, and tactics, in general, these plans are either obsolete (i.e., they contain outdated information on vegetation and fuel conditions) or are inadequate (i.e., have not undergone rigorous scientific analysis or informed public input in accordance with NEPA). Consequently, these planning documents may not offer much guidance or decision support at all, potentially making AMR both more complex and more risky for managers to implement. Wildland fire management operations may also become less publicly accountable if every action or decision taken is considered to be, by definition, the appropriate one. In this regard, the AMR concept suffers from a kind of self-serving circular reasoning: the AMR is any response a manager deems appropriate. How can agencies convince the public that AMR does not cover up arbitrary or ad hoc responses, that the new management flexibility is not simply managerial fiat? Unfortunately, there is widespread confusion over AMR: Is it merely an alternative, "kinder, gentler" form of fire suppression? Does it avoid the need to revise Forest Plans and Fire Management Plans? Is there no such a thing as an inappropriate management response? This presentation will wade through some of the conceptual confusion over AMR, and advocate the need for rigorous pre-fire planning to develop critera for assessing appropriateness and accountability, and ensure appropriately safe, ethical, and ecological responses to wildland fire.

NEW POSTER HIGHLIGHTS THE IMPORTANCE OF HOMEOWNER RESPONSIBILITY FOR CREATING DEFENSIBLE SPACE

Kurt Naccarato
Idaho Department of Lands Fire Bureau

Idaho Department of Lands has developed a new education tool to bring the concept of defensible space home. "Your Fuels, Your Problem, Your Loss" shows homeowners the need to protect themselves and their property before a wildland fire reaches their community. Homes that have been prepared with hazardous fuels reduction/defensible space have shown that they can survive a wildfire. The hard-hitting message highlights the need for homeowners to take personal responsibility in protecting their homes. The poster was produced by the Idaho Department of Lands Fire Bureau and will be available on our Web site at www.idahofireplan.org, or to obtain copies for your community, contact Harry Steele, Fire Coordinator for Idaho, at hsteele@idl.idaho.gov or 208-666-8673.

COMMUNITY PREPAREDNESS FOR WILDFIRE

Lisa Sturzenegger
Director Community Safety

Fire agencies in Victoria, Australia, have developed a comprehensive strategy to increase community preparedness for wildfire events. The Fire Ready Victoria (FRV) strategy is a 3-year, joint agency strategy that seeks to raise awareness of the wildfire risk, promote adoption of preparation actions, encourage planning about what to do during a fire and to provide information to threatened communities during wildfires to support decision making. The FRV strategy aims to deliver the key messages to the community that underpin the "stay and defend or leave early" position supported by Australian fire agencies. The FRV program represents the current form of a long-running approach in Victoria to increase preparedness through a broad-ranging program of awareness, education, and support activities. In 2006 and 2007, the program delivered >1,000 street corner and community meetings, nearly 300 meetings during major fires, and conducted >400 meetings in neighborhoods as part of the Community Fireguard program. In addition, the program involved a media campaign of television, radio, and press advertisements, including ethnic radio, publicity events, and partnerships with major media to profile the wildfire issue. In addition, the strategy has also established an information hotline and Web site that provides up-to-date information about current wildfire incidents and relevant warnings and safety advice. The presentation will outline the principles underpinning the strategy and provide an overview of the various components. FRV provides a model for an integrated statewide program of community education and engagement that has achieved agency and government support, and high levels of community participation. The presentation will also present findings from evaluation studies on the reach and effectiveness of the strategy.

STATE PRESCRIBED FIRE COUNCILS FORM A NATIONAL COALITION: AN INITIATIVE TO NATIONALLY ADDRESS KEY MANAGEMENT, POLICY, AND REGULATORY ISSUES

Mark Melvin
Chair, National Coalition of Prescribed Fire Councils

Prescribed fire managers face new and increasingly complex challenges in the 21st century that limit or threaten the use of prescribed fire. Although prescribed fire is used to accomplish diverse resource benefits across the United States, most burners share a number of common concerns, including public safety/health, ecological stewardship, liability, public education, and air quality regulation. To assist in addressing these challenges, a diverse group of public and private leaders collaborated to form a National Coalition of Prescribed Fire Councils (National Coalition) on 16 November 2006. The mission of the National Coalition is to provide a forum for exchange of knowledge and ideas, and to serve as an umbrella organization to provide a more powerful voice through partnering with state and local prescribed fire councils. Since its formation, the National Coalition has reached out to embrace existing councils (extant in only five states in 2006) and provide guidance in the formation of new ones. Membership now includes active or developing councils in 30 states, British Columbia, and Mexico, and we continue to gain momentum. The interim Steering Committee has approved a charter and strategic plan, and is in the process of selecting a Board of Governors. Besides its work in supporting existing councils and assisting in formation of new councils, the National Coalition continues to actively promote the judicious use of prescribed fire as "The Ecological Imperative," to emphasize prescribed fire's ability to enhance public health/safety, and to serve as an advocate for prescribed fire on regional and national levels. The National Coalition strives to facilitate networking among member councils in the belief that by working together we can leverage outreach efforts, including public education; strengthen the role of prescribed burners in fire policy decision making; and speak with a more forceful voice on regulatory issues.

LESSONS FROM THE DEPLOYMENT OF AN AUTOMATED WILDFIRE SENSOR NETWORK IN RUGGED WILDLAND IN SOUTHERN CALIFORNIA

John Kim
Field Stations Program, San Diego State University

At least two models of automated wildfire sensors are commercially available, and promise to be a critical tool in wildland fire protection strategy. I present lessons learned from a 3-year project to deploy and demonstrate a network of automated wildfire sensors in Southern California. In 2004, we began a 3-year project to deploy a network of automated wildfire sensors at the 4,500-acre Santa Margarita Ecological Reserve (SMER). Our goal was to demonstrate their utility as an early-warning system for wildfires to the surrounding rural communities. We used FireAlert-DCS by Ambient Control Systems, Inc., a self-powered, IR-light sensor package. We performed GIS analysis and field reconnaissance to select 13 locations within SMER. In collaboration with the manufacturer, we performed numerous field tests and calibrations. Sensor data were gathered over a wireless network and disseminated via a project Web site. We met with local firefighting agencies and the public to solicit usage of the sensor network. We also evaluated Fire-Scout X3, which uses an ultraviolet sensor. We derived several lessons from our experience: 1) A sensor package intended for backcountry deployment must contain several key features: adequate sensitivity, fail-safe power management, reliable communications unit, and rugged, tamper-proof design. 2) Given the diversity of sensor hardware types and features, and the diversity of environments in which the sensors are to be deployed, clear performance standards and a rating system are needed to guide those selecting and deploying the sensors. 3) Sensor deployment locations are a function of topography, deployment goals, topography, weather, and fire behavior. Sophisticated GIS analysis and fire behavior modeling is required to optimally choose deployment locations for automated sensors. 4) Adoption of this technology by firefighting agencies requires robust proof of system performance and reliability, and seamless integration into agencies' existing information infrastructure. The ability to confirm sensor data via another method (e.g., Webcam) is instrumental. We believe the current state of automated wildfire sensor technology is adequate for structure protection and for deployment as sentinels at limited topographic features. We believe automated wildfire sensors are in relatively nascent stages of development, and their deployment in the backcountry and wide adoption of the technology by the larger fire protection community as well as the public will occur only when the above issues are satisfactorily addressed.

SMOKE MANAGEMENT TOOLS: WHAT MODERN TOOLS WOULD HAVE TOLD US ABOUT YELLOWSTONE

Sim Larkin,[1] Robert Solomon,[2] Tara Strand,[3] Brian Potter,[4] Dana Sullivan,[5] Sean Raffuse,[6] Neil Wheeler,[7] and Pete Lahm[8]

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Since the Yellowstone fires of 1988, advances in fire science and air quality modeling have led to advances in decision support tools. In no field is this more pronounced than in smoke management. Only recently have national systems been developed to predict air quality impacts from fires in real time, and currently there are several such tools available to fire managers and air quality regulators. Related to this is the fact that the public's tolerance for smoke impacts has decreased and that newer scientific studies have led to large reductions in the National Ambient Air Quality Standards. This presentation examines what modern smoke management tools such as the FCAMMS real-time smoke prediction systems, the National Weather Service's smoke prediction system, the Wildland Fire Decision Support System – Smoke module, the longer-range Air Quality Impacts Planning Tool, and others are able to tell us now that we did not know back in 1988. Where possible, this is done by running these tools with the observational information available at the time of the Yellowstone fires, in order to answer the question of how much better prepared our new scientific tools allow us to be in dealing with smoke impacts.

MODIFYING GUIDANCE FOR IMPLEMENTATION OF FEDERAL WILDLAND FIRE POLICY

Richard Lasko
Assistant Director, Fire and Aviation Management, USFS National Headquarters

The changing role of land management plans as defined by the 2008 U.S. Forest Service Planning Rule, recent court decisions on Fire Management Plans, the development of new event-specific decision-making processes (Wildland Fire Decision Support System), and federal land managers declared interest in developing modifications to Federal Wildland Fire Policy, create an opportunity to examine relationships between policy, public involvement, Land Management Plans, Fire Management Plans, and the management of unplanned ignitions. A proposed framework of policy and implementation guidelines is presented.

PREDICTIVE SERVICES UPDATE: IMPROVED 7-DAY AND MONTHLY/SEASONAL WILDFIRE POTENTIAL OUTLOOKS

Rick Ochoa
Bureau of Land Management, National Interagency Fire Center

The Predictive Services program integrates fire weather, climate, fuels, fire danger, and resource information into decision support products for fire managers. The use of these products allows for proactive resource allocation and prioritization to maximize safety, cost containment, efficiency, and ecosystem health. Two of these products have recently been improved to provide more detailed information to the user. The 7-Day National Significant Fire Potential Outlook forecasts fire potential based on fuel dryness, weather, and ignition triggers such as dry lightning. The updated product now includes "High Risk Days" based on either a critical burn environment (fire growth) or ignition triggers (new starts). The enhanced National Wildland Significant Fire Outlook, issued at the beginning of each month, now provides a monthly forecast (above, below, or normal) and 3-month trend forecast (increasing, decreasing, or persisting) of significant fire potential. These products will be described in-depth and will include examples from the 2008 fire season.

THE LARGEST FIRES OF 2005 AND 2006 IN PORTUGUESE NATURAL PARKS: DID THEY CONTRIBUTE TO IMPROVE FOREST FIRE POLICY?

Fantina Tedim
Professor, Faculty of Arts

In Portugal, all protected areas acknowledge the existence of a policy of forest protection against fire, which includes prevention and surveillance measures as their main priorities. There is a generalized belief that there have been improvements in forest fire prevention over the last few years, especially due to the availability of a greater number of surveillance and detection means that are highly effective in dissuading possible criminal actions, but are also pedagogically efficient as they alert the populations to risk behavior. Since the decrease of the burned area is intimately related to a fast and effective initial attack, the surveillance teams in some protected areas are also equipped with a first intervention kit. These initial attack teams are generally very effective because they are highly trained, extremely professional experts who keep regularly updated on the latest techniques. Despite all these measures, recent data suggest that the largest forest fires that affected the Portuguese natural parks occurred in 2005 and 2006. We have chosen the five biggest events, with >2,200 ha of burned area, which affected areas with different biogeographical, topographic, and demographic features to understand the main factors that could explain the severity of these fires. Using the official database on forest fires published by the Institute for Nature Conservation and Biodiversity and interviews of Natural Park management, firefighters involved in suppression operations, and representatives of affected communities, this paper intends to 1) present the main characteristics of the forest fire episodes (locale of ignition, hour, duration of the fire, human and technical resources used in the combat, fire suppression strategy); 2) describe the geographical characteristics of the area affected and the conditions of fire propagation; 3) explain the causes of these largest forest fires; and 4) identify the different factors that explain the largest area burned. Our main concern is to understand if the lessons taken from these severe events contributed to improve the forest fire management policies as far as protected areas are concerned.

THE DEVELOPMENT OF SHIFT FOOD LUNCHES FOR WILDLAND FIREFIGHTERS

Steven Gaskill
Ph.D., The University of Montana, HHP Department

PURPOSE: The purpose of these studies was to evaluate work shift food strategies to improve physical and cognitive performance of wildland firefighters (WLFF) during the course of repeated work shifts. METHODS: During the 2003 to 2007 fire seasons, a variety of strategies were used to evaluate both cognitive and physical performance under different supplemental carbohydrate (CHO) and lunch delivery strategies during wildland fires with both type I and II hand crews. We first evaluated the effects of hourly CHO supplementation on physical activity, blood glucose, cognitive performance, and immune function during the 2003–2005 fire seasons. In 2006 we provided complete lunches containing multiple small 150- to 200-Kcal food units (Shift food) and requested that WLFF eat small portions spread across the day. During the 2007 seasons, a mobile catering service provided the "shift food sack lunch" (SF lunch) at two major fire complexes. Educational efforts at each camp were made to educate WLFF to eat regularly throughout the day. Subject-satisfaction surveys were administered on the last day of each experimental trial. An option for lower-calorie lunches for in-camp personnel was provided. RESULTS: During 2003–2005, CHO supplementation resulted in the equivalent of about 1.8 more hours of work per shift than with the regular sack lunch. Additionally, WLFF maintained better reaction times, improved immune function, and recovered better for the following work shift (Cuddy et al. 2007). This positive data led to the two shift food trials of 2006 and 2007. The small-scale shift food study in 2006 received excellent qualitative feedback in addition to showing similar work activity results as the CHO trials. Results from the 2007 full fire camp shift food trial were mixed, with 46.0% preferring the shift food to 31.3% preferring the traditional sack lunch. A large number of recommendations, both by WLFF and caterers, were made to improve the SF lunches. The lower-calorie lunch option for camp personnel was well received. CONCLUSIONS: For physically active WLFF, eating smaller amounts regularly across the work period improves both physical and mental performance when compared with normal lunch habits. The SF lunches provided through a catering contract were generally well received, but there were educational and menu problems, resulting in many recommendations for improvements. During the 2008 fire season, we will be implementing an improved SF lunch via a mobile caterer implementing the recommendations. The ultimate goals are improved safety, increased work capacity, ease to carry and eat, and a high level of WLFF satisfaction.

INTERAGENCY COLLABORATION

FIRE MANAGEMENT IN THE GYA TODAY

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ABSTRACT

Question: What is the general status of Āre management today in the Greater Yellowstone Area?

Background: Our objective is to highlight Āre management today. We present a visual depiction of Āre management coordination and cooperation on the landscape in the Greater Yellowstone Area (GYA). The poster emphasizes how we deal with boundary issues, cross-boundary Āres, resource sharing, and planning for Āre starts through collaboration.

Location: The Greater Yellowstone Area (centered on approximately lat 44°47′N, long 109°4′W), Wyoming, USA, which includes parts of six national forests, two national wildlife refuges, and two national parks. Contiguous portions of these lands encompass roughly 14.0 million acres.

Methods: We provide an organizational framework for Āre management coordination and cooperation.

Results and Conclusions: Attendees viewing these posters will have a better understanding of how interagency Āre management programs are implemented in the GYA.

keywords: boundary issues, cooperation, coordination, Āre management, GYA, planning, resource sharing, visual depiction.

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PRESCRIBED FIRE IN MIXED-CONIFER FORESTS OF SOUTHWESTERN COLORADO: A CASE STUDY IN SCIENCE AND MANAGEMENT COLLABORATION

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ABSTRACT

Question: Can better collaboration between scientists and land managers improve the management of a complex forest system?

Background: Major federal legislation has arisen from big wildfire years in the West, most notably in 2000 (National Fire Plan) and 2002 (Healthy Forests Initiative). These initiatives stemmed largely from a single premise—that a century of fire suppression led to increased forest density, and thus to an increased hazard of larger and hotter fires. Management practices aimed at mitigating these conditions were implemented across the western United States. Banded Peak Ranch, a large property bordering the Continental Divide in southwestern Colorado, followed this general trend in its prescribed fire program. With little information available on the use of prescribed fire in mixed-conifer forests, the program's efforts were based on standard prescriptions and objectives for ponderosa pine (*Pinus ponderosa*) stands, which had been the focus of most early fire regime research. Over time, it became apparent that new objectives and techniques were required. Many questions arose that could not be answered with existing data. What are appropriate objectives for prescribed fire in mixed fuels? Are low-intensity fires appropriate in mixed-conifer stands? If so, at what interval? Is thin/burn an appropriate treatment? To help answer these questions, the ranch collaborated with researchers from Colorado State University, designing a study specific to our management goals. Given that historical fire regime in the mixed-conifer forest type, particularly on cooler, wetter aspects, is not well understood, our study objectives were as follows: 1) to ascertain the relative proportion of high-frequency, low-severity fire vs. low-frequency, stand-replacing fire; 2) to investigate the possibility of a mixed-severity fire regime; and 3) to determine whether the current status of the forest is primarily within or outside of its historical range of variability.

Location: Bounded by the Continental Divide in the San Juan Mountains, Banded Peak and its sister ranches together comprise >55,000 acres centered at approximately 37.1°N, 106.7°W.

Methods: Core and remnant samples were collected in 2007 from >1,300 trees in 45 plots at various spatial scales across the study area. Fire scar samples were also collected at each plot when available. Dendrochronological methods were used to date the samples for age structure and fire history.

Results: A paucity of fire scars—among the species known to scar—suggested that the "low-severity/high-frequency" fire regime type was not common on the landscape within the last 2–3 centuries. Among the available, dateable fire scars, 1879 appeared as a fire date on nearly half the samples, indicating widespread fire. Aspen (*Populus tremuloides*) age structure data showed a notable spike in recruitment throughout the ranch in the decade of the 1880s, supporting our findings in the fire scar sampling and indicating that these fires burned at a high severity, i.e., they were stand-replacing fires. Preliminary conifer age data showed that extensive tree recruitment began in the mid-19th century and continued into the early 20th century, with the majority of sampled trees being <150 years old. In the minority were some older living trees, including ponderosa pine and Douglas-fir (*Pseudotsuga menziesii*) dating to the 1700s, and at least one living Douglas-fir dating to the mid-1600s. These older, living trees were found both in stands including fire scars and stands without fire scars. This suggested that patches of low-severity and high-severity fire generally were closely intermingled among the stands we sampled, and that intervals between successive high-severity fires at a point on the ground varied widely (up to several centuries). This represents a complex historical fire regime, sometimes referred to as a "mixed-severity" fire regime. Fire frequency and severity varied from place to place across the landscape, and probably varied through time at any given location.

Conclusions: The diversity of the ranch's mixed-conifer forests is valued from both ecological and fire management perspectives. This diversity appears to be declining. Management's initial assumptions were that high-frequency, low-intensity fire was the historic norm and that prescribed fire should be applied as a restoration treatment. This study is changing those early assumptions. If these complex forests evolved in response to a mixed fire regime, then it may be appropriate to consider ways to reintroduce that regime. While it would be ideal to restore mixed-severity fires, current forest conditions, public tolerances, and liability/regulatory concerns largely preclude this. The ranch is now experimenting with a combination of prescribed fire and mechanical thinning treatments, and is collaborating with university researchers and local foresters to monitor their effects. As diversity is restored, it may be possible to allow naturally ignited fires to resume their role on the landscape.

keywords: Colorado, dendrochronology, fire management, fire regime, mixed conifer, prescribed fire, San Juan Mountains.

Citation: Allison, L., and C. Aoki. 2009. Prescribed fire in mixed-conifer forests of southwestern Colorado: a case study in science and management collaboration [abstract]. Page 122 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

COLLABORATIVE FUELS PROJECTS IN UTAH

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ABSTRACT

Question: What is the status of collaboration in the Utah Bureau of Land Management's fuels treatment program?

Background: With the inception of the National Fire Plan and in subsequent supporting documents and legislation, collaboration has been a focus for federal hazardous fuels treatments. Collaboration has traditionally focused on working with cooperators in developing priorities for treatments and on wildland–urban interface projects and community fire-related planning efforts. In Utah, the Bureau of Land Management (BLM) has added depth to our collaborative relationships by working with the State of Utah, other federal agencies, and nongovernmental organizations on hazardous fuels treatments. This collaborative work has allowed for the integration of fuel treatment objectives with other land management activities, including wildlife, range, forestry, and watershed. This work is in concert with current interests in cooperative conservation, where through environmental partnerships the federal government can enhance wildlife habitat, protect the environment, and promote conservation practices.

As part of the BLM's 2008 Fuels Management, Community Assistance and Fire Planning Program Evaluation, Utah's collaborative work was identified as a Best Management Practice within the Bureau. As part of the collaborative effort, interested federal, state, and nongovernmental organizations have set up the Utah Partnership for Conservation and Development (UPCD). UPCD acts as a clearinghouse for multiple funding sources and maintains a list of all planned and implemented projects in the state for all agencies. This unprecedented organization ensures that all agencies plan for multiple objectives and coordinate implementation across agency lines. This multiagency, centralized approach breaks down barriers and provides a vested interest across land ownership boundaries. While much of the collaboration was originally carried out for financial reasons and for providing a greater level of funding towards projects, additional benefits have been realized.

Location: Utah, USA. Statewide, including the Vernal, Cedar City, Moab, Salt Lake, and Richfield fire zones of the BLM.

Methods: Acreage and funding data were collected during summer of 2008.

Results: Since the start of the National Fire Plan in 1991, 72 projects for 225,250 acres of collaborative treatments have occurred on the >343,736 acres of land treated for hazardous fuel treatments. The contributed funds total $9,866,927 on these 72 projects.

Conclusions: As identified throughout this paper, the BLM's hazardous fuels program in Utah has benefited in numerous ways through the development of various collaborative partners. These partnerships continue to expand in numbers and scope throughout the state. It is expected that collaborative activities will continue well into the future as both the BLM and partner agencies and organizations reap the benefits of collaborative working relationships.

keywords: collaboration, fuels, fuels management, hazardous fuels treatments, National Fire Plan, partners.

Citation: Washa, J.B. 2009. Collaborative fuels projects in Utah [abstract]. Page 123 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

NATIONAL PARK SERVICE COMMUNICATION AND EDUCATION PROGRAM: A REGIONAL PERSPECTIVE

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ABSTRACT

Question: How does the National Park Service promote Āre communication and education regionwide?

Background: Within the National Park Service (NPS) Intermountain Region, three Fire Communication and Education Specialists currently support 79 parks in eight states. These positions were distributed geographically to divide the region into three zones of support. Each is hosted by a park unit, yet provides broader support by coordinating and collaborating with stakeholders and partners for maximum efficiency and effect; identifying and coordinating the development of products or materials for regional, Service-wide, and interagency use; incorporating the best available science; and enhancing the Service's collective efforts toward its number one priority, ĀreĀghter and public safety.

Location: NPS Intermountain Region (AZ, NM, TX, OK, CO, UT, MT, WY).

Methods: The Intermountain Region Fire Communication and Education program paradigm is presented as a case study.

Results: The Intermountain Region Fire Communication and Education has developed a regional program that emphasizes disseminating NPS Āre ecology and science-based Āre management accomplishments to a wide audience, coordinating landscape-scale fuels management and Āre-use strategies with neighbors and cooperators, supporting community assistance in concert with partners, and actively participating in small and emerging park programs across the region.

Conclusions: Regional resources play a valuable role in facilitating, coordinating, and supporting proactive and coordinated communication with the National Park Service's internal and external audiences to increase understanding and support for Āre and Āre management practices. A comprehensive communication and education program emphasizes the entire scope of wildland Āre management activities, particularly the role of Āre in ecosystems.

keywords: collaboration, communication, education, Intermountain Region, National Park Service.

Citation: Fidler, M., D. Eaker, and T. Weaver. 2009. National Park Service Communication and Education program: a regional perspective [abstract]. Page 124 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

NWCG FIRE ENVIRONMENT WORKING TEAM—OUR PURPOSE, GOALS, AND RESPONSIBILITY

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ABSTRACT

Question: Describe the purpose, goals, and responsibility of the National Wildfire Coordinating Group Fire Environment Working Team.

Background: The National Wildfire Coordinating Group (NWCG) Fire Environment Working Team (FENWT) is a multiagency committee engaged in fire environment issues. FENWT comprises three subcommittees (Fire Behavior, Fire Weather, and Fire Danger) with specific goals that focus on emerging technologies, research and development, and decision support in the fire environment. These committees play a support role in advancing the mission of NWCG by providing leadership in establishing and maintaining consistent nationwide standards and procedures for the assessment of the wildland fire environment. Furthermore, the committees facilitate consistent and standardized use of ongoing science- and knowledge-based information to support management decisions made by wildland fire agencies in fire prevention, preparedness, suppression, fire-use activities, and to enhance firefighter safety. This poster is designed to raise awareness about FENWT's goals, current projects, and our dedication to supporting the fire community.

Location: United States.

Methods: The NWCG Fire Environment Working Team (FENWT) and its three subcommittees meet twice annually face to face and schedule monthly conference calls as a means of communicating and advancing the committee goals and strategic plan. Each subcommittee reappraises its charter and strategic plan yearly in order to maintain focus and reaffirm group projects and goal.

Results: The overall guidance and direction taken by the three subcommittees that constitute FENWT work closely with the parent body to maintain a focused strategic plan. Each subcommittee is given the freedom to establish a working agenda that prioritizes committee goals and objective that fall under the scope of FENWT's strategic mission. It is important to maintain various pathways of communication in order to advance the FENWT mission statement at various agency levels with the overriding goal being firefighter safety. This is done by integrating the latest peer-reviewed science into the current curriculum and maintaining an ever-evolving training program. FENWT and its subcommittees recruit members from diverse multiagency backgrounds as a means of ensuring a progressive evolution to the NWCG training.

Conclusions: The NWCG Fire Environment Working Team (FENWT) and its subcommittees are composed of agency personnel who are leaders in their individual areas of expertise. These individuals not only bring a wealth of knowledge to the FENWT infrastructure but are the underlying thread for communicating the needs of managers in the field to evolving research and training efforts.

keywords: fire behavior, fire danger, fire weather, National Wildfire Coordinating Group, NWCG.

Citation: Jimenez, D., P. Schlobohm, and B. Butler. 2009. NWCG Fire Environment Working Team—our purpose, goals, and responsibility [abstract]. Page 125 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

INTERAGENCY COOPERATION IN FUELS AND FIRE ECOLOGY IN THE NORTHERN GREAT PLAINS

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Land management decisions require a strong scientific foundation to inform the planning process and guide future management of public lands. In South Dakota, the Bureau of Land Management (BLM) and the National Park Service Fire Ecology Program cooperated on a project to collect fuel treatment and fire ecology data for inclusion in the statewide BLM Resource Management Plan. This interagency study represents the first time fire history, fuels data, and fuel modeling information have been included in this planning document. This collection of baseline fire ecology information represents a successful interagency partnership in fire and fuels management. This project utilized a rapid site assessment protocol on lands across the state in a variety of fuel and vegetation types. We assessed fire regime condition class, provided a general description of the vegetation community, identified nonnative species issues, and listed relevant fuel models. Additional products included photopoints with watermarked, geo-referenced images for each site visited. A continuation of the project during the 2008 field season will collect stand structure and fuel loading data for BLM-managed sites in the Black Hills of South Dakota. This monitoring and site assessment will provide BLM managers with quick and inexpensive tools to determine the results of fuel management projects, and will aid in generating more informed fire and fuels management decisions.

INTERAGENCY FIRE EFFECTS MONITORING: A PROJECT-LEVEL APPROACH

Kristen Shive
Lead Fire Effects Monitor, Grand Teton National Park

For the last several decades, prescribed fire treatments have been conducted in northwestern Wyoming as a result of strong interagency cooperation between the Bridger-Teton National Forest (BTNF), Wyoming Game and Fish Department (WGFD), and Grand Teton National Park (GTNP). In 1998, the need for a consistent monitoring program for GTNP fire management projects resulted in the creation of a National Park Service (NPS) fire effects monitoring crew; 1 year later, the BTNF agreed to provide funding support for this monitoring and the Teton Interagency Fire Effects Crew was established. The crew is part of the Teton Interagency Fire Program, represented by two federal agencies: the United States Forest Service (via the BTNF) and the National Park Service (via GTNP). The Wyoming Game and Fish Department continues to work alongside these agencies in support of prescribed fire projects. With the new interagency crew, the monitoring program began to diverge from other traditional NPS fire effects programs. While the program began by using the NPS *Fire Management Handbook* plots and protocols, it became clear over time that this approach did not adequately monitor local objectives, nor did it provide timely assessments of whether or not those objectives were being met. In order to better inform future management decisions as they apply to both the myriad of vegetation types and to site-specific management goals, the fire effects monitoring program has taken a project-level approach. Annual interagency meetings are held to discuss proposed projects and objectives. Once objectives are delineated, individual monitoring plans are developed. Protocols and monitoring schedules are tailored to each project and results are shared annually at interagency planning meetings, as well as at the annual Teton Interagency Fire Science Symposium. The direct feedback facilitates timely responses that enable adaptive management on both current and future projects. These responses can include changes to the treatments, tools used, monitoring design, and/or to the objectives themselves. By providing quick feedback on project successes, future management decisions can be more efficient and effective.

NWCG'S FIRE WEATHER COMMITTEE: PROVIDING LEADERSHIP TO IMPROVE FIRE WEATHER OPERATIONS AND DECISION SUPPORT FOR FIRE MANAGEMENT

Rick Ochoa
Bureau of Land Management, National Interagency Fire Center

The Fire Weather Committee (FWC), formed in 2007 under the auspices of the National Wildfire Coordinating Group's (NWCG) Fire Environment Working Team, provides leadership to improve fire weather operations and decision support for effective fire management. It consists of 10 members who represent the federal wildland fire agencies, the western and eastern states, wildland fire agency and academic atmospheric research, Predictive Services, the National Weather Service, and fire operations. Through collaborative efforts and input from user groups at all levels across the United States, the FWC strives to improve weather data, products, and services to provide wildland fire management with the best information and ultimately enhancing wildland fire decisions. The FWC has identified the following goals:

- Products and services
- Standards and policy
- Technology
- Research and development
- Communication and dissemination
- Education

Recent activities of the FWC include updating the *NWCG Fire Weather Station Standards* handbook, reviewing Remote Automatic Weather Station (RAWS) standards, and exploring the development of a one-stop Web site for fire weather, fuels, fire danger, etc.

NPS SOUTHWEST AREA WILDLAND FIRE COMMUNICATION AND EDUCATION STRATEGY AND TOOLBOX

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A National Park Service (NPS) Fire Communication and Education Strategy and Toolbox were developed for the Intermountain Region Southwest Area (Arizona, New Mexico, Texas, and Oklahoma). The goal of the project was to develop an easy-to-use tool for parks with little to no fire information experience to be able to easily implement successful fire communication and education activities. The strategy outlines overarching objectives, key messages, target audiences, strategies, tactics, implementation timeline, and evaluation. An accompanying toolbox reorganizes and expands upon existing resources, including the NPS Information Officer Toolbox and the NWCG Communicator's Guide for WIldland Fire Management. The toolbox provides links to resources for outreach methods, resources, and issues. For each outreach method, templates and/or detailed examples are provided, along with specific hazard communication tips. Resources include communication planning, emergency action plan, forms and templates, talking points, and Spanish resources. Issues range from fire behavior to invasive species to evacuations. These products were compiled in response to frequently asked questions and requests for assistance by Southwest Area parks. The strategy and toolbox is the product of a cooperative effort by NPS and Stephen F. Austin State University as part of the requirements for the degree of Masters of Science in Resource Interpretation.

CENTENNIAL VALLEY FIRE LEARNING NETWORK: A COLLABORATIVE APPROACH TO RESTORING FIRE

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The Centennial Valley Fire Learning Network (FLN) provides a model of integrated fire restoration at a meaningful scale across several jurisdictions. Since 1988, there has been an increasing understanding about both the role that fire plays in ecosystems in the Greater Yellowstone Ecosystem and the variability of fire regimes across the area. Through collaborative workshops among agencies, landowners, and nongovernmental organizations (NGOs), partners have brought diverse strengths together to develop holistic visions and accepted solutions for sustaining fire-related conservation targets and communities. The 400,000-acre Centennial Valley of southwest Montana is a hot spot of biological diversity, important linkage habitat for carnivores, and one of the last large, undeveloped, low-elevation valleys in the Greater Yellowstone Ecosystem. The long-term viability of several ecological systems in the Centennial Valley depends upon ecologically appropriate fire. Conservation planning in the Centennial Valley identified altered fire regimes as a key stressor for the following targets: sandhills communities, aspen woodlands, old-growth Douglas-fir stands, and west-slope cutthroat trout. These conservation targets occur across lands managed by the BLM, USFWS, USFS, State of Montana, TNC, and private landowners, yet effective stewardship requires an integrated approach. Different mandates and expertise result in different solutions to common problems, but a collaborative vision and framework for monitoring and measuring success can turn those differences into assets and promote learning through active adaptive management. There is no substitute for collaboration when it comes to restoring the complex role of fire at ecologically appropriate scales. A learning process that includes stakeholders in the visioning process produces more refined strategies that have broader support among the private and NGO partners.

SPECIAL TOPICS IN FIRE MANAGEMENT

MILITARY SUPPORT FOR WILDLAND FIRE FIGHTING: FROM YELLOWSTONE '88 TO TODAY

Richard Jenkins
Colonel, U.S. Army, Defense Coordinating Officer, Region X, U.S. Army North

This presentation will provide an overview of the wildland fire suppression role of the U.S. military during the 1988 wildland fire season and examine how that role has changed since 1988. We will discuss the background on the agreement between the Department of Defense (DoD) and the Departments of Agriculture and Interior concerning military support in forest and grassland fire emergencies in the continental United States. The use of the U.S. military during the 1988 wildland fire season will be presented. Further, we will examine the employment of both military ground and air assets for fire suppression during the period 1989 to 2006. Finally, we will discuss the changes in defense support to civil authorities resulting from the terrorist attacks on the United States in 2001 and natural disaster consequences in the aftermath of Hurricane Katrina in 2005. These events led to the establishment of the U.S. Northern Command, U.S. Army North, and permanently assigned Defense Coordinating Officers and Defense Coordinating Elements at each of the 10 Federal Emergency Management Agency regions. Some of the topics we will examine include the forces DoD has available for wildland firefighting (modular airborne firefighting systems, ground units, helicopters, imagery, civilian DoD firefighters) and how those forces are activated in support of the National Interagency Fire Center.

CRIMINAL FIRE LAW

Michael Johns
Assistant U.S. Attorney, Senior Litigation Counsel, District of Arizona

Burnover fatalities currently create a random collision of law, policy, fire science, safety science, politics, sociology, and psychology among those who will judge the bad outcome. The judges include survivors, family members, peers, media, interest groups, elected officials, agency administrators, accident investigators, writers, prosecutors, trial judges, and jurors. Law instructs us not to judge foresight in the light of hindsight. Science instructs us that this is impossible unless outcome knowledge is actually withheld from the judge. This creates serious problems, which require serious solutions. The presentation will provide context for the Panel Discussion on criminal liability in fatality fires. A paper covering this subject will be available from the presenter, along with a paper prepared for the Serious Accident Investigations Course, "What Was He Thinking: Beyond Bias—to Decision Making and Judging." Legal principles applicable to manslaughter prosecutions will be explained in the context of post-accident investigations by USDA, DOI, OIG, OSHA, and DOJ. Subjects include the role of the U.S. Attorney; standards of proof at the administrative and judicial levels; important rules and practices applicable to criminal prosecutions; the use of accident reports; use of the 10 Standard Fire Orders and the 18 Watchout situations in accident investigations, and civil, and criminal litigation; the "discretionary function" exception's relation to criminal law; and pretrial diversion. Willful violation of OSHA's safe working conditions regulation in relation to the Hazard Pay regulation will be examined in the context of the Cramer Fire. Self-incrimination in fatality fire situations will be covered, including OIG warnings, the *Garrity* case limits on use of compelled statements, and the ability of agencies to compel statements and/or take disciplinary action for refusal to give a statement. Concerns about existing rules and policies that provide liability problems for firefighters, and changes being brought about by implementing new doctrine, will be addressed. Recent gains in cognitive science will be explored in the context of decision making, decision support systems, high reliability organizing, and achieving a just culture in which to fight fire, investigate accidents, improve safety, and provide for accountability. Cognitive biases, heuristics (mental shortcuts), coherence theory, critical thinking, counterfactual reasoning, causal attribution theory, and decision theory will be addressed for both decision making on the fire ground and judging those decisions in hindsight. A joint effort by all the federal agencies to meet and form mutual understandings for all aspects of burnover cases, would significantly improve the response to future accidents. It would also reduce the anxiety that occurs following a burnover fatality.

GA/FL FIRES 07–YELLOWSTONE 88: COMPARE AND CONTRAST

Mike Zupko
Executive Director, Southern Group of State Foresters

This presentation will be a look at a recent large-scale fire event in the southeastern United States and make comparisons to Yellowstone '88 and discuss what changes since '88 were utilized during the recent fire(s) in the Okefenokee Swamp, Georgia, and surrounding private and state lands. Looking back 20 years, there are many technologies, concepts for management, and dare I even say tactics that are drastically different (and hopefully improved/enhanced), but are by no means perfect, nor will they ever be. It will pull in some of the differences between more of a purely federal fire event/response ('88) with what was most definitely a joint event in Georgia and Florida, especially in Florida where they operate under unified command (state/federal/local) for nearly every fire. It will be interesting to non-Southern folks to learn of some of the geospatial technologies utilized (Southern Wildfire Risk Assessment), joint command lessons, and potentially tactics, and would be interesting to the Southern folks there to hear the comparison/contrast being made to the '88 fires. The presentation will focus on the policy impact, potential for change, and will focus more on the lessons learned and opportunities for continued learning within the wildfire community from large (and even small) fire events.

SCENERY AND ECOSYSTEMS 1988–2008: TWENTY YEARS OF REPEAT PHOTOGRAPHY AFTER THE YELLOWSTONE WILDFIRES

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ABSTRACT

Questions: What are the short- and long-term effects of wildfire on Yellowstone's scenic resources? How do the short- and long-term effects differ, and should management address these differences? Should the National Park Service develop a system for conserving scenery, what would be its components, and how would it address the paradox of visitor experience versus conservation of scenery and ecosystems? How successful is short- and long-term repeat photography for understanding the relationship of scenery and fire, and what lessons have been learned over the 20-year course of this research?

Background: Scenery is the most important visitor experience and the first resource cited in the National Park Service's (NPS) 1916 Organic Act. This research explores the relationship of Yellowstone's *scenery* and wildfire.

Location: Yellowstone National Park (centered on approximately lat 44°47′N, long 109°4′W), Wyoming, USA.

Methods: Since 1988, the author has photographed the aftermath of the Yellowstone wildfires. Photographs were taken from >300 points. Approximately 50 "typical" Yellowstone scenes were selected for annual repeat photography, illustrating how the fires affected the Yellowstone scenery short term, how some areas have "recovered" scenically (others not), and how repeat photography can monitor the recovery of Yellowstone's scenic resources long term. This on-going research was first reported at the International Association of Wildland Fire conference in 1995, only 7 years after the wildfires. The results and implications of 20 years of research are reported here.

Results and Conclusions: Ecosystem and scenery recovery are not the same. Fire is necessary in the ecosystem, fire management actions will affect scenery, and therefore their relationship must be better understood. Research, such as reported here, is one step in that direction.

The photographs document Yellowstone's ecological recovery, but more importantly for this research illustrate the wildfires' impacts on the park's scenery. Image analysis reveals several interesting factors in the relationship of fire and scenery. Short term, many people find the "devastation" disturbing yet undeniably fascinating. Scenes of primarily foreground landscape reveal additional aspects of the scenic resource impacts. The mosaic effect offers the most visual variety in middle-ground and background scenes. Slope is a major factor in scenic resource recovery. Additional implications are reported.

Repeat photography has been used as a research tool before; however, there is no known research of this study's scope and duration related to the impacts of public-land wildfire on scenic resources, and the short- and long-term recovery of those resources. This research has significant implications for NPS fire management policy as well as for other state and federal land management agencies.

keywords: repeat photography, scenery, scenic resources, wildfire.

Citation: Ellsworth, J.C. 2009. Scenery and ecosystems 1988–2008: twenty years of repeat photography after the Yellowstone wildfires [abstract]. Page 129 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

MYTH BUSTING ABOUT FIRE: ARE ANIMALS GETTING BURNED?

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ABSTRACT

Question: Are current public perceptions accurate about wildlife being endangered by fire?

Background: Emotions run high and perceptions diverge from reality when most people imagine wildlife encountering fire. A generally accepted belief that fire poses a danger to animals has been unwittingly reinforced by 65 years of Smokey Bear, a singed cub turned fire-prevention icon, and >50 years of Disney's Bambi and friends running in fear from fire. Without being balanced by factual information, the influence of these familiar characters, mixed with strong public support for protecting wildlife, fosters counterproductive sentiments about fire. Public discomfort with fire, along with images of fictitious animals in fear of fire, furthers the exclusion of fire needed in natural areas supporting wildlife. The absence of fire inadvertently leads to overgrown vegetation that chokes out usable habitat and generates more hazardous conditions, decreasing benefits to both wildlife and people. Accurate information about the immediate effects of fire on wildlife is critical to promoting support for long-term, ecologically sound fire management practices.

Location: Contiguous United States and Alaska, USA.

Methods: Review of limited scientific research available online and collection of anecdotal evidence and photographs, 1925–2008.

Results: Research on this topic is sparse. That data and personal accounts from the fireline paint a picture of wildlife reacting in ways different from Bambi or Smokey's friends on fire-prevention posters. Wildlife species have evolved with fire in natural areas and know how to respond to it. Animals, like people, know all the ways in and out of their homes and have a range of reactions to fire. An animal's response depends on its species, its habitat, and the fire's behavior. Most wildlife have the ability to move away from fire. In any case, successful wildlife management focuses on the health of animal populations, not individuals. Wildlife managers have been using fire since the 1930s to improve habitat conditions, even at the risk of harming individual animals. While wildlife mortality in any fire event is possible, the overall immediate impact on wildlife populations is generally minimal. Fire will kill a few individuals but not entire populations. This is true even with rare populations in isolated geographic areas. More animals are burned in fast-moving, high-intensity fires that may limit opportunities for escape. Prescribed burns can be designed to provide escape routes and timed to avoid nesting season. But wildlife don't always flee from fire. Slow, creeping ground fires actually provide opportunities for many mammals and birds to forage and hunt. Some insects are attracted by smoke, seeking out weakened trees, and are then followed by other animals seeking them as a food source.

Conclusions: While a few animals in the wild are sometimes trapped or burned during wildfires, most remain unharmed and many actually benefit. Whether retreating to safe areas when necessary or taking opportunities to hunt or forage, wildlife are no strangers to fire. Though fire can harm individual animals, it does not destroy entire wildlife populations or species. Most animals survive fire and enjoy better living conditions afterwards. When fire is excluded from natural areas, risks increase and benefits decrease for wildlife. While fast-moving, high-intensity fires pose greater dangers for wildlife, fire remains critical for keeping wildlife habitat healthy. Prescribed burns can be planned to ensure escape routes for wildlife and avoid mating and nesting seasons. By presenting a complete picture about the risks and benefits of fire to wildlife, we can raise public confidence in the natural role of fire and build support for ecologically sound fire management.

keywords: animals, Bambi, fire prevention, prescribed fire, Smokey Bear, wildlife.

Citation: Miranda Gleason, K., and S. Gillette. 2009. Myth busting about fire: are animals getting burned? [abstract]. Page 130 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

FIRE ON THE LAND

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The landscape that European Americans first saw when they traveled west was not a natural terrain in the sense of being untouched by humans. It was a cultural landscape in which the plant and animal communities had been shaped in large part by 12,000 years of burning by Indian people. Understanding how and why Indians burned and the impact that Indian burning had on ecosystems is crucial if today's managers are to restore fire to the landscape. Indeed, it could be argued that true restoration is not possible unless we understand how, when, and why Indian people used fire. The goals of the project were to restore an appreciation for the depth and complexity of the Salish, Kootenai, and Pend d'Oreille's use of fire and to improve the Tribes' and other land management agencies' ability to implement prescribed burn plans in the Northern Rockies by increasing the public's knowledge about the major role that fire has played in the forest ecosystems of the region. The tribes interviewed tribal elders, reviewed existing oral history archives, and conducted in-depth historical research to produce an integrated set of educational materials. These materials include 1) a storybook; 2) an iconographic storybook DVD; 3) an interactive DVD on the Indian use of fire, fire ecology, and modern-day fire management activities on the Flathead Indian Reservation; and 4) a Web site. It is hoped that these materials will increase public acceptance of prescribed fire by helping to inform both tribal and non-tribal people about the historic use of fire by Indians and how the native plant and animal communities that we have inherited are the legacy of those fires. In the end, it is our hope that these materials will benefit the Tribes and can be used as a template for other forest managers.

PERISHABLE NATIVE AMERICAN STRUCTURES AND RELATED SITES IN THE GYE OF NORTHWEST WYOMING

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Bighorn sheep traps in foothill/mountain zones of northwest Wyoming have attracted interest since the late 1800s. Past studies linking Protohistoric and Early Historic Shoshonean groups with sheep trap construction and use did so with limited material or ethnohistoric evidence. Post-wildfire assessment of high-elevation traps and other sites in the Absaroka Range has revealed site types that both provide physical evidence for a Shoshonean connection to trap construction and demonstrate that a regional decline in forest health may lead to increased wildfire and a general loss of data related to Native American use of high-elevation environments.

NEW DIRECTIONS IN WILDFIRE RISK MANAGEMENT

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Historically, wildfire research in Australia and the United States has focused on the geophysical dimensions of wildfire hazards and disasters, with only marginal consideration of how cultural, social, economic, and political factors shape people's vulnerability to fires. In recent times, social scientists have begun to question what makes people and communities vulnerable or resilient to wildfires; however, the vast majority of this work has focused narrowly on cognitive processes of hazard perception and decision making. This paper critiques social science research on wildfires in Australia and the United States. It is argued that to understand wildfire vulnerability and resilience, greater attention must be paid to the social, economic, and political contexts in which wildfires occur, decisions are made, and actions are taken. Drawing on evidence and examples from a case study of community vulnerability to wildfires in rural southeast Australia, the paper highlights how the pressures and challenges of people's everyday lives—such as climatic variability, low incomes, low levels of service provision, political marginality, and social disadvantage—increase people's exposure to wildfire hazards and reduce their capacities to cope with and adapt to possible impacts. The paper concludes with a discussion of the implications of research on vulnerability and resilience for wildfire management in Australia and the United States. This work is funded by the Australian Bushfire Cooperative Research Centre.

USE OF SPOTS (STRATEGIC PLACEMENT OF TREATMENTS) ANALYSIS IN WUI HAZARD REDUCTION PLANNING IN SOUTHEAST BRITISH COLUMBIA

Robert Gray

The Resort Municipality of Kimberley is located in southeastern British Columbia in the Rocky Mountain Trench. The municipality is in the process of transitioning its economy from a long history of mining and timber extraction to tourism and recreation. Property values are rapidly increasing, and population demographics are shifting to young professionals, retirees, and seasonal residents. Unmanaged forests adjacent to the municipality have historically been widely used by both residents and nonresidents for hiking, mountain biking, cross-country skiing, etc. These same ecosystems have undergone significant changes in structure, composition, and function, since the late 1800s. Nearby fire-history reconstructions point to historic fire regimes characterized as either frequent, low severity, or frequent, mixed severity. Current-century fire history points to a large number of fires that either burned through the town or threatened it. Compounding the wildfire threat is the current mountain pine beetle epidemic killing both lodgepole and ponderosa pine. Following the 2003 fire season, the municipality embarked on Community Wildfire Protection Planning and fuel treatment operations. Initial treatment activities received minimal opposition; however, plans to treat large areas of Crown land received a great deal of obstruction. Issues identified by the public included access for treatments and suppression resources, intensity of treatments, treatment cost, funding, long-term forest management objectives, and long-term commitments to maintenance. Identifying a minimal amount of area to treat, the spatially high-priority areas to treat, and the intensity of treatment were seen as primary planning objectives. A suite of landscape-scale fire growth and fire behavior models (Farsite and FlamMap), coupled with a stand-level fire behavior and fire effects suite of models (FMAPlus), were used in a SPOTS (Strategic Placement Of TreatmentS) analysis format to game the location and intensity of treatments over a range of management alternatives. The alternatives were developed by a stakeholder group consisting of local politicians, government agency representatives, industry representatives, NGOs, chamber of commerce, private landowners, and technical experts from the consulting field. The stakeholder group identified a number of key management objectives, performance measures, and minimal critical threshold values for each alternative. Model runs were then used to assess the objectives and report back to the group. The stakeholder group successfully reached consensus on an ecosystem restoration alternative, although, with a price tag of upwards of $10 million, there is concern that the plan is too expensive.

STATISTICAL ANALYSIS OF LARGE WILDFIRES USING EXTREME VALUE ANALYSIS

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Large, infrequent wildfires cause dramatic ecological and economic impacts. Consequently, they deserve special attention and analysis. The economic significance of large fires is indicated by the fact that approximately 93.8% of fire-suppression costs on U.S. Forest Service land during the period 1980–2002 resulted from a mere 1.4% of the fires. Further, the synchrony of large wildfires across broad geographic regions has contributed to a budgetary situation in which the cost of fighting wildfires has exceeded the Congressional funds appropriated for suppressing them (based on a 10-year moving average) during most years since 1990. In turn, this shortfall has precipitated a disruption of management and research activities within federal land management agencies, leading to a call for improved methods for estimating fire-suppression costs. Understanding the linkages between unusual natural events, their causes, and economic consequences is of fundamental importance in designing strategies for risk management. Standard statistical methods such as least squares regression are generally inadequate for analyzing rare events because they focus attention on mean values or "typical" events. Because extreme events can lead to sudden and massive restructuring of natural ecosystems and the value of economic assets, the ability to directly analyze the probability of catastrophic change, as well as factors that influence such change, would provide a valuable tool for risk managers. Over the past few decades, special statistical methods, known as *extreme value* models, have been developed for analyzing the probability of catastrophic events. Extreme value models utilize stable distributions, including the heavy-tailed Pareto, and have been applied to problems in ecology, finance, and insurance. The goals of this paper are to 1) show how extreme value methods can be used to link the area burned in large wildfires with a set of explanatory variables, and 2) demonstrate how parameters estimated in the linkage function can be used to evaluate economic impacts of management interventions. The statistical methods are applied to an empirical analysis of nearly a century of fire history in the Sierra Nevada of California. The linkages between catastrophic wildfires and a set of explanatory variables, including climate and aircraft suppression, are discussed along with the implications for fire management decision making.

ORGANIZATIONAL LEARNING AND CHANGE: FACING THE FIRE

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Faced with increasing numbers of catastrophic wildland fires, diminishing resources, and longer and more intense fire seasons, wildland fire agencies are finding themselves in the grip of an emerging dilemma. Belief systems and values that have once served management so well in the past can no longer deliver the quick fix or any real lasting relief. As wildland fire organizations dig into the work of strategic planning, other organizations around the world are experiencing massive institutional failure. In an effort to "fix" their way out of dilemmas, organizations are unintentionally creating more of what they do not want. We are in fact blind to our own tendencies that shape the organizations we live and work in throughout most of our lives. This plays a huge role in sustaining our inability as humans to successfully manage problems and issues. The temptation to rush into action needs to be tempered with a new capacity for collective leadership. To engage the planning or problem-solving process in a more conscious, intentional, and strategic way may seem like common sense but is in fact not commonly practiced. Without addressing this human factor, potential failure may be imminent. Taking a long and "real" look at the organization during its good and bad times while speaking to the truth of the situation—everyone's truth—is of vital importance. The concept is simple yet challenging in application. Developmental practices such as truth telling and assumption testing are essential in the cultivating a "high awareness" culture. When trust is present, people begin to build the capacity to operate as highly effective teams and are able to collectively create a future of greater possibility. Our ability to put learning into action hinges on this very capacity. Research has concluded that organizational failure is attributed to two basic defensive strategies that emerge when humans are exposed to threatening or embarrassing situations. This defensiveness is described as controlling people through domination and/or by maintaining polite relationships. Both strategies are manipulative and dishonest in nature in order to protect personal interests. What makes it manipulative is that one person unilaterally decides for the other person what is good for them without asking for their input. The result is usually translated into a climate of low trust among members of the team. Developmental practices such as good dialogue, candor, and collective learning are foundational to any initiative implemented by a human system. These practices are highly valued and espoused by organizations but are rarely seen in action. Not walking the talk creates a team disconnect that breeds cynicism and low trust.

SHAPING PERCEPTIONS: WILDLAND FIRE EDUCATION AND OUTREACH

PARTNERS IN FIRE EDUCATION: CREATING SOCIAL ACCEPTANCE OF FIRE MANAGEMENT ACTIVITIES

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ABSTRACT

Question: What are the key public attitudes with regard to fire and what messages resonate with the public to increase their acceptance and understanding of the ecological role of fire?

Background: Wildland fire management in the United States is becoming increasingly complex and costly given a variety of factors, ranging from the largely unchecked growth of the wildland–urban interface to the effects of climate change. While fire managers and scientists are increasingly aware of this need, and fire policies are evolving to better enable implementation of a full range of ecologically and socially appropriate fire management options, public acceptance of alternatives to suppression has not kept pace with these changes.

To change this dynamic, Partners in Fire Education (PIFE), a broad stakeholder and interagency Steering Committee, under the umbrella of the Western Governors' Association's Forest Health Advisory Committee, used public opinion research and social marketing techniques to create a public education program focused on the beneficial role of fire.

The two key goals of the research were 1) to establish a baseline of public attitudes toward fire from which to measure future changes in attitudes, and 2) to craft language and messages that increase acceptance of an ecological role for fire. The ultimate goal of the program will be to allow land managers to use all the tools available for fire management where appropriate, not just suppression.

Location: Nationwide with emphasis in fire-prone forested counties in the Southeast and West, fire-prone grassland/shrubland counties in the Rocky Mountain and Plains states, and southern California.

Methods: Telephone interviews were conducted with adults aged 18 and older among four distinct audiences: 800 adults nationally proportionally throughout the United States; 400 adults in fire-prone counties in forested areas in the West and Southeast; 400 adults in fire-prone counties in shrubs/grasslands in the Rocky Mountain and Plains states; and 400 adults in southern California. Interviews nationally and in the forest sample were conducted 23–26 February 2008.

Results: The research found that while Americans have a fairly sophisticated understanding of the ecological role of fire, they do not have much experience with wildfire or fire use and have a strong fear of fire. 1) Three-fourths of people agree that "some fires in natural areas are beneficial." 2) Two-thirds of people understand that "putting out all fires in natural areas can create conditions that will make later fires burn faster, hotter and more out of control."

Overall, the public supports proactive management activities. The following approaches were idea tested in the research: 1) Allow fire teams to use controlled burns when and where doing so will safely reduce the amount of fuel for fires: 90% support, 52% strongly support; 2) Cut and remove overgrown brush and trees in natural areas that act as fuel for fires: 79% support, 51% strongly support; 3) Allow naturally started fires that do not threaten homes, people, or the health of that natural area to take their natural course, rather than putting the fire out: 62% support, 31% strongly support.

Still, a strong minority did not know or care enough about wildfire to form an opinion about fire management. A striking number of Americans (45% nationally and 49% in forest wildland–urban interface or WUI) are unsure whether the management approaches described in the quantitative survey would be a step in the right or wrong direction.

Conclusions: The knowledge gap identified in the survey indicates there is opportunity and need for a public education campaign simply to increase awareness. Once people get more information on the issue, they move to support for appropriate fire management actions. These findings indicate that persuasion and communication can work to close the gap if the right messages are used consistently.

These three key messages should be used at every opportunity to communicate about fire: safety, emphasize cost-effectiveness, and connect healthy natural areas to benefits for people.

Specific words and phrases were tested with the public in order to learn what language will effectively communicate about fire use. For effective communication use:

Natural areas not *Wildland*, *ecosystem*, or *landscape*
Homes near natural areas not *Wildland–urban interface* or *WUI*
Controlled burns not *Prescribed fire*
Cut/remove overgrown trees/brush not *Mechanical thinning*
Manage natural fires where safe not *Wildland fire use*

keywords: communication, controlled burns, cost-effectiveness, human benefits of, messaging, public education, public opinion research, safety.

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1988 YELLOWSTONE FIRES—WINNING HEARTS AND MINDS—SOCIAL AND POLITICAL TRIGGERS AND APPROPRIATE MANAGEMENT RESPONSE

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ABSTRACT

Question: Has public acceptance of naturally occurring Āre, controlled burning, the ecological role of Āre, and the media's portrayal of Āre changed since 1988?

Introduction: Today's appropriate management response to suppress naturally occurring wildĀres in either highly desirable recreation areas such as the greater Yellowstone area or in areas where homes are in proximity to natural or forested regions like those in the Black Hills, South Dakota, is arguably the same today as it was just prior to the historic Yellowstone Āres of 1988. Public sentiment still demands that Āres are extinguished despite increasing pressure among federal agencies to manage wildĀre suppression costs and improve public understanding of the need for Āre. Increased awareness and understanding of Āre ecology has allowed for greater public acceptance of Āre. Prescribed Āres are embraced more today by the public because of two decades of high Āre activity, improved communications from Āre agencies, and more informed media coverage. The public has come to understand that Āre in wildlands is necessary. At least some public acceptance of Āre is related to how information about Āre ecology is being communicated and to empirical evidence that Āre sites recover quickly even following uncharacteristically large and severe Āres. The message of Āre and Āre use has changed over the years and is evident in the new Smokey Bear message distinguishing wildĀres as just one type of Āre. Research suggests that the support for Āre use on the landscape is affected by the way in which Āre officials describe their activities. It has been shown that the public supports proactive management approaches in Āre-prone forests and grasslands much better if Āre-use messages are expressed in terms of protecting public health and safety rather than in protecting ecosystems. The political response to Āres is determined by public sentiment toward Āre and is evident in shaping policy to return Āre to the forest. During the Yellowstone Āres of 1988, the media portrayed Āre as destructive to the environment and socially and politically unacceptable. At that time, Āre management decision-makers were unfamiliar with large landscape-scale Āre since, in the previous two generations, Āre intensity and severity was considerably less than was observed in Yellowstone in 1988. Today, both the older and the younger generations of Āre management decision-makers, the media, and the public have observed signiĀcant Āre activity and are able to respond more appropriately due to their shared experience with large Āre. Therefore, decisions about how to communicate, educate, use, and respond to Āre reÈects increasing acceptance tempered by realistic perceptions of the threat or opportunity posed by large Āre.

Methods: Personal interviews and literature searches.

Conclusions: Fire managers today have a greater ability to use Āre, especially in remote areas on the landscape, as a result of increased public knowledge of the importance of Āre and the observance of forest regeneration following Āres. The public still demands suppressing Āre near homes or in desirable recreational areas. Fire-use messages will be better received by the public if they portray public and ĀreĀghter safety foremost. Today's decision-makers are composed of people who have observed past and recent Āres and are better informed of how to portray Āre to the media and the public and how to use Āre more effectively on the landscape.

keywords: 1988 Yellowstone Āres, Black Hills, decision-makers, Āre ecology, Āre suppression, prescribed Āre, public acceptance.

Citation: Benson, R.P., and F. Carroll. 2009. 1988 Yellowstone Āres—winning hearts and minds—social and political triggers and appropriate management response [abstract]. Page 135 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

THE FUTURE OF FIRE EDUCATION AND OUTREACH IN THE NATIONAL PARK SERVICE

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ABSTRACT

Question: What did National Park Service public information officers learn during the summer of 2008 regarding the modification in fire policy guidance and Wildland Fire Decision Support System (WFDSS) that will facilitate future communication efforts regarding modified policy and WFDSS implementation?

Background: Several National Park Service units were pilot areas to test the modification to policy implementation, which allows for flexibility in management response and managing a fire for one or more objectives, during the summer of 2008. Among these were Sequoia and Kings Canyon national parks, and Yellowstone National Park. National Park Service (NPS) Fire Communication and Education Specialists who staffed these fires as Public Information Officers had the opportunity to test messages and see if park visitors, staff, and media understood the policy changes for responding to wildland fire. The Tanana Zone in Alaska, which includes Denali National Park, was a pilot area for modification to policy and the Wildland Fire Decision Support System (WFDSS). A member of the Alaska Interagency WFDSS work group, NPS learned about challenges and opportunities WFDSS and modification to policy implementation will likely bring to Alaska National Parks fire management programs. The Tehipite Fire in Sequoia and Kings Canyon national parks began 14 July 2008 and later burned onto the Sierra National Forest, adjoining the park. The LeHardy Fire in Yellowstone National Park started on 30 July and was contained in August. The Alaska Interagency WFDSS work group was formed to work on challenges and opportunities regarding WFDSS and modification to policy implementation.

Location: Sequoia and Kings Canyon national parks, California; Alaska Parklands, Alaska; Yellowstone National Park, Wyoming, Montana, Idaho.

Methods: We present a case study on the outcomes of pilot projects testing messages about policy changes with park visitors, park staff, and the media.

Results: The NPS Fire Communication and Education Specialist working on the Tehipite Fire had challenges with the media understanding the spectrum of responses to one fire. When the fire moved onto the Sierra National Forest, other challenges in communication came to light. On the LeHardy Fire, visitors were very accepting of the fire, and of its management actions, but staff at concessions areas near the fire had difficulty with the response to the fire and appeared to have the philosophy that the fire would somehow hurt business. A challenge Alaska National Parklands face is communicating with internal and external audiences that traditional responses to the Alaska Interagency Fire Management Plan, management options will need to evolve. Drawing on the expertise of Long Term Fire Behavior Analysts in order to communicate about long-term strategies is an opportunity to enhance the Alaska Interagency key messages.

Conclusions: It is abundantly clear that fire agencies need to speak in a consistent voice about managing fire. Media, park staffs, concessioners, and the public need further targeted communication before the 2009 fire season in order to be educated about the range of responses and management actions that may be taken on a given fire (e.g., suppression on one side, resource benefit on another). Given that a visitor to a park may have many more opportunities to interact with a concession employee than with an NPS employee, it is just as important, if not more important to educate the concessionaires. Parks and other units should work with staff, concession management, and local media to achieve these goals.

keywords: adaptive management, fire communication, fire education, fire policy, modification to policy implementation, WFDSS.

Citation: Boehle, C., M. Fidler, M. Warthin, and M. Johnson. 2009. The future of fire education and outreach in the National Park Service [abstract]. Page 136 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

FACTS ABOUT FIRE: INCREASING PUBLIC AWARENESS AND SUPPORT OF PRESCRIBED BURNING THROUGH THE FIRE IN FLORIDA'S ECOSYSTEMS PROGRAM

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ABSTRACT

Question: How do fire managers gain public support for the use of prescribed fire as a land management and wildfire prevention tool?

Background: Florida's 16 million citizens gain >800 new neighbors each day. In the last 50 years, settlement has dramatically expanded around major urban centers and inland from coastal zones, creating an interface between suburban–urban development and forest lands. Much of this development has taken place in ecosystems with more volatile fuel types, such as pine (*Pinus* sp.)–palmetto (*Serenoa repens*) flatwoods and sand pine (*Pinus clausa*) scrub. In the wake of devastating wildfires in Florida (1998–2000), a Governor's Commission Report identified wildfire prevention education as a major need in the state. Fire managers have reported that a lack of public awareness about wildfire prevention and lack of public support for prescribed burning and other fuel reduction measures are factors that contribute to fuel buildup and devastating fires. Although recent surveys show that many Florida citizens recognize the benefit of prescribed burning in wildfire prevention, the public often does not fully support prescribed burning as a fuel reduction measure. It is believed that there is a broad misunderstanding about if and how wildfire can be prevented in the state. Thus, many citizens are resigned to the fact of wildfires and yet complain when fire protection agencies are unable to protect them fully from wildfire effects.

Florida is a national leader in wildfire mitigation and prescribed fire, but the state still needs to catch up from years of fire exclusion and the resultant backlog of land that needs to be treated or burned on a regular basis. The Florida Division of Forestry (DOF) is undertaking even more aggressive prescribed burning and fuel reduction campaigns in order to reduce the state's wildfire hazard. A high level of public awareness and acceptance is necessary to successfully carry out a wildfire prevention program of this magnitude. A critical piece of the DOF efforts to increase public awareness was the creation of the Fire in Florida's Ecosystems (FIFE) educator training and curriculum program in 2000.

Location: Throughout Florida, USA.

Methods: The FIFE program provides free in-depth training and instructional materials for use in classrooms or nature centers. Educators participate in a 6-hour workshop on fire ecology and prescribed fire. The curriculum package is targeted primarily at grades 3–8, although it can be used for grades 9–12 and adults. All types of educators may attend the trainings, and the package is used in both formal and nonformal educational settings (i.e., both schools and visitor centers).

Results: Since 2000, >2,500 educators have participated in FIFE workshops. All phases of the program were evaluated. Evaluation included:

- The program started in 2000 with a needs assessment of Florida's 67 school districts to determine the best methods and techniques for forming and delivering the training and curriculum package.
- Pre- and post-assessment at every training session assessed planned use as well as shifts in knowledge and attitudes as a result of the training session. Results were examined on a quarterly basis to make sure the trainings were on target.
- Anonymous surveys at the end of every training session assessed the training itself.
- Random follow-up telephone surveys of program graduates (2004, 2007) assessed long-term training impacts on knowledge and attitudes, determined actual rates of adoption of project materials, and gathered comments and suggestions for program improvement.

Training sessions resulted in statistically significant improvements in educator knowledge of and attitudes toward prescribed fire. At the end of the training workshops, most educators (95%) planned to use the instructional materials in their classrooms or nature centers. Six-month random follow-up evaluations found a 75% classroom adoption rate, with 100% of educators saying that they planned to use the curriculum materials in the future. Follow-up surveys showed long-term knowledge and attitude changes in educators.

Conclusions: Each educator trained through the FIFE program is reaching an average of 150 students per year. The 244 educators trained in 2006–2007 could be reaching about 36,600 students each year. These students may take the information home to share with their families, for a total potential impact to over 87,000 Floridians each year (2.4 citizens/Florida household). Over the life of the FIFE program to date (2000–2007), trained educators have potentially reached over 1.2 million residents with fire information. FIFE educators and their students will gain improved knowledge and attitudes about fire prevention and safety, the natural role of fire in Florida's ecosystems, and the use of prescribed fire in reducing wildfire danger and managing Florida's ecosystems. As a result, community behaviors and actions are expected to shift toward increased awareness of and support for wildfire prevention and safety activities including fuel reduction measures for wildfire prevention.

keywords: evaluation, fire ecology, fire education, outreach, training, wildfire prevention.

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INTEGRATING SCIENCE INTO FIRE MANAGEMENT: UNDERSTANDING USERS' PERSPECTIVES

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ABSTRACT

Question: From the perspective of potential fire and fuels research users, what influences their use of research?

Background: One of the guiding principles of the 2001 Federal Wildland Fire Management Policy Review and Update states that "Fire management plans and activities are based upon the best available science." To date, the Joint Fire Science Program and National Fire Plan have invested approximately $300 million to improve the scientific foundation of fire and fuels management. Scientific research supports many aspects of wildland fire management, including assessments and management of fire effects, fire behavior, firefighter safety, fuel treatment, and public values. Research also provides crucial tools for mapping conditions, predicting fire spread, weighing risks and benefits, calculating costs, and tracking decisions. Even for the most relevant scientific products, a variety of individual, organizational, and external factors influence whether they are used and the length of time to adoption.

There is a wealth of research on human behavior and decision making, interpersonal and organizational communication, organizational learning, and organizational management that provides insight into how and when federal agency managers adopt research products. The project presented here synthesizes and applies knowledge from the social sciences to understand the science application process and increase the effectiveness of fire and fuels science delivery.

This study aims to understand perceptions of potential users about influences to the use of fire and fuels research, to compare prevalence of influences as perceived by different user groups, to evaluate the strength of individual, organizational, and external influences, and to develop recommendations for prioritizing limited fire and fuels science delivery resources. Studied groups include decision makers, fire management officers, fuels specialists, and fire ecologists at regional, state, and field offices in the United States Forest Service (USFS), National Park Service (NPS), and Bureau of Land Management (BLM).

Location: The study occurred in the western United States, including NPS Intermountain and Pacific West regions; USFS regions 1, 2, 3, 4, 5, and 6; and the corresponding BLM states.

Methods: This study used agency meetings, in-depth interviews, and a quantitative survey. Four agency meetings were held in the western United States to identify influences to research application. During 2007, 49 interviews were conducted at USFS, NPS, and BLM study sites to better understand these influences. Finally, a survey was administered at 43 meetings and training sessions during winter 2007–2008 to assess the prevalence of perspectives among different potential user groups.

Results: When asked about influences to their use of research, interviewees discussed the relevance of research to management goals, relevance of research to a specific position's duties, personal interest in research, time needed to evaluate and apply new approaches, motivation to learn new approaches at different career stages, politics, public pressure to use science, differences in scientist communication styles, the timing of science delivery, model flexibility, and the compatibility of research results with experiential knowledge. They cited the following tools or programs that facilitate the communication and application of research: brown-bag presentations; conferences, workshops, internal meetings; training courses; the Internet; the Fire Modeling Institute; and the Fire Effects Information System. Several interviewees requested an information clearinghouse for relevant research.

Interview discussions also included the changing role of science in management; organizational changes such as budget and staffing declines and the increased administrative burden of professionals; changing cultures within fire management; differences in agency cultures regarding science; interactions with scientists and logistical support of research; and interdisciplinary differences in management objectives and research application. Interview and survey data analysis are ongoing.

Conclusions: Interviews with decision makers and fire staff specialists offered rich descriptions of individual, organizational, and external influences to their use of research. The relative strength of these influences is being tested within a framework of social science theory on human and organizational behavior. Results will be used to develop recommendations for both scientists and managers. Recommendations for scientists will focus on improving science communication to research users in different agencies, positions, and levels of administrative responsibility. Recommendations to managers will focus on improving agency and work unit capacity to apply scientific research.

keywords: research application, science application, science communication, science delivery, social science.

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FIRE EDUCATION AND OUTREACH IN THE NATIONAL PARK SERVICE

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Purpose: The poster session will complement the breakout sessions regarding Āre communication, education, and outreach and provide information on programs and products available for these purposes. Approach: The National Park Service Fire Communication and Education group will approach this topic from a national, regional, and park perspective using examples and information from across the United States. Key Messages: There are many products already available, so new programs do not have to reinvent the wheel if they would like to build their program. There are many products available for loan, for free, or for shipping fees from a national or regional level that can be borrowed during festivals and events, as well as during incidents. Conclusions/Recommendations: Parks and other units should utilize the resources available to create a dynamic program through utilization of products that have already been created that will be highlighted during this poster session.

LIVING WITH WILDFIRE IN COLORADO

Patricia Champ,[1] Nicholas Flores,[2] and Hannah Brenkert-Smith[3]
[1] Economist, USDA Forest Service, Rocky Mountain Research Station
[2] University of Colorado, Department of Economics and Institute for Behavioral Studies
[3] University of Colorado, Institute for Behavioral Studies

In this presentation, we describe results of a survey to homeowners living in wildĀre-prone areas of two counties along the Front Range of the Rocky Mountains in Colorado. The survey was designed to elicit information on homeowners' experience with wildĀre, perceptions of wildĀre risk on their property and neighboring properties, mitigation efforts undertaken to reduce wildĀre risk, information sources for wildĀre risk and mitigation, level of involvement in the local community, and attitudes toward wildĀre and the environment in general. The sample was randomly drawn from a population database created using GIS (Geographic Information Systems) technology. The representative sampling allowed us to hear from individuals who might not be participating in community wildĀre programs or be concerned with wildĀre risk, as well as individuals who are involved and concerned. A letter of introduction offered each household in the sample the choice of completing a paper or a Web-based survey. Preliminary data analyses suggest that most of the survey respondents are year-round residents living in single-family homes that are >100 feet from the next nearest residence. Most of the respondents have experienced a wildĀre <10 miles from their current residence. However, very few respondents' homes were damaged by a wildĀre or smoke from a wildĀre. Local Āre departments are the most commonly cited source of information about wildĀre risk and also the source in which survey respondents said they had the most conĀdence with respect to accuracy of the information. Further analyses will look at the relationships between information sources and wildĀre risk reduction actions taken on a survey respondent's property. Likewise, the role of social interactions and wildĀre risk mitigation actions will be explored. Conclusions will be based on additional data analyses.

CONSERVATION EDUCATION FOR FIRE, FUEL AND SMOKE PROGRAM

Wayne Cook
Fire Technology Transfer Specialist, USFS Rocky Mountain Research Station, Missoula Fire Sciences Laboratory

The mission of Conservation Education for the Fire, Fuel and Smoke (FFS) Program is to develop and deliver high-quality, science-based education about wildland Āre to students, educators, the general public, and agency staff. Goals: 1) Increase awareness of the scope and content of FFS research. 2) Improve understanding of fundamental concepts in wildland Āre science. 3) Increase interest in the application of science to wildland management.

LESSONS LEARNED FROM THE YELLOWSTONE FIRES OF 1988

Roberta D'Amico,[1] Paula Nasiatka,[2] and Dave Thomas[3]
[1] National Park Service Fire Communication and Education Program Lead
[2] Center Manager, Wildland Fire Lessons Learned Center
[3] Renoveling LLC

More than 9,000 fire managers participated in the Yellowstone Fires of 1988. In most cases, the individual lessons learned from this "once in a lifetime" experience are still locked in these fire manager's heads. The people involved with the management of the Yellowstone fires, whether they were dealing with the national and local media, working out solutions in the political realm at the local, state, and national levels, developing the tactical and strategic plans to control and contain the fires, or, in deciding what was to be done with the ecological and policy issues that surfaced after the fires, all acquired a huge amount of experienced-based knowledge. The overriding goal of this special session is to describe the results of our efforts to unlock the knowledge and wisdom that exists in the heads of manager's who worked on the Fires of '88, to ensure that some of the knowledge they gained is not lost. Our knowledge-capture method was a series of 22 videotaped interviews, up and down the chain of command, with print and broadcast journalists, fire ecologists, fire information officers, Park staff, and interagency cooperators. Included in the interviews are former Secretary of the Interior, Don Hodel; *NBC Nightly News* reporter, Roger O'Neil; commander of the Army's contingent of firefighters, Major General J. B. Taylor; West Yellowstone–based Area Commander, Rick Gale; Yellowstone National Park Superintendent, Bob Barbee; and Dean Clark, the first resource ordered for the fires. Specific objectives of this session:

- Describe what a learning organization is and how the concept of organizational learning can be applied to the Yellowstone Fires of '88.
- Discuss the potential application, using the interview material obtained from personnel working on the Yellowstone Fires, the "Deep Smarts" model (learning from people with high expertise) as developed by Dr. Dorothy Leonard (Harvard Business School) and Dr. Walter Swapp (Tufts University).
- Show the knowledge management products created from the interviews and discuss how this experienced-based knowledge can best be transferred to individuals still working within fire management organizations.
- Through interactive group discussions, explore, using the Fires of '88 as a foundation, other creative applications of organizational learning, deep smarts, and knowledge management.

BEYOND TECHNOLOGY TRANSFER: BETTER USE OF BETTER FIRE SCIENCE

Ronald W. Hodgson
Fire Social Scientist, Adaptive Mgmt. Services Enterprise Team, Tahoe National Forest

Federal policy encourages use of best science in fire management. For fire managers, fire science is often difficult to find, hard to understand and use, and of dubious immediate practical value. Those problems are being addressed for fire social sciences in a new Evidence Based Fire Management project within the Fire Research and Management Exchange System (FRAMES) at the University of Idaho. The project builds on the USFS Northern Research Station "Social Science to Improve Fuels Management" project. It draws its structure from the successful Evidence Based Practice movement in medicine. This poster paper illustrates the kinds of fire science products being developed for and with fire managers. It describes the process through which scientists and science users collaborate to identify topics, synthesize available research and practical experience on the topic, and coproduce and diffuse fire management knowledge. Poster session visitors can learn more about FRAMES at a vendor display.

DISCONNECTIONS BETWEEN WILDFIRE THREAT, AWARENESS, AND PREPAREDNESS IN TWO SOUTHERN CALIFORNIA COMMUNITIES: A CASE FOR RETHINKING EDUCATION AND POLICY

John Kim[1] and David Dozier[2]
[1] Field Stations Program, San Diego State University
[2] School of Journalism & Media Studies, San Diego State University

We argue for rethinking wildĀre preparedness education and policy, given our interpretation of survey data from two rural communities in Southern California. We conducted parallel surveys in Fallbrook (population 29,100) and Valley Center (population 7,323), addressing wildĀre threat awareness and preparedness activities. An initial survey was conducted in spring 2005, at the beginning of a public wildĀre education campaign conĀned to Fallbrook. A follow-up survey was conducted in spring 2007. A total of 664 residents were interviewed. WildĀre preparedness campaigns logically assume there is a link between actual wildĀre threat and the public's awareness of it. And the campaigns logically assume a link between awareness and action: that if citizens were given relevant information and the right opportunities, they would rationally and proactively act to improve their likelihood of safety. Using our survey data to compare the two communities, we identify a disconnection between persistent Āre threat in the area and the residents' attitudes about wildĀres. We also identify a disconnection between their wildĀre awareness levels and their preparedness activities. We interpret these disconnections in light of recent studies that qualitatively document quasi-rational and irrational attitudes and behaviors of people facing natural disasters. These include undue optimism and fatalism; commitment to esthetics or to questionable ecological concepts; and being swayed by social or political dynamics. Given the disconnections between the actual wildĀre threats and the residents' attitudes and behaviors, we recommend rethinking of education campaign strategies and public policies to fully embrace and exploit human irrationalities. Reformulated policies should include distribution of free safety equipment; making wildĀre preparation a requirement with the ability to opt out; and folding current wildĀre preparedness costs into future gains. Education campaigns should disseminate information through small, trusted social venues, and emphasize the dollar cost of inaction while championing preservation of the community.

MEASURING YOUR WILDFIRE EDUCATION PROGRAMS USING THE "BALANCED SCORECARD"

Lisa Sturzenegger
Director Community Safety, Member-IAWF

This presentation will explain how Fire Services in Australia use the "Balanced Scorecard" to measure both organizational and public value. The Country Fire Authority (CFA) in Victoria, Australia, is one of the world's largest volunteer Āre services. CFA is well known for its comprehensive engagement with communities about the "stay or go" message. The stay-or-go message is delivered through a strategy called Fire Ready Victoria (FRV). But how does a Fire Service demonstrate to government that it provides public value and how does it measure its effectiveness? CFA has a corporate plan that is based on the Balanced Scorecard approach. The Balanced Scorecard was developed by Harvard professors Kaplan and Norton. The Balanced Scorecard is a carefully selected set of measures derived from the organization's strategy. It allows the translation of the organization's strategy into objectives, measures, and targets, making it easier for staff throughout the organization to relate their activities to the organizational vision. FRV is based around the balanced scorecard. This presentation will explain how FRV uses the balanced score to demonstrate its value to the organization and contribute to public value. It will also show some examples of the costs of delivering services through CFA versus being contracted out.

THE WESTERN ASPEN ALLIANCE: PROMOTING SUSTAINABLE ASPEN ECOSYSTEMS IN WESTERN NORTH AMERICA

Paul Rogers,[1] Dale Bartos,[2] and Ronald Ryel[3]
[1] Director, Western Aspen Alliance, Utah State University, Department of Wildland Resources
[2] Research Scientist, Rocky Mountain Research Station
[3] Associate Professor, Utah State University, Department of Wildland Resources

A group of researchers and managers formed the Western Aspen Alliance (WAA) to coordinate and facilitate advances in aspen ecology in western North America. Our prime goal is to disseminate state-of-the-science aspen information to interested managers, scientists, the public, and other entities. In many ways, the 1988 Yellowstone fires have acted as a catalyst for emerging principles in aspen ecology. For instance, documentation of large-scale seedling establishment following catastrophic disturbance, or furthering understanding of trophic interactions, have significantly modified our collective understanding. Wildlife pressures on the emerging aspen progeny of the '88 fires is an issue of concern for managers throughout the Greater Yellowstone Ecosystem. WAA will incorporate these lessons, along with research conducted elsewhere, into an ongoing resource bank for resource managers throughout the region. From a science perspective, we wish to engender a cross-disciplinary network of researchers willing to take on pertinent aspen topics. For example, there is a current need to assess the extent of Sudden Aspen Decline, seral/stable aspen stands, and historic aspen coverage. Basic research on aspen physiology, disturbance ecology, water yield, genetics, herbivory, and biodiversity/trophic interactions issues are also desired. The social/aesthetic value of aspen is an up-and-coming research area needing further exploration, too. We will form working groups for these issues and pursue additional aspen topics that arise. Though sponsored by Utah State University's College of Natural Resources and the USDA Forest Service, Rocky Mountain Research Station, we are currently working with numerous state and federal agencies, NGOs, and universities. We welcome your input and participation!

FIREFIGHTERS UNITED FOR SAFETY, ETHICS, AND ECOLOGY (FUSEE): TORCHBEARERS FOR A NEW FIRE MANAGEMENT PARADIGM

Timothy Ingalsbee
Executive Director, Firefighters United for Safety, Ethics, and Ecology (FUSEE)

Firefighters United for Safety, Ethics, and Ecology (FUSEE) is a nonprofit organization promoting safe, ethical, and ecological wildland fire management. FUSEE believes firefighter and community safety are ultimately interdependent with ethical public service, wildlands protection, and ecological restoration of fire-adapted ecosystems. Our members include current, former, and retired wildland firefighters, other fire management specialists, fire scientists and educators, forest conservationists, and other citizens who support FUSEE's holistic fire management vision. FUSEE's primary function is to provide public education and policy advocacy in support of a new, emerging paradigm that seeks to holistically manage wildland fire for social and ecological benefits instead of simply "fighting" it across the landscape. We seek to protect fire-affected wildlands, restore fire-adapted ecosystems, and enable fire management workers to perform their duties with the highest professional, ethical, and environmental standards. Our long-term goal is the creation of fire-compatible communities able to live safely and sustainably within fire-permeable landscapes. This poster will display FUSEE's philosophy, mission, research, education, and advocacy projects. Elaboration of some key FUSEE concepts will be featured, including the FUSEE triad of safety, ethics, and ecology; reidentifying firefighters as fire-guiders; expanding community wildfire protection into community fire preparation; recreating fire-compatible communities; and restoring fire-permeable landscapes.

WILDLAND FIRE, THE MEDIA, AND PUBLIC PERCEPTION

REPRESENTATION MATTERS: A CULTURAL STUDIES APPROACH TO THE STORY OF WILDLAND FIRE IN BROADCAST NEWS

Joe Champ[1] and Daniel Williams[2]
[1] Colorado State University
[2] USDA Forest Service, Rocky Mountain Research Station

This presentation shares the results of a qualitative content analysis of broadcast news coverage of wildland fire events along Colorado's Front Range in the 2005 fire season. Researchers installed a bank of video recorders to simultaneously capture multiple newscasts from four commercial stations in the Denver television market (i.e., ABC, CBS, NBC, FOX) and CNN. With the help of Forest Service officials, the researchers started the recorders at the first sign of significant wildland fire events in the region and recorded until the fires were no longer considered a threat (usually 2–3 days). They recorded coverage of multiple fire events. A cultural studies construct known as the *circuit of culture* guided interpretation of the broadcast transcripts, particularly a set of ideas organized under the term *representation*. Transcript analysis was used to test the idea that, instead of serving as mere transporter of unbiased information about wildland fire, broadcast news institutions present particular stories about the phenomenon. In a contradictory way, they blend sensational accounts of wildland fire with scientifically based discourses of fire ecology. The conclusion will be made that such journalistic texts reveal ongoing culture-wide ambivalences and contradictions about wildland fire. Rather than being seen as negative, it will be argued that these mixed messages may be a part of the natural evolution of a society coming to terms with a changing landscape.

THEN AND NOW, FROM 1988–2008, AND WHERE ARE WE NOW? THE 1988 MEDIA FIRESTORM AND PREPARING FOR MEDIA OF THE FUTURE

Facilitated and moderated by Roberta D'Amico, National Park Service Fire Communication and Education Program Lead, and Rocky Barker. Barker is currently an environmental reporter for the *Idaho Statesman*. In 1988, he was the lead reporter for the *Idaho Post Register's* award-winning coverage of the Yellowstone fires. As an author, he was a finalist for the Western Writers of America's Spur Award in nonfiction for *Scorched Earth: How the Fires of Yellowstone Changed America*.

Yellowstone—the name itself evokes concepts of firsts and 1988 was the first wildland fire to capture the media and public attention, locally, nationally, and internationally. Twenty years ago, CNN and the concept of 24/7 news coverage was in its infancy. Reporters and producers didn't know much about fires, forest science, or any of the many elements in the 1988 fires. But today, fire coverage in America has gone through a transition of sophistication that still has a hard time overcoming the public's attitudes about wildfire. This special session will present and discuss media coverage, public and media perception of wildfire as a result of media coverage, and communication challenges and opportunities from the past (1988), the present, and insights into future media technology. Moderated by Rocky Barker, speakers will include Al Nash, Yellowstone's public information officer today and a broadcast journalist in 1988; Joan Anzelmo, Yellowstone's public information officer in 1988 and today superintendent of Colorado National Monument; Robert Ekey, Northern Rockies Representative for the Wilderness Society today and a member of the *Billings Gazette*'s Pulitzer Prize finalist team for coverage of the 1988 fires; and Angus Thuermer, who is editor of the *Jackson Hole News and Guide* and was editor of the *Jackson Hole News* in 1988. Panelists will talk about the media coverage in 1988, the media world of 2008, and then explore the continuing challenges of the modern electronic media arena.

HOW WE LEARNED TO STOP WORRYING AND LOVE THE FIRE: THE RHETORICAL REGENERATION OF FIRE LANDSCAPES AND FIRE COMMUNITIES

Ron Steffens
Professor of Communications, Green Mountain College

The theory and practice of rhetoric and persuasion offer insight into why some fire narratives prove captivating and offer support for evolving fire management strategies. The concept of why a story can be "Made to Stick," based on the book by Chip Heath and Dan Heath, helps to explain the stickiness of the "Let it burn" phrase from the '88 fires. The Heaths' stickiness concept also offers insight into two decades of post-'88 fire narratives in the Teton region that makes up the southern half of the Yellowstone ecosystem. Case studies of these fires examine high-risk/high-complexity suppression fires and low-risk/low-complexity fire-use actions, as they are interpreted into a continuum of narrative plots. As we come to understand how these past fire narratives resonate within fire organizations and with the public, we may develop support for evolving concepts of "appropriate management response" to wildland fires while also learning to apply successful narrative plots when using new communication media.

OVERCOMING THE CHALLENGES: ONE VISION FOR A SUCCESSFUL PROFESSIONAL DEVELOPMENT SYSTEM

Chris Dicus,[1] Monique Rocca,[2] Leda Kobziar,[3] Chad Hoffman,[4] Neil Sugihara,[5] Andi Thode,[6] Morgan Varner,[7] and Penelope Morgan[8]
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[3] Assistant Professor of Fire Science and Forest Conservation, University of Florida
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[6] Assistant Professor, Northern Arizona University, School of Forestry
[7] Assistant Professor of Wildland Fire Management, Humboldt State University
[8] Professor of Forest Resources, University of Idaho

The current structure of wildland Āre professional development programs makes it difficult for students to simultaneously achieve education, training, and on-the-ground experience. Here, we address these and other challenges with potential solutions, and outline the Ārst steps toward their implementation. We propose a new model of professional development for wildland Āre professionals in which education, training, and experience are integrated, and the professional development process streamlined. We suggest that the Ārst step towards resolving the challenges with the present system of Āre education is to foster open dialogue among the agencies that hire Āre professionals, the developers and instructors of NWCG training programs, and the higher education providers that represent degree programs. We then recommend further practical implementation steps to ensure that wildland Āre career development is more accessible, efficie nt, and effective over the long term.

THE ROLE OF HIGHER EDUCATION IN PREPARING THE FUTURE WILDLAND FIRE WORKFORCE

Leda Kobziar,[1] Andi Thode,[2] Monique Rocca,[3] Chris Dicus,[4] Chad Hoffman,[5] Neil Sugihara,[6] Morgan Varner,[7] and Penelope Morgan[8]
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[7] Assistant Professor of Wildland Fire Management, Humboldt State University
[8] Professor of Forest Resources, University of Idaho

Due to a century of fuel accumulation, a growing wildland–urban interface, and more extreme climatic conditions, the duties of U.S. Āre professionals have become more complex and risk laden. Widespread incorporation of Āre use, ecological principles, and Āre restoration into land management has further expanded the range of expertise and knowledge required of Āre professionals. The educational and training systems that produce these professionals, however, have been slow to organize an updated and coordinated approach to preparing them. As a consequence, aspiring Āre professionals face numerous challenges related to scheduling conÈicts, limited higher education programs in Āre science, lack of coordination between Āre training and higher education providers, and the overall difficulty of obtaining education, training, and experience without sacriĀcing competitiveness in the job market. Here, we address these and other challenges and discuss the role of higher education in Ānding solutions. Current providers of Āre education have both the opportunity and responsibility to develop a viable future for the next generation of wildland Āre professionals in the United States.

PARK PLANNING AND FIRE

ASSESSING THE RELATIVE RISK OF FIRE DANGER FOR DEVELOPED AREAS IN YELLOWSTONE NATIONAL PARK

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ABSTRACT

Question: Which developed areas in Yellowstone National Park are at greatest threat from wildland fire?

Background: Wildland fire managers are becoming increasingly concerned with the ability to protect or defend communities, inholdings, and structures from wildfire throughout the West. As a result, the proactive planning and implementation of risk-reducing fuels treatments on public lands have increased as well. In Yellowstone, small-scale fuels reduction efforts aimed at creating defensible space have been implemented over the past decade around some frontcountry developments and backcountry patrol cabins. In anticipation of increased funding opportunities, more and larger-scale fuels treatments are being considered, yet no systematic or programmatic approach to identifying, distinguishing, or quantifying wildfire "hazard" or "risk" for prioritized fuel treatments has occurred. Such a process is desirable for Yellowstone given the challenging and competing mandates of minimizing human influences on ecological processes while protecting human lives and property within the park.

We recognize that to truly quantify wildland fire risk, a two-step process must occur: 1) to identify the level of hazard that exists prior to management action, and 2) to further identify the burning conditions necessary to exceed initial attack or control capabilities of a given fire. To avoid confusion and inconsistency, we use the term *hazard* in reference to the amount of fuel available within the area of concern around developed areas, whereas the joint occurrence of fuel loads and burning conditions constitutes *risk*. Here we present a simplistic, intuitive, and unbiased approach to rating wildland fire hazard as an initial but critical first step toward a fire risk assessment.

Location: Yellowstone National Park (lat 44°38′N, long 110°33′W), Wyoming, USA.

Methods: To develop the initial fuel hazard rating, we 1) identified all of the LANDFIRE Rapid Refresh fuel models within a 2-mile radius of each developed area; 2) applied surface live and dead fuel model input values (tons/acre, <3 inches diameter) for each fuel model; 3) and summed the resultant area × fuel load, by fuel model, to derive a measure of total fuel loading (tons) within the 2-mile buffer. Developed areas were then grouped into six total fuel load categories.

Results: Timber-understory (TU5, TU1), timber-litter (TL3), grass–shrub (GS-1, GS-2), and grass (GR2) fuel models were common to virtually all sites. Fuel model TU5 generally contributed most to total fuel loading at each site. Total fuel load values approximated a normal distribution, with a mean value of 37,600 tons and a standard deviation of 13,800. Total fuel loads at the Bechler and South Entrance were greater than 1.5 standard deviations from the mean, whereas Madison, East Entrance, and Northeast Entrance fell between 0.5 and 1.5 standard deviations. All other developed areas were at or below mean fuel load values. The gateway community of Gardiner, Montana, dominated by fuel model GS2, had the lowest total surface fuel load of all developments associated with the park. If not for the presence of Yellowstone Lake, total fuel load values would be higher for the Grant, Bridge Bay, Fishing Bridge, and Lake developed areas. Four of the five developed areas with the highest fuel loads occurred at the park boundary where the total fuel load buffer included areas beyond park boundaries.

Conclusions: In an unbiased manner, we demonstrated differences in fuel hazard among developed areas in Yellowstone using the LANDFIRE fuel model layer that is the basis for all deterministic and probabilistic fire behavior modeling. The resultant rating suggests the highest fuel load hazard levels are found within the buffer of some developed areas that extend beyond park boundaries. The next step to ultimately quantifying wildfire risk involves the likelihood and behavior of a fire burning a point on the landscape given the variability in ignition sources and weather acting upon the fuels and topography for each respective developed area. Previously published research into the weather and forest cover type influences on fire occurrence and behavior in Yellowstone can facilitate this final step in wildland fire risk analysis. Our intention here was to provide a framework for managers to develop a defensible, acceptable, and sustainable program of hazard fuels reduction within Yellowstone.

keywords: developed areas, fuel models, hazard fuels, LANDFIRE, wildland fire risk analysis, Yellowstone National Park.

Citation: Renkin, R., and B. Sorbel. 2009. Assessing the relative risk of fire danger for developed areas in Yellowstone National Park [abstract]. Page 145 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

THE 1988 NATIONAL FIRE POLICY REVIEW

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ABSTRACT

Question: What went on during the National Fire Policy Review and what was found?

Background: In early September of 1988, U.S. Forest Service (USFS) Chief Dale Robertson issued a letter to rally his troops. Thousands of people had been fighting large, dangerous wildfires since June. Key components of this one-page letter were to put out the fires and once this was done there would be a serious review of national fire policy. He also laid out the makeup of the committee, which was to include representatives from each of the federal wildland fire agencies, a representative of the western governors, the state foresters, and members of the academic community. Federal scientists encouraged me to toss my hat in the ring. The team was established to review the then-current U.S. Department of Agriculture (USDA) and U.S. Department of the Interior (USDI) policies on fire management in light of the extreme fire situation experienced in the summer of 1988. Co-chairs of the committee were Charles Philpot, Special Assistant to the Deputy Secretary, USDA; and Brad Leonard, Deputy Director, Office of Program Analysis, USDI. Other members were Gary Cargill, Regional Forester, USFS; Boyd Evison, Regional Director, National Park Service (NPS); Bruce Kilgore, Regional Chief Scientist, NPS; Blaine Cornell, Forest Supervisor, USFS; Dean Stepanek, Assistant Director, Bureau of Land Management; Thomas Follrath, Deputy Division Chief, U.S. Fish and Wildlife Service; and Charles Tandy, Fire Director, Bureau of Indian Affairs. Others originally asked to be on the committee were myself, University of Montana; Robert G. Lee, University of Washington; Harry Layman, National Association of State Foresters; and Paul Cunningham, Executive Director of the Western Governor's Association.

Location: Rosslyn, VA; Jackson, WY; Boise, ID; Lakewood, CO.

Methods: Team meetings took place around the West and Washington, D.C. "Listenings" took place in the West where various members of the team listened to "knowledgeable people," as was our charge. The team's report was submitted to the Secretary of Agriculture and the Secretary of Interior on 15 December 1988. Oral testimony from 11 public meetings and >400 letters were subjected to content analysis, the results of which were later incorporated into the Final Report issued in May 1989.

Results: Many fires, initially designated prescribed natural fires (PNF) that were allowed to burn, had become large, costly wildfires. The team quickly realized that Yellowstone Park's fire management plan was clearly not a good example of national fire policy. A 1986 plan was utilized by Yellowstone Park officials, although it did not have the required approval by the NPS Regional Director nor had it been signed by any USFS official responsible for managing the surrounding national forests. The only signature on it, the Yellowstone Park Superintendent's, was written in by an assistant. There were no written prescriptions or decision trees in the plan. In fact, half (16 of 32) of the NPS plans for PNF programs in the United States had no prescriptions in them although this was required by NPS-18, the NPS Wildland Fire Management Guideline. No other agency's plans were found without written prescriptions.

Conclusions: The 1988 National Fire Policy Review Team was asked to review then-current fire management policies. Although the Yellowstone situation frustrated us, we worked to be constructive. National definitions for all fire management actions were needed. Plans needed to be updated to a uniform national policy. Public information on fire incidents and fire management plans needed to become priority. Divergent budgeting processes had led to problems within and between agencies. Regional and national coordination was needed if fires were to be allowed to burn. Interagency coordination and participation in fire management actions had to be more than just lip service.

keywords: fire planning, fire prescriptions, national fire policy, Yellowstone Park.

Citation: Wakimoto, R.H. 2009. The 1988 National Fire Policy Review [abstract]. Page 146 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

1989 FIRE MANAGEMENT POLICY REVIEW—WORK TOGETHER WITH AN INTERAGENCY EMPHASIS

Richard Bahr
USDI National Park Service, Fire Management Program Center

Question: After 72 years of National Park Service fire policy changes that reflected the attitudes, science, and management views of how national parks should respond to fire, the "Final Report on Fire Management Policy, May 5, 1989" makes ten recommendations to the Department of the Interior (USDI) and Department of Agriculture (USDA). The focal point for public concern and agency criticism was aimed at the Greater Yellowstone Area, but the fire management programs for both agencies would feel the impact of the findings and recommendations. As we now look in retrospect 20 years later, what did it mean and how has it been handled? Methods: I reviewed agency and interagency fire policy in place before the events of 1988 and those subsequent to see if the findings and recommendations reflect change in how an individual agency works and how they collectively work in an interagency relationship. Results: The review of the ten recommendations shows we continue to struggle with the conflicts between agency missions and the ability to work in wildland fire as an interagency community where we readily accept each other's differences. Interagency planning still has the components of our agreeing to disagree on how some things will be done that challenges cross-boundary implementation of fire. What defines contingency and how the need to respond to unanticipated events and conditions is balanced with scarce resources and costs continues to test each agency's field units as they implement prescribed fire and respond to wildfire. The hazardous fuels program remains subservient to preparedness and responding to fire. Agency utilization of National Environmental Policy Act requirements to involve the public is lost somewhere in politics and priorities. Agencies continue to struggle to provide adequate knowledgeable and trained personnel to manage the fire program. Integration of research, analysis, and management of the fire program remain elusive as each continues along their own path. Funding methods remain a push-button topic where effectiveness is the loser. But there is a shining star of being prompt to investigate and act upon allegations of misuse of policy and do so within an interagency context. Conclusions: Even where the Final Report issued recommendations and the agency Secretaries followed up with specific direction to act, the overall shortcomings of the finds from the review team still exist across the agencies, which affects the ability to manage fire across agency and interagency landscapes. Fire management today remains a reflection of what it had been prior to the events of 1988. Attitudes, science, and management views at local, geographic, regional, and national levels all influence direction and decisions in fire management and those interrelationships are not shared across agency boundaries.

WILDLAND FIRE USE PLANNING IN PARKS CANADA

Mike Etches
National Fire Management Officer, Parks Canada

This will be a two-part presentation on how the Yellowstone 1988 fires transformed wildland fire management planning in Parks Canada. The first part will be a retrospective on how the 1988 Yellowstone fires significantly influenced the emerging fire-use program in Parks Canada. The second part of this presentation will be on how the lessons learned from Yellowstone shaped the current Parks Canada fire management program and provide positive future direction.

NATIONAL PARK SERVICE FIRE PLANNING IN THE FUTURE: IS WILDLAND FIRE USE JUST A LUXURY?

Tom Nichols
Chief, Fire and Aviation Management, National Park Service

Twenty years after the 1988 Yellowstone fires, wildland fire use management has improved significantly with the establishment of Fire Use Management Teams and Fire Use Modules, better fire behavior models, and more sophisticated decision support tools. Nonetheless, as of mid-August 2008, only 120 wildland fire–use fires covering 117,000 acres had burned, out of 56,000 total fires covering almost 4 million acres nationally. Wildland Fire Use is not for every management unit or fire agency. However, even in areas suitable for Wildland Fire Use programs, planning and implementation are still impeded by questions about "how will it look" to allow fires to burn, even in wilderness areas, when homes are threatened elsewhere in the country, especially at National Preparedness Level 5. Other concerns, such as air quality, are further restrictions. Such questions cannot be answered solely with better technology, such as improved fire behavior models and risk assessment planning, or even with more firefighters and funding. The expansion of the National Park Service Fire Use program requires a much more comprehensive and efficient communication strategy. The strategy must integrate: 1) the mission of the National Park Service, 2) the methods employed in fire-use management, 3) the creation of effective messages to encapsulate this information, and 4) the utilization of a variety of modern communication media to convey information to a wide variety of individuals and groups. The National Park Service fire management program is embarking upon such a strategy.

INTERPRETING FIRE OVER A CENTURY: SEQUOIA & KINGS CANYON NATIONAL PARKS AS A CASE STUDY

Deb Schweizer
Fire Education Specialist, Sequoia & Kings Canyon National Parks

Purpose: Public and agency perceptions of wildland fire have had a huge influence on the fire management policies in the United States. Sequoia and Kings Canyon national parks are one of the leaders in prescribed fire and managed lightning fires programs and as such have often cut their teeth on the range of controversies, some anticipated and some not, that come with an integrated and complex program. Approach: Using Sequoia and Kings Canyon national parks as a case study, this talk will briefly explore the following eras of fire management and how the education programs evolved with them. 1) Native American practices. 2) Light burning vs. suppression in the early 1900s. 3) The coming of age of suppression policies and prevention campaigns. 4) The growing question: Is suppression hurting the forests? The Leopold Report. 5) The first studies into sequoia ecology and the results of fire exclusion and the first managed lightning fire: getting buy-in from our own agency, other federal land management agencies, communities, and the public. 6) An ever-evolving program that has dealt with black bark controversy, smoke, and the belief that wildland fire is only destructive. 7) An ever-evolving program that has promoted fire ecology and science, the benefits of fire on a landscape, and community protection. Key Messages: public perception of wildfire management has a direct impact on success and failure of a program. The perception of wildfire management has been shaped by wildland fire agency messaging in the past. Public perception will continue to be shaped by messaging of wildland fire agencies. Conclusions/Recommendations: The continued success of complex and innovative fire management programs must include an educational component to help various audiences learn to understand and accept these programmatic changes. Sequoia and Kings Canyon national parks' fire management program has evolved over the years to include fire education, which has led to improved acceptance of the program. This program will continue to adapt with new directions into the future.

BURN-SEVERITY FIELD VALIDATION IN WESTERN CANADIAN NATIONAL PARKS USING THE DIFFERENCED NORMALIZED BURN RATIO (dNBR) ALGORITHM

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Wildland fire is a major disturbance event and driver of ecosystem processes in Canada. Parks Canada as an agency is committed to understanding fire's role on the landscape and monitoring its effects. The purpose of this study is to validate the correlation between Composite Burn Index (CBI) plot data and Landsat 5 TM differenced Normalized Burn Ratio (dNBR) data in Canadian environments. This approach has been shown to be effective for many regions in the United States; however, Parks Canada fire managers and scientists are interested in testing the model in their federal parklands. The experimental design includes the creation of an initial assessment (IA), or immediate burn-severity assessment raster grid for park fires that occurred in 2007 and 2008. CBI point samples are extracted through stratified random sampling based on homogenous areas determined in a geographic information system (GIS). Plot points are located in the field based on these stratified random samples and the CBI field work is conducted. For field season 2008, CBI data were taken from the Split Peak prescribed fire in Kootenay National Park and from the Boyer Rapids Complex wildfire in Wood Buffalo National Park. After field work is conducted, a final dNBR grid is created using a Landsat image taken a year after the initial fire, which is called the extended assessment (EA). The two grids (IA and EA) are used to assess their correlation with the CBI plot data. Results are not wholly complete, as the field-season portion finishes summer 2009. Statistical models developed from the different vegetation types studied in this project will be used to interpret image grids for future fires on Canadian park lands. Various methods of analysis, including variations on the CBI assessment process and different types of statistical regression models, are being investigated. Final products from this work will demonstrate the efficacy of the dNBR raster grid for future use in mapping burn severity in Canadian parks along with continued research applications that involve many fire-related topics.

A CHRONOLOGICAL FIRE HISTORY OF THE 1988 FIRES

Phil Perkins
Retired FMO, Retired NPS Employee

This presentation, by an informed (retired) Yellowstone staff employee charged with implementing the established fire management plan at the time, will describe the fire policy, fire management activities, fuels, and weather conditions prior to the 1988 fire season with a chronological narrative of major fire events from May to November, 1988. Discussion will include the early part of the fire season, the internal debate about allowing fires to burn naturally, the early growth of the major fires, the events that led to full fire suppression efforts, and the weather and fire suppression efforts that continued until the fires were declared controlled. The presentation of the facts, without placing blame or passing judgment, will allow the listener to evaluate the information, ask questions, and make their own informed opinion of how the 1988 fires were managed.

INTERNATIONAL PERSPECTIVE: LESSONS AFTER YELLOWSTONE

COMMUNICATION STRATEGY ON FIRES AND NATURAL DISASTERS IN EUROPE

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ABSTRACT

Question: We study the process of communication in order to propose efficient ways to communicate in the event of wildfires or natural disasters.

Background: We reviewed different approaches that may be useful for the purposes of effective and efficient communication. First, we present the classical communication approach, which considers the process of communication mainly in a "mechanistic" way. Second, we insist on a media role because the media are nowadays the main channels of communication and they contribute to influence collective attitudes, perceptions, or beliefs. We also took into account different analyses of the process of communication, in particular the approaches that integrate human dimensions of communication and risk.

Location: Europe, in particular the Mediterranean regions.

Methods: We synthesized the specialized literature, general research on the process of communication, analysis of previous communication campaigns in different cases, and the definition of a new theoretical and applied framework to define an efficient communication strategy.

Results: First, we present the classical communication approach. At this stage we already propose a general theoretical framework that is very operational to develop a public awareness strategy in the field of wildland fires: we indicate main key points of the communication strategy in the case of wildfires. Review of the literature confirms that these key points are often used as a basis in applied communication strategies in the case of natural disasters. Second, we insist on the role of the media. We highlight the necessity to adapt the messages, the communication channels, and tools to the categories of public. Then we show that it is necessary take into account the complexity of the information system concerning communication on fire. A preliminary information system will be presented concerning communication on fire in France. Next we propose to articulate this information system with the communication strategy by integrating the human dimensions of communication. Involving the stakeholders is very important for an efficient communication process. Finally, all the preceding analyses and the lessons drawn from risk communication studies lead us to a new approach integrating different dimensions of communication, in particular risk, human relationship, and the information system.

Conclusions: We propose a new theoretical framework and some initial guidelines to define a public awareness strategy adapted to the Fire Paradox case.

keywords: communication strategy, communication theory, public awareness, risk communication, wildfires.

Citation: Badillo, P.-Y., and D. Bourgeois. 2009. Communication strategy on fires and natural disasters in Europe [abstract]. Page 149 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

MEDIA COVERAGE IN PORTUGAL OF ENVIRONMENTAL CATASTROPHES AND PUBLIC AWARENESS

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ABSTRACT

Question: How has the Portuguese media covered the Yellowstone fires of 1988 compared with coverage of national fires and other U.S. environmental catastrophes in that period?

Background: Environmental catastrophes are great catalysts for the formation of environmental awareness and the arising of environmental issues. The media has a double role in this process: first, by selecting these events, more or less newsworthy, among many others; second, by picking up certain stories about catastrophes, using familiar frames of reference.

The amplification given by the media—especially television—to these events promotes public awareness and modulates public interpretations, as well as political action. News about catastrophes also reveals problems that are usually concealed from the public eye. That is, it is only when accidents occur that institutions let their lack of foresight appear to the public.

In addition to the emotional claims, stunning images, and overall dramatization, which feature mass media strategies to achieve and maintain high levels of audience share, news about catastrophes has become quite subject to media manipulation by companies and public institutions.

Portugal has been timelessly and intensely exposed to fires. The successive media reporting of annual forest fires revealed the complexity of the forest and this "national" catastrophe as a phenomenon with deep historical and political resonance.

We analyze how the media of a country accustomed to forest fire outbreaks reacts to an environmental catastrophe like Yellowstone fires of 1988, in comparison with 1) all other national fires covered at that time; 2) other types of distant environmental catastrophes that occurred in the United States.

Our analysis seeks to determine if journalistic norms of newsworthiness emphasize some types of environmental catastrophes—proximate or distant; naturally or human induced—and how the pattern of news frames developed to report fires, blame or absolve protagonists, suggesting stereotyped "good and bad guys." It also seeks to determine if the reports simplify events, conceal topics, and are responsible for shaping a biased public perception of facts.

Location: This study has been conducted in Portugal using RTP, the public national television, the sole broadcaster until 1992.

Methods: We provide some empirical results of a content analysis of the Portuguese television network news and newspapers. The first sample includes all television news about national and international fires reported from June to September 1988, including the Yellowstone fires. The second sample includes all items of the main newspaper articles about the Yellowstone fires of 1988 in the Portuguese press (*Expresso* and *Diário de Notícias*) and also the main Spanish daily newspaper (*El País*).

Results: Content analysis of Portuguese television network news shows that most of the news coverage of fires between June and September of 1988 related to a major urban fire that destroyed part of the core shopping area of Chiado, at the center of Lisbon, by 25 August. This event became so important that it overshadowed all other fire events. In fact, unlike what has been noticed in previous and subsequent years in Portugal, 69% of all television news analyzed focused on events connoting destruction of society/urban environment, while only 15% focused on the destruction of forests/natural sites.

Other indicators show a marginalization of forest fires. In news sequencing, 82% of items focusing on the destruction of human/urban settings were opening news, whereas 61% of news on natural environments/forest were poorly ranked. Also, news related to urban fires received more time: 57% lasted from 1 hour 31 minutes to 2 hours 30 minutes, while 44% of news about forest fires lasted from 41 minutes to 1 hour 30 minutes.

In this context, coverage of the Yellowstone fires was mainly reported from the perspective of economic losses (tourism) and not from wildlife damage or loss of biodiversity—contrary to the news reports on the *Exxon Valdez* oil spill, for instance.

In the news, firefighters are portrayed as heroes, with active roles fighting, controlling, risking their own lives; politicians, scientists, and technicians, however, tend to fade away.

Conclusions: The relevance of the fire at the heart of Lisbon and its cultural significance allows for understanding how biased was the media coverage of forest fires in and outside the country. News about fires benefits from its drama and action, but fire occurrence in rural areas and connotation with a simple summer misfortune does not make them an issue.

In the case of the Yellowstone fires, despite its rare mention in news bulletins, it was emphasized as the "crown jewel" of an elite country. Unlike news about the *Exxon Valdez* disaster, where victimized animals were transformed into true icons of public awareness, there were no images of wildlife casualties. Instead, animals were reported on as if nothing had happened.

Media coverage of catastrophes is a complex production process that is deeply embedded in journalistic norms of newsworthiness such as geographical criteria, i.e., closeness of events and elite nations; or of national interest, interpreted by journalists as the number of people affected by an event.

keywords: broadcasting, environmental catastrophes, *Exxon Valdez*, fires, journalistic newsworthiness, media coverage, oil spill, Yellowstone 1988 fires.

Citation: Schmidt, L., and A. Horta. 2009. Media coverage in Portugal of environmental catastrophes and public awareness [abstract]. Page 150 *in* R.E. Masters, K.E.M. Galley, and D.G. Despain (eds.). The '88 Fires: Yellowstone and Beyond, Conference Proceedings. Tall Timbers Miscellaneous Publication No. 16, Tall Timbers Research Station, Tallahassee, Florida, USA.

LESSONS FROM THE PAST AND THE PHILOSOPHY OF THE EUROPEAN PROJECT FIRE PARADOX

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Recent periods of catastrophic wildfire events in several countries in southern Europe, as in other regions of the world, were largely unpredicted. This was due to the difficulty in understanding the relative contributions of weather, fuels, ignition sources, and firefighting strategies in determining the number and potential impacts caused by wildfires. However, lessons from the past in Europe and in many other regions of the world show that periods of significant successful reduction in wildfires are followed by fuel buildup and major catastrophic events. At the same time, it is well known that fires have been used extensively in Europe in past and recent history for vegetation management, but this historical knowledge has been largely lost in recent times. The FIRE PARADOX is the fact that fire can be a very significant threat or a very valuable tool, both in prevention and in firefighting. These different dimensions of fire, from prescribed fire to suppression fire, are captured in the European Project FIRE PARADOX and further extended to non-European countries such as Morocco, Tunisia, South Africa, Mongolia, and Argentina, with scientific advisors from the United States, Canada, and Australia. This project aims at promoting the wise use of fire in the scope of Integrated Fire Management, and it is structured in components of Research, Technological Development, and Dissemination. Special focus is dedicated to some issues that are very poorly developed scientifically but that are fundamental for the adequate use of prescribed fire and suppression fire, such as the interaction between firelines. Dissemination of specific results and of the philosophy of the project are presented as other communications and as a special documentary film in this conference.

INTERNATIONAL PERSPECTIVE: LARGE WILDFIRES IN PROTECTED AREAS

FIRE ECOLOGY AND MANAGEMENT IN ARGENTINA: LESSONS LEARNED AND FUTURE CHALLENGES

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Although fire was used since ancestral times by aboriginals and later by settlers and farmers in an empirical way, professional use and management of fire in Argentina is very recent. From the early 1900s and up to 1948, fire management in public lands only involved suppression activities. This model, adopted by the Argentine Administration of National Parks (APN), closely followed the policies proposed in those times by the U.S. National Park Service. Federal law 13273 (Protection of Forest Resources, passed in 1948) had a chapter related to fire prevention and control but was not fully enforced by provincial governments. Since then and up to the late 1970s, only APN had an organized service to combat forest fires. In 1980–1990, Patagonian provinces started to organize suppression services in response to severe wildfires, and other provinces later followed. In January 1994, 25 volunteer firefighters lost their lives trying to combat a wildfire in a shrubland near the city of Puerto Madryn, in Patagonia. This event, plus large unprecedented fires in Andean Patagonia, forced the federal government to create the National Fire Management Plan (PNMF) in 1996. The main objectives of the PNMF were to promote and coordinate the development of a Federal Fire Management System, aimed to maintain essential ecologic processes, preserve the genetic diversity, and guarantee the sustainable use of species and ecosystems. Specific objectives were, among others, to provide operational support to provinces and APN in fire management and control, create public awareness through education and diffusion, and promote research programs in fire management. Concomitantly, research projects started in the early 1980s, carried out by researchers trained in fire science in the United States and Canada. As a result, several articles in refereed publications and books were written about fire effects on Argentine ecosystems. Some agronomy, biology, and forestry colleges started to teach courses related to fire ecology, and the first courses in prescribed burns were conducted by the National Institute of Agricultural Technologies (INTA). Today, PNMF and provincial services work together, and with the aid of international cooperation, produced great advances in fire management nationwide. From a research perspective, two Argentine institutions (INTA and CIEFAP) joined the European Program FIRE PARADOX in 2007. Diverse fire projects are carried out now within the framework of this program. Future challenges, however, include the creation of a cooperative MS program in Fire Ecology and Management with the University of Lleida, in Spain, and the participation in a joint international training certificate in Fire Ecology, Management and Technology with universities in Spain, the United States, and Portugal.

FIRE IN SOUTHERN EUROPE: EFFECTS OF LANDSCAPE CHANGES

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A long history of anthropogenic fires, mostly related to pasture and agricultural management, has characterized areas of southern Europe with a Mediterranean climate, shaping the landscape and its vegetation cover. This has been ongoing for thousands of years, but land cover changes in the last century have been assessed by GIS analysis comparing historical documents and aerial photos of different periods. Furthermore, an analysis of fire selectivity of actual given land cover classes has been done by Monte Carlo simulation to compare observed fire distribution with a null distribution model. In this geographic region in the last 50 years, major land abandonment has been occurring with population moving from inland and mountain to coastal and urban areas. This process corresponded to deep changes of traditional practices of vegetation management and dramatic increases of urban–forest interfaces. In this context, pastures and forests have been undergoing new successional dynamics with extensive colonization by shrubs, increasing the plant cover and the fuel accumulation. Recent studies showed that fire occurrence, besides the obvious climatic relations and anthropogenic causal factors, is significantly affected by the type of vegetation cover. In this view, shrublands are usually significantly selected by fire, i.e., the occurrence of fires in this vegetation type is more frequent than expected if fires were distributed proportionally to the available extension of the different vegetation types. The new fire propagation scenario is deeply changing the fire prevention problems and the related needs of updated management practices and firefighting methods. This requires capability of prevision of trends of vegetation cover changes and management aimed to reduce fuel structural homogeneity over extended areas, especially adjacent to urban settlements.

GREATER YELLOWSTONE 2028: THE NEXT 20 YEARS

MULTI-PARTNER DEVELOPMENT OF TAXONOMIC ECOLOGICAL LANDSCAPE TYPES FOR THE GREATER YELLOWSTONE AREA

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ABSTRACT

Question: What are the benefits from, challenges to, and potential for developing a taxonomy of ecological landscape types and related attributes for the Greater Yellowstone Area?

Background: Ecological processes do not start and stop at administrative borders. Incongruously, the environmental data used to help document, model, understand, and manage public land and resources often do stop abruptly or change dramatically at jurisdictional edges. Understanding and addressing macroscale issues, including fire, climate, biodiversity, landscape integrity, animal migration, ecosystem health, and landscape dynamics, requires a common language and ecological classification system to support and better correlate the hundreds of studies that occur at dozens of scales and countless extents across the Greater Yellowstone Area (GYA).

Location: The GYA covers >20 million acres of mostly public land in Idaho, Montana, and Wyoming, USA, including six national forests, two national parks, two national wildlife refuges, and other interests.

Methods: In order to produce a common taxonomy for ecological types in the GYA the following approach is proposed. Develop leadership of an individual or small group to champion collaboration and cooperation in the realm of vegetation ecology, landscape ecology, or similar discipline. This group will pursue an interagency and interdisciplinary approach to establish measurable objectives, identify existing systems and standards, develop procedures to resolve key questions, and bridge real and perceived barriers. This group will also establish project milestones and time frames.

Results: To be determined.

Conclusions: This conceptual approach for classifying ecological types across the GYA is an important step toward developing a consolidated inventory to support analytical derivatives, model inputs, and map products that are crucial for understanding and managing resources in the GYA. Example outputs include area-wide maps and vegetation characterizations for fire planning and analysis. Additional outputs might include modeling the spread of invasive species, wildlife movement analysis and prediction, and identifying ways to refine, improve, and maintain the taxonomy and related data.

keywords: classification, ecosystem, function, interagency, interdisciplinary, landscape, process, taxonomy, vegetation.

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GREATER YELLOWSTONE 2028—THE NEXT 20 YEARS

Paul Hansen

Director, GY Program, The Nature Conservancy

While the heart of the Greater Yellowstone Ecosystem (GYE) is protected in two national parks, the winter habitat surrounding the parks—the land most critical to the survival of much of the ecosystem's wildlife—is under-protected and is disappearing rapidly. Unlike the more dynamic and temporary impact of fire, even considering the dramatic fires of 1988, this habitat loss is insidious and permanent. While millions of acres are held in park, forest, and refuge status, the most essential winter feeding areas and migration corridors are rarely protected. Almost all of the acreage in protective status includes important but relatively abundant summer habitat, but very little crucial winter habitat. This is the most critical and most threatened habitat in the Greater Yellowstone. Its availability effects overall ecosystem health and species survival. At the current rate of permanent habitat loss, the extraordinary wildlife that characterizes the Greater Yellowstone region will not be maintained. The region's population is now growing at twice the national rate. Land conversion and habitat loss is six times the national average. Invasive species are destroying even more habitat. The impacts of climate change will add even more stress to plants and animals, reducing the ecological resilience of the entire system. Protecting this vital habitat will require an unprecedented effort and a great deal of cooperation. The Nature Conservancy and its partners have identified the 2.8 million acres that are the most important to the survival of the Greater Yellowstone's wildlife. Working collaboratively, we want to protect 1 million acres, the most important 4% of all Greater Yellowstone wildlife habitat, by 2015. This is an ambitious goal, but the Conservancy has protected >117 million acres of land and 5,000 miles of rivers around the world with cooperation and support of a variety of partners. A primary focus on voluntary habitat protection agreements with willing private landowners can ensure that future generations will experience Yellowstone wildlife as we have. Our work requires significant outreach to the millions of visitors who love Yellowstone. It requires local, state, and national attention, and, ideally, national legislation and funding. Finally, it requires the awareness and support of the region's residents and the millions of Americans who love this special place.

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