A Statement of Common Ground Regarding the Role of Wildfire in Forested Landscapes of the Western United States

Fire Research Consensus Working Group

Final Report

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SNAPP Science for Nature and People PARTNERSHIP

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Cover photo caption: Night and day on the Pioneer Fire in central Idaho in 2016. How this fire burned and what will happen next reflects the history of fire and fire suppression in this region, as well as land use and changing climate. The Pioneer Fire burned >188,000 acres in 2016, despite active fire management to limit its spread, at a cost of >$100 million. Photo ID_16-08-30 by Kari Greer, Kari Greer Photography, www.wildland-fires.smugmug.com and used with her permission.

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Acknowledgements

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The Steering Committee (Craig Allen, Paul Hessburg, Penelope Morgan, Max Moritz, Dennis Odion, Christopher Topik, and Thomas Veblen) is collectively responsible for the work summarized here, and we adhered to a Project Charter that clarified our goals, roles, and responsibilities. The contributions of Ian McCullough were valuable and substantial enough to merit coauthorship. Excellent project facilitation was provided by Julian Griggs of the Dovetail Consulting Group. The substantial suggestions of Rachel White, science writer/editor for the US Forest Service, were very helpful; additional constructive comments were provided in the USGS internal review process.

Many scientists and managers contributed to this report, either through input to a questionnaire or by providing feedback on interim drafts. Please refer to the online supplemental materials associated with the questionnaire and review process, which include a record of contributors and other documents. The project would not have been possible without the time, effort, and trust of our colleagues, and we are grateful for all contributions.

Executive Summary

For millennia, wildfires have markedly influenced forests and non-forested landscapes of the western United States (US), and they are increasingly seen as having substantial impacts on society and nature. There is growing concern over what kinds and amounts of fire will achieve desirable outcomes and limit harmful effects on people and nature. Moreover, the increasing complexity surrounding cost and management of wildfires suggests that science should play a more prominent role in informing decisions about the need for fire in nature, and the need for society to adapt to the inevitable occurrence of different kinds and amounts of fire and smoke.

Scientists widely view the natural wildfire regime as essential to western US forest ecosystem functioning. However, debates continue over how much low-, moderate-, and high-severity fire is "natural" or desirable in these forests. Ongoing disagreement centers on the characteristics and importance of historical proportions and patch size distributions of low-, moderate-, and high-severity fires of dry, moist, and cold forests, and on the ecological consequences of changing fire-patch patterns and relative abundances. Scientists also debate the relative importance of climate and extreme weather versus fuel as drivers of high-severity fire, as well as the effectiveness and value of fuel treatments for reducing risks of undesired fire effects.

Climate research shows that we should expect shifting future climates in all ecoregions. These expected changes make it difficult for scientists, land managers, and decision-makers to know the degree to which future forest management should be informed by historical conditions. There also is disagreement about how to make western forests more resilient to future disruptions in both climatic and fire regimes. To complicate matters, areas of scientific agreement -- the "common ground" shared by those in the research community -- are poorly articulated. Thus, the focus of the Fire Research Consensus (FRC) project has been to identify common ground among scientists, and provide a summary that can inform management. Land and fire managers are one audience for this report, as are stakeholders and the interested public.

Our analysis, which results from extensive scientific literature reviews and questionnaires sent to western fire scientists and land managers, is summarized in nine key topics:

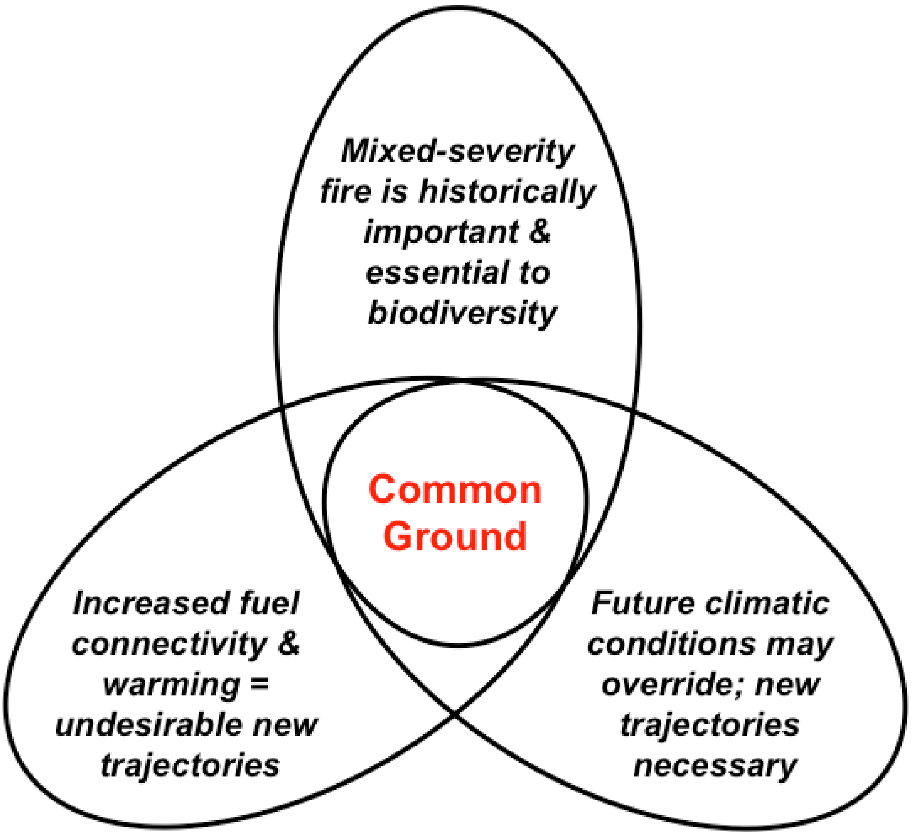
A. Fire history and fire ecology vary with geography.
B. Human impacts and management history vary with geography.
C. Fire is a keystone process, which occurs in almost all western US forest types.
D. Knowledge of historical range of variability (HRV) is useful but does not dictate land management goals.
E. Forest structure, composition, and fuels have changed, affecting burn severity and fire extent.
F. Climate and fuels both influence current fire sizes and their severities.
G. The role of changing climatic conditions is increasingly important.
H. Multiple fire ecology and fire history research approaches can be useful for characterizing fire regimes.
I. Many existing fire management tools and strategies can be useful moving forward.

We found much common ground that will be useful to scientists, managers, citizens, and policy decision-makers. For example, there is wide agreement among scientists that fire is one of the most essential influences on western forests and that more fire is needed on most landscapes, but not all wildfire behavior or extent will do. Fires can produce more positive benefits and fewer negative impacts when they burn with an ecologically appropriate mix and pattern of low, moderate, and high severity. Managers will need assistance and funding to create landscape conditions that favor more desirable fire behavior at broad spatial scales. Note that much societal impact from western wildfires occurs in non-forested landscapes that are not covered in this report, where findings would differ from those reported here for forested landscapes. We summarize additional key points below.

High-severity fire

Respondents disagreed about whether large, high-severity fires have increased to a significant and measurable degree in all forest types *in comparison to historical fire regimes* (i.e., prior to modern fire suppression). There was strong agreement that in dry pine forests at low elevations there has been either an observed increase in high-severity fires or an increase in the potential for fires of elevated severity as the result of increased abundance and connectivity of woody fuels since the late 19th century. There was similar strong agreement about dry mixed-conifer forests in the Inland Northwest, Pacific Southwest, and Inland Southwest (Arizona and New Mexico) that there has been an increase in high-severity fires and an increase in the potential for fires of elevated severity. There was less agreement about the changes in extent, and causes of changes in extent, of high-severity fires in moist mixed-conifer forests. Although there is general agreement that high-severity fires historically played an important role in moist mixed-conifer and cold subalpine forests, there is strong disagreement over the degree of changes in burn severity patch-size distributions and associated successional conditions for these forests between different regions.

Opinions also vary over the consequences of any increases in fire severity. For most dry forests, although there may be some disagreement about trends in burn severity and their causes, there is broad agreement that under current and projected climate, post-fire forest resilience is less than in the past. Some forest habitats, particularly at drier sites, but also in some moist and cold forest sites, show evidence of converting to more flammable non-forest vegetation or less dense forests following recent fires where large patches burn severely, especially if reburned. Reburn potential may depend on the interaction of vegetation, weather, rate of fire spread, time since prior fire, ignitions and fire suppression. Opinions are varied concerning the ecological consequences of departures from historical patterns of fire severity in various mixed conifer and subalpine forests. For example, one viewpoint supports the historical precedence of mixed-severity fire (including relatively large patches of high-severity fire), and the concept that pyrodiversity begets biodiversity. Another viewpoint asserts that increased woody fuel connectivity in combination with a warming climate trend is setting large areas of landscapes on fundamentally new trajectories, with significant undesirable ecological and societal consequences. Still a third viewpoint emphasizes that climatic changes increasingly are of overriding importance, and that new trajectories are unavoidable and thus may be considered desirable in many cases to incrementally foster necessary ecosystem transitions. The figure below characterizes these divergent viewpoints – typical of many areas of disagreement we addressed – and the potential common ground among them.



Uncertainties associated with relative proportions of different burn severities and patch-size distributions combine to cloud key points of consensus that have important management implications. We suggest that resolving many fire science disagreements depends on greater consideration of specific geographical context. This may imply that a narrow range of field experience can limit one's ability to accept findings that depart from that range. A logical way forward is to increase in-depth cross-regional field research experiences of the fire research community. Cross-regional comparisons of top-down and bottom-up determinants of fire activity in similar forest cover types is a fertile area of future research to examine how differences in seasonality, productivity, understory fuels, land use history, and other factors may explain some of the reported geographical differences in historical fire regimes in broadly similar forest types.

There are several reasons for the disagreements about the amount and roles of past higher-severity fire. Both scientists and managers often transfer concepts and findings from one place to another, yet we know that "no one size fits all" for historical fire regimes, even within the same forest type. Likewise, the extent of change in abundance and connectivity of woody fuels varies across forest types and ecoregions. Some of the disagreement derives from use of different scientific approaches. For instance, there is strong debate about the fire regime inferences made from historical and modern tree inventory data, simulation models, and other approaches. We believe that application of diverse research approaches will be useful going forward. Further, multiple approaches will be useful in "triangulating" interpretations for which there is some scientific consensus (see Topic H). We challenge fire scientists who do not share similar perspectives on historical fire regimes in particular ecosystems to engage in civil discourse to better understand the reasons for their disagreement, and to objectively communicate those reasons to managers and other stakeholders. We are heartened by the positive outcomes achieved by some previous attempts when small or large groups work together to find common ground.

The Wildland Urban Interface and Beyond

Respondents strongly agreed on the need for fuel treatments and fire suppression to protect human infrastructure within and adjacent to the wildland urban interface (WUI). There is a strong consensus that preventing undesired human-set fires in the WUI is essential to reducing societal vulnerability. The strategies for managing fire may be different within and adjacent to the WUI than in areas far from the WUI. However, what fire managers do beyond the WUI has implications for fire behavior approaching the WUI, forest resilience, smoke production and its human impacts, water quality, and many other ecosystem services people value.

Fuels management alone, especially if limited to public land, will be insufficient to address the vulnerability of WUI communities to fires. Fuels management will be important for influencing how wildfire behavior will approach the WUI. Thus, policies to make current WUI communities more fire adapted (e.g., implementing current WUI codes) are a critical piece of the puzzle, as are changes in land use policies that influence where and how future WUI areas develop, and the spatial extent and arrangement of managed and wildfire fuel treatments. Controlling human ignitions is important to address fire risk, especially in landscapes where ignitions have the potential to radically increase fire frequency. Communities in fire-prone areas need to learn to live with fire and increase their use of fire and other methods to reduce susceptibility to unacceptable fire damage.

Pattern and Process for Fires in Forest Landscapes

Heterogeneity of fire effects, including the patterns of patches created by fires of all severities, is important to forest resilience to future fires (see Topic E). The scale of the problem is vast, however, so it is likely that the scale of analysis and solutions (e.g., fraction of landscape treated via wildfire use) is also necessarily vast. There are potentially profound implications for forest regeneration, watershed protection, biodiversity, and carbon sequestration if the proportion and spatial pattern of area burned with high-severity fire change. Where wildfires severely burn large areas of forest, local elimination of conifer tree seed sources and reduced tree regeneration under emergent warmer-drier conditions can occur. Large areas of forest are converting to persistent grasslands or shrublands post-fire in some regions. Even relatively small changes in the proportion of large patches can alter system behavior for decades and even centuries. Thus, the patch-size distributions of both forest and non-forest patches are of concern to policy makers, scientists, and managers.

Climate, Fuels, and Implications of Landscape Change

Both fuel and climate are important drivers of fire activity. Increased woody fuel connectivity in combination with a warming climate trend are setting large areas of many landscapes on new trajectories where very large patches burn with high severity. There is agreement that all fire regimes are the product of interactions among varying degrees of top-down climate and weather forcing and bottom-up spatio-temporal controls of local topography and fuels, which reflect legacies of past fires and other agents altering vegetation. In other words, fires respond to interacting influences of climate, weather, fuels, topography, legacies of prior disturbance, and management. The relative importance of these factors varies across landscapes and through time.

While climate is of increasing importance, fuels management is also important. Indeed, fuels are the main landscape characteristic that management can change. But an ecologically and socially appropriate mix of fuel management tools and practices is needed. More flexible management of wildfires and prescribed fires will be useful, depending on local objectives and conditions, to increase the footprint of land areas showing reduced surface and canopy fuel abundance and connectivity. Increased use of prescribed burning combined with thinning will be helpful where forest conditions are not currently manageable via wildfires and prescribed fires alone, and where high certainty about fire perimeter control and fire behavior are key objectives (e.g., adjacent to WUI). Some respondents suggested that accepting a more proactive approach to fire and fuels management on public lands may initially be more expensive, but may reduce overall costs and improve climate change adaptation in the long-term. Other respondents questioned the practicality and effectiveness of fuel treatments under a changing climate. Notably, in their responses, respondents did not integrate the concomitant effects of weather, climate, topography, and fuel abundance.

Decades of research in landscape ecology show that emergent properties have central importance to ecosystems and their pattern and process regulation, whereas many recent studies of climate-driven fire and vegetation change are less focused on local-scale feedbacks and emergent patterns. This difference creates a fundamental problem in linking climate change and landscape ecology research. Climate models assume that top-down climate covariates drive temperature, precipitation, and solar radiation conditions. Landscape ecology research shows that those top-down inputs can be highly modified by meso- and fine-scale bottom-up environmental controls to produce emergent climatic conditions that are strictly speaking neither the top-down or bottom-up inputs, but are influenced by these inputs. Climatic forcing alone poorly explains the shifts in landscape patterns because lagged patterns of historical disturbances continue to influence emergent patterns, under all but the most extreme events. The path forward to more effective projection of future fire and landscape change includes better integration of feedbacks from landscape ecological models into climate-driven models of future fire and landscape change. Broad-scale studies are still needed to tease apart the roles of changing climate and changes in fuels in the observed trends in frequency of large fires.

Effective Management will Depend on Both Science and Trust

Our understanding of historical fire regimes can inform decision-making; indeed, such evidence-based decision-making can build trust. While history does not provide precise prescriptions for managing landscapes, it does offer precautionary principles. Adaptive resilience for the future will require applying what we learn from history to some future range of variability, where fires burn and ecosystems respond in both similar and different ways.

At the same time, fire science points to complex patterns that vary with local conditions. Unique ranges of vegetation and fuel patterns are the result of interactions among regional climate, topography, landforms, geology, and biotic communities of an area, along with associated meso- to fine-scale pattern heterogeneity. Thus, no single solution, such as logging or limiting all logging, will accomplish desired objectives in all forests. Further, any management, including no intervention, has consequences, so all decisions need monitoring to evaluate the assumptions of management. Effective monitoring can improve knowledge, and through collective learning can build common understanding and trust.

Fire management can become more proactive and strategic. Existing tools, such as mechanical fuel treatments, prescribed fire, prevention of accidentally-ignited human fires, and managing wildfires, will all be useful, but adaptation and mitigation responses to climate change and changing fire activity will require using these tools in strategic ways to fit area-specific goals. Some past disagreements about fire and fuel management strategies may be due to lack of clarity about specific goals, such as resident and firefighter safety, cost reduction, biodiversity issues, and ecosystem resilience under a changing climate.

The timing of fires is important, particularly in the context of a changing climate. While recognizing that wildfire seasons are long and getting longer, we must also take advantage of the milder fire weather and associated effects of fires in the "shoulder seasons." Managers may find that both less-aggressive fire suppression and expanded use of managed wildfire under relatively moderate weather conditions can aid them where reducing the vulnerability of people and natural resources to fires is the objective. Managing wildfires may be one important way to achieve relatively widespread vegetation change at the spatial scales and in the short timeframe needed.

One of the grand challenges of fire management is balancing the reality that wildfires will occur and are needed by western forest ecosystems, yet people, property, and economies need protection from the adverse effects of fire. Another grand and fairly urgent challenge is discovering the tipping points of transformative change for various forest landscapes in their respective geographies, where large, high severity fires (regardless of whether they are considered unprecedented or not) may tip forest ecosystems into persistent non-forest states by constraining tree regeneration opportunities. Particularly as climate changes, we also need a deeper understanding of which landscapes may not be able to sustain forests in the future and how fast such transitions are likely to occur. It is clear that our western history of substantial forest fire activity will continue, one way or another -- many fires will occur in the future and some will be large. Ultimately, we must find ways to both sustainably use and live with fires that are well-adapted to both ecosystem and societal needs of local landscapes.

Introduction

Wildfires have, for millennia, markedly influenced forests and non-forested landscapes of the western United States (US), and they are increasingly seen as having substantial impacts on society and nature, even though less area burns in many forests than burned historically. Informed planning and fire management preparations and responses are thus becoming more important, with lives, property, government expenditures, biodiversity, and ecosystem services at stake. Federal and state firefighting costs now routinely exceed available funds, which are then either borrowed or permanently taken from funds that would ordinarily support resource management activities.

At the same time, climate research shows that we should expect to experience future climates in many ecoregions that will, to varying degrees, differ from those of the recent past. These expected changes make it more difficult for scientists, land managers, and decision makers to know the degree to which future forest management and wildfire policy should be informed by the past. The increasing complexity surrounding cost and management of wildfires suggests that science might play a prominent role in informing decisions about the need for fire in nature, and the need for society to adapt to fire.

Scientists widely view fire as a normal part of ecosystem functioning and one of the most essential influences on forests of the western US. They also recognize that fire directly affects the health and wellbeing of people living near fire-prone landscapes, influencing the water, wildlife, recreation, forest products, and other aesthetic and spiritual benefits these landscapes provide. However, scientific debates continue over several important fire-related topics, including: how much low-, moderate-, and high-severity fire[1] is "natural" or desirable in varied forests across the western US; the relative importance of climatic versus fuel factors as drivers of high-severity fire; and the effectiveness and value of fuel treatments for reducing risks of undesired fire effects.

There is also apparent disagreement about how to make these forests more resilient to future disruptions in both climatic and fire regimes. In many policy and management arenas—from national forest policy to state, county and Tribal-level management—debates about wildfire have sometimes slowed effective integration of research into public policy, and hindered informed planning and management. Much is clearly at stake.

[1] Low, moderate, and high burn severity are usually defined in the western USA by level of mortality of overstory trees or shrubs within individual fires. Low-severity burns are often surface fires with scattered tree torching, where most trees survive (e.g., <20% mortality), while high-severity burns are often stand-replacing fires that kill >70% of the overstory trees (derived from some mix of surface and crown fire behavior). Moderate-severity fires include areas with intermediate levels of overstory mortality (20-70% of basal area or canopy cover of a given patch) from fire. All low-, moderate- and high-severity fire regimes result in intermixed patches of burned and unburned vegetation, but the scale of patchiness differs. Note that we use moderate for intermediate effects of individual fires and mixed for fire regimes. From Agee (1993) Fire ecology of Pacific Northwest forests. Island Press.

Overview: Purpose and Scope of this Report

This report summarizes work of the Fire Research Consensus (FRC) project, which formed to provide insights for scientists, land managers, and human communities with respect to recent controversies over the role of low-, moderate-, and high-severity fires in western US forests. The goal has been to clarify agreements, disagreements, research needs, and possible management implications of scientific common ground. Our hope is that stakeholder groups will avoid the selective use of particular scientific papers to argue for their particular ends. Instead, they will be able to point to key shared assumptions, common understandings considering the entire body of fire science literature, and terminology to support decision-making in constructive ways. This should facilitate better awareness and application of existing and future scientific findings. In particular, land and fire managers are a key audience for this report, as are other stakeholders and the interested public engaged in discussions about land management. Future work is needed to more directly emphasize fire-related research needs and open scientific questions.

We acknowledge that public land management agencies are charged by society to make management decisions, and take associated actions on those lands. Actions are constrained and focused by existing laws, land use plans, policies, and pertinent Acts. We further acknowledge that management agencies are required to accomplish annually-funded land management targets, which can be at odds with some societally-held land-use values, or other landscape and resource management goals. Our focus on areas of broad scientific agreement within the fire science community is intended to make the application of fire science more useful to land management agencies and lawmakers, but it does not, and cannot, resolve diverse social, economic, philosophical, and political debates about preferred land use values across a spectrum of ideologies and management methods. These societal debates play out through broader public conversations and decision-making processes that are only partly informed by fire science. Key roles of fire science are to provide high-quality information to support high-quality societal conversations and decision-making about land (and fire) management, and to assist in monitoring outcomes. In our implications comments at the close of each major section, we provide case examples of how areas of agreement might be considered in the development of management applications.

As a prelude to more in-depth coverage in the report, our analysis can be summarized to nine key topics:

A. Fire history and fire ecology vary with geography.
B. Human impacts and management history vary with geography.
C. Fire is a keystone process, which occurs in almost all western US forest types.
D. Knowledge of historical range of variability (HRV) is useful but does not dictate land management goals.
E. Forest structure, composition, and fuels have changed, affecting burn severity and fire extent.
F. Climate and fuels both influence current fire sizes and their severities.
G. The role of changing climatic conditions is increasingly important.
H. Multiple fire ecology and fire history research approaches can be useful for characterizing fire regimes.
I. Many existing fire management tools and strategies can be useful moving forward.

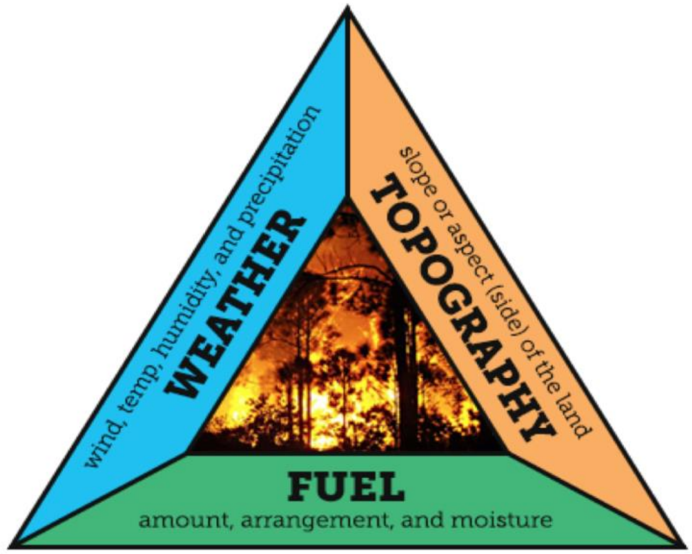
Given the intertwined nature of these topics, there is repetition of themes among some of the material presented. The FRC steering committee believes that the summaries derived from this work are representative of current fire science and can usefully inform fire and land management. It is our intent that in the future, land managers and community leaders will be able to better understand, and more accurately and precisely communicate, the need for fire in the environment and how to better prepare for its impacts. Further, the goals and priorities for fuel and climate change adaptation treatments will be better understood, such that responses to them are less polarized. Scientists will have a clearer picture of the key research questions that underpin current debates. Instead of a focus on disagreements, a deeper appreciation of the research that is agreed upon will allow us all to be more deliberate and proactive when thinking about and managing wildfire environments in the West.

Note that much societal impact from western wildfires occurs in non-forested landscapes that are not covered in this report, where findings would differ from those reported here for forested landscapes.

Fundamental Principles vs. "Common Ground"

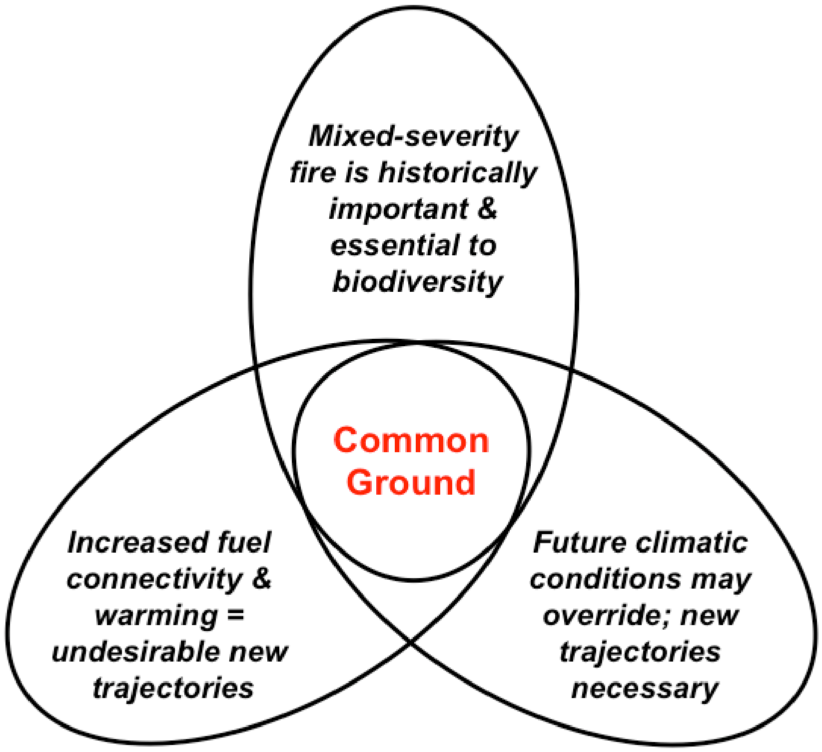
At the outset, we acknowledge some core scientific principles that are widely accepted by those engaged in all sides of these debates. One example is the idea that wildfire is inevitable, and it is a process essential to all western forest ecosystems. Wide agreement therefore exists about the extensive benefits of fire, even if this agreement may not be shared outside of the research community. The notion that fire is an essential ecological process was universally shared and was a guiding principle of most questionnaire respondents.

Another key example is the set of factors making up what is considered the "fire behavior triangle" shown below. This construct was developed by scientists to capture the physical and chemical principles that govern fire behavior, namely characteristics of 1) fuel, 2) weather, and 3) topography in affecting a given fire's rates of spread, flame lengths, and intensities. There is also extensive agreement about there being trade-offs in the relative importance of these factors, such as the influence of fuel characteristics in some instances diminishing in more extreme topographic settings (e.g., steeper slopes) and weather conditions (e.g., higher wind speeds, lower humidities). There is natural variation in how different factors intersect in space and time, resulting in often complex dynamics and only semi-predictable outcomes. Even so, certain relationships are predictable enough at finer scales to be useful for models of fire spread and crown fire initiation; broad-scale simulation of fire behavior patterns is also possible, although with known limitations.



Fire Behavior Triangle

In the context of our project, the fundamental science that underpins the study of fire is not what we mean by "common ground" shared among disagreeing groups. Here instead we are referring to areas of agreement, or the overlap in perspectives, that emerge when debates over a given issue are deconstructed. As a hypothetical but realistic example, consider the Venn diagram below, which represents three partly overlapping views about possible causes and consequences of increases in high-severity fires. There is evidence that some forest habitats, particularly at drier sites, are converting to non-forest vegetation or less-dense forests following recent fires, where large and severely burned patches are created. Conversely, afforestation has occurred in some forest types as a result of fire suppression, which can reduce fire intensity and spread, compared to some non-forest vegetation. Opinions are varied concerning departures from historical patterns of fire severity in various mixed-conifer and subalpine forests, as well as their ecological consequences. One viewpoint supports the historical precedence of mixed-severity fire (including relatively large patches of high-severity fire), and the concept that pyrodiversity begets biodiversity. Another viewpoint asserts that increased woody fuel connectivity in combination with a warming climate trend is setting large areas of landscapes on fundamentally new trajectories, with significant undesirable ecological and societal consequences. Still a third viewpoint emphasizes that climatic changes increasingly are of overriding importance, and that new trajectories are unavoidable and thus may be considered desirable in many cases to incrementally foster necessary ecosystem transitions.



In the realm of public discourse, these three perspectives might be reduced to simplistic and utterly contrasting sound bites, spanning the following extremes:

- Fuel treatments are urgently needed across nearly all forests.
- Fuel treatments should be focused around communities and plantations; hazard reduction elsewhere is futile.
- There is high uncertainty about where and when fuel treatments are beneficial.

Regardless of public perception, there is still a solid scientific basis for each of the three perspectives shown in the example above, and much can be learned by examining the common ground of their intersection. We explore the common ground of these and other such areas of overlap in divergent scientific perspectives in this document.

Philosophical and Contextual Issues

At times, differences in perspective may be linked to whether one's research emphasizes fire effects on tree survival, residual vegetation structure, or fire effects on overall ecosystem function and biodiversity. Frustrations and value judgements about management activities and their impacts on public lands have also contributed to differing scientific perspectives about possible paths forward. Scientist and public mistrust of past and current management on some public lands is one of the largest impediments to forward progress, and yet most discussions focus on improving fire science rather than improving trust. Fire scientists, ecologists, and land managers need to better understand how science has been used in the past to justify various management actions, and how various breaches of trust have affected adoption of modern scientific findings. Such trust can be rebuilt with monitoring and stakeholder engagement in land management decision making.

There was wide agreement among questionnaire respondents that fire science often gets overly simplified in the media, even when more nuanced views may be held among scientists doing the research. Sometimes simplification links back to early narratives and research findings, which may then be inappropriately applied by others beyond their original context. An example of this is the notion that climate change will universally increase fire frequencies and severities, despite growing evidence of more complex outcomes. In other cases, scientists, journalists, policy makers, land managers, NGOs, or politicians may simplify stories to increase their clarity or impact, or to deliver specific messages to the public, and these stories are then carried forth as “debates.”

Many respondents also recognize the need for better terminology and conceptualizations of fire regimes[2], both for communicating with the public, and for use among scientists. To some extent, imprecision or ambiguity of terms and concepts may be partly responsible for certain debates in the fire literature. For example, numerous respondents commented on how fire regimes have been oversimplified as fitting into one of the three broad classes of low-, mixed-, or high-severity. Imprecision or lack of agreement on objective classification of fire regimes conflates with actual disagreements over the interpretation of fire history evidence. Although disagreements are not simply based on semantics, poor semantics contribute to confusion. In addition, scientific interpretations of fire regimes made at specific spatial and temporal scales are sometimes fraught with unspecified assumptions, imprecision, or error in the scope of the inferences made.

Additionally, respondents often had differing priorities for, and definitions of, “restoration” and “resilience,” generally reflecting the plurality of these definitions and priorities in modern society. For example, how important is the past to understanding and planning for the future? What exactly is being restored, to what benchmark, and for what purposes? What ecological and social values support any intended restoration? Underpinning each of these questions are differing perspectives about the importance of historical ecology based on differences in human social values, even on the part of scientists.

Restoration[3] and resilience[4] are often identified as goals of forest management, and yet the enabling legislation and funding sources of different land management agencies actually

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[2] A fire regime is the pattern, frequency, fire size, spatial complexity, and severity of fires over space and time. Fire regimes are characterized based on fire frequency (how often fires occur), intensity (amount of heat released at the flaming front), severity (both soil and tree mortality effects), type (ground, surface, crown), size, spatial pattern (including patch size distribution) and seasonality. Ground fires burn organic matter in the soil. Surface fires burn leaf litter, fallen branches, and plants on and near the soil surface. Crown fires burn through to the top layer of trees and shrubs. From Morgan et al. (2001) Mapping fire regimes across time and space: understanding coarse and fine-scale fire patterns. International Journal of Wildland Fire, 10(4): 329-342.

[3] Restoration is “the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed” (Society for Ecological Restoration International Science & Policy Working Group [2004] Primer on Ecological Restoration. www.ser.org). Also see Hessburg et al. (2015) Restoring fire-prone forest landscapes: Seven core principles. Landscape Ecology 30(10): 1805-1835.

[4] Resilience: The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks (Society for Ecological Restoration www.ser.org). See also Schoennagel et al. (2017) Adapt to more wildfire in western North American forests as climate changes. Proceedings of the National Academy of Sciences. 114(18): 4582-4590.

dictate how restoration and resilience are defined and implemented. Therefore, even if common ground might exist on the need for fire to play a more natural or culturally central role, there can be widely varying opinions about what to do, and varying options as to how to make that happen, legislatively and administratively.

Not surprisingly, there were differing opinions about tradeoffs between human social values and the ecological benefits of fire. For example, smoke from wildfires or prescribed fires is a great concern that can have important influences on how various fire treatments are applied. Reconciling these varied opinions and the associated trade-offs was not in the purview of this effort. Views on forest restoration and ecosystem resilience are thus embedded in this larger context of other human social values, which greatly adds to the complexity of consensus-building and informed decision-making.

Looking forward, assessments of the effectiveness of fire management under climate warming will provide important results, ideally through science-based monitoring and management actions that are intentionally adapted by lessons learned. Most fire scientists and managers agree that fuel treatments can affect fire behavior, though effectiveness can vary with weather, treatment type, location, and time since treatment. Clearly, wildfire researchers recognize the importance of both extreme weather and fuel conditions on fire behavior. However, some respondents suggested that policy makers are unaware of uncertainties associated with attaining fire mitigation goals in the face of more frequent extreme-fire weather, but the management requirement to address such goals persists. Fire managers look to fire science for clear answers about methods, and their reasonable application, because planning and implementing actions in response to climate change, forest restoration, and other needs are essential to their mission.

A number of respondents lamented the time and energy devoted to disagreements over the interpretation of fire history in forest management debates. They suggested that the real challenge is to face the reality of a changing climate and changing fuels by considering the effectiveness of fire mitigation strategies (both old and new). There was also wide agreement on the need for land-use strategies that reduce societal and resource vulnerability to negative consequences of wildfire and climate change, while providing for the essential role and many benefits of fire in forests. We acknowledge that this is an example of fire scientists pointing to a need for stronger engagement with social scientists.

Numerous western fire scientists, when asked, chose not to participate in this survey, and others reluctantly participated. Several cited previous unproductive and unprofessional interactions in the context of debating fire science and related land management issues. Some questioned the motives of researchers not sharing compatible viewpoints on fire issues. Quite a few, including individuals from all sides of the debate, expressed frustrations with the peer review process of some mainstream ecology and forest science publications, and the resulting contradictory messages conveyed to land managers. The FRC Project Steering Committee is well aware of deep division within a portion of the fire research community that is impeding healthy, productive scientific debate. It is beyond the scope of the FRC to examine the non-scientific bases of these conflicts. Instead, our focus has been to identify the common ground shared among a majority of fire scientists on key issues, and to provide a summary that can support informed management decision-making going forward.

Methods and Data

We considered the entire extent of the scientific literature and views of scientists relating to fire research in western US forests. The Steering Committee is committed to inclusion of the full range of scientific perspectives reflected in the questionnaire responses and in the peer-reviewed literature. To facilitate a broad scope of input, we invited responses to a multi-part questionnaire from scientists from many different geographic areas and scientific perspectives. Invited respondents were those who had "*published significant primary research on fire occurrence and fire effects on ecosystem attributes in forests of the western US prior to intensive management, or in areas with limited active management such as large wilderness areas*."

This invitation criterion filtered out potentially important scientific contributions (e.g., those focusing on Native American use of fire, wildlife, post-European settlement periods, ecosystem resilience, and climate change adaptation) from the initial questionnaire. However, a broader range of scientific perspectives was included when the draft common ground statement was distributed for external review. After several rounds of invitation, 77 researchers were contacted, which yielded 36 respondents, including steering committee members. We believe that the depth and geographical breadth of responses were sufficient to identify key areas of agreement and disagreement among fire scientists.

Individual questions in the questionnaire were often intentionally structured as false dichotomies. Using this mechanism, we intended to generate thoughtful responses that would include details as to why a respondent might agree or disagree with the framing of a given issue. While this approach worked overall, it was clearly frustrating to some, and even appeared to a few as evidence of inherent bias in the process.

Between November 1st and 4th, 2016, our steering committee convened a workshop to summarize and organize responses to the questionnaire. Due to great variation in the nature of the questions and how much respondents tended to use literature citations in their responses, we opted not to incorporate citations throughout this report; doing so in a consistent manner was simply seen as intractable. In addition, our common ground document draws upon our own experience and critical reading of the literature, also without the use of citations. As an archived supplement to this report, however, we list citations that were used by respondents in supplemental online materials; any future refereed publications derived from this work will incorporate citations. Note that an exception to this approach is our inclusion of citations in a relatively small number of definitional footnotes throughout the report.

An external evaluation of the completeness and tone of our common ground statement was undertaken in June of 2017. For scientific perspectives, we invited 100 researchers for feedback on our draft statement; this group was larger than the original 77 invitees, to include a broader range of expertise. We received feedback from 36 individuals, not including the FRC steering committee. We also invited review and comments on the draft and its usefulness from 60 land managers and other stakeholders, 22 of whom provided feedback. To the best of our ability, we then integrated the feedback we received into this final document.

Forest Type Classifications

We based our discussion on three broad forest types in the western US, which we refer to as 1) dry pine and/or dry mixed-conifer (*aka*, dry forests), 2) moist mixed-conifer (moist forests), and 3) cold subalpine (cold forests). These are broad terms that are used colloquially to generalize forest types across the western US. Within particular regions, these terms can be crosswalked to classifications that are commonly used by land managers and in peer-reviewed literature.

To the extent that it may be helpful for cross-regional communication and possible generalizations we provided some examples of forest types covered in the questionnaire based on the US National Vegetation Classification (US NVC).

Dry forests, including for example:

- Central Rocky Mountain Dry Forest Macrogroup M501 (1.B.2.Nb.2 *Pinus ponderosa var. ponderosa - Pseudotsuga menziesii - Pinus flexilis*)
- Southern Rocky Mountain Forest & Woodland Group G228 (1.B.2.Nb.1.b *Pinus ponderosa*)

Moist forests, including for example:

- Central Rocky Mountain Mesic Lower Montane Forest Macrogroup M500 (1.B.2.Nb.3 *Tsuga heterophylla - Abies grandis - Larix occidentalis*)
- Central Rocky Mountain Forest Group (1.B.2.Nb.3.c *Abies grandis - Pseudotsuga menziesii* East Cascades Forest Group)
- Mesic Southern Rocky Mountain Forest Group G225 (*Abies concolor - Picea pungens - Pseudotsuga menziesii)*
- Vancouverian Lowland & Montane Forest Macrogroup M023 (*Calocedrus decurrens – Pinus jeffreyi – Abies concolor* var*. lowiana* Forest Macrogroup (exclude *Pseudotsuga macrocarpa –Quercus chrysolepis*)

Cold subalpine forests, including for example:

- Rocky Mountain Subalpine-High Montane Conifer Forest (1.B.2.Nb.5 *Abies lasiocarpa - Picea engelmannii - Pinus albicaulis)*
- California Red Fir - Mountain Hemlock - Sierra Lodgepole Pine Forest (1.B.2.Nd.4 *Abies magnifica - Tsuga mertensiana - Pinus contorta* var. *murrayana)*

Topic A. Fire history and fire ecology vary across geography

Common Ground

Key points of common ground among respondents to the questionnaire include:

- Generalized models of historical fire regimes vary by ecoregion and forest type.
- Even within the same ecoregion and forest type, there is variation in historical fire regimes among differing environmental gradients.
- There are many different historical fire regimes throughout the western US, and a single model cannot represent this variation (i.e., one size does not fit all).
- Historically, some degree of low-, moderate-, and high-severity fire has occurred in all forest types, but in substantially different proportions and patch size distributions at different locations.
- Classification of historical fire regimes according to forest types can be coarse; thus, failure to recognize variation of historical fire regimes *within* forest types can lead to overgeneralization and oversimplification of landscape conditions.

Respondents strongly emphasized how geographical context is critical in understanding and characterizing past, present, and future fire regimes. Many respondents commented that their responses were dependent on geographical context, or they simply noted that the geography under consideration is important. Respondents described numerous examples of how fire regimes vary at a broad scale across large gradients from warm-dry to cool-wet habitats.[5] Within the fire research community, there is essentially unanimous agreement that historical fire regimes differed fundamentally among strongly contrasting forest types such as low-elevation dry pine forests (mainly involving relatively frequent surface fires) versus cool to cold subalpine forests (mainly involving relatively infrequent high-severity fires), so that a one-size-fits-all approach clearly should not apply to management discussions. The spatial and temporal scales at which generalizations about natural or cultural fire regimes are valid vary, and can be uncertain or as yet poorly researched, which may be an important explanation for some disagreements about fire history among researchers, and appropriate management goals among practitioners. In these latter cases, managers with a need to make progress toward agency goals may inappropriately apply knowledge gained from different but related systems, or from expert panels.

A majority of respondents agreed that any singular characterization of fire regimes and how they have been altered by modern land-use practices—at the scale of the western US—is clearly inappropriate. For example, only at the scale of an ecoregion can we estimate patch size distributions of low-, moderate-, and high-severity fires of any particular forest type. However, individual landscapes within ecoregions do not show the full variability extant within an ecoregion. Neither is it always appropriate to simply assign fire regimes by forest type. Within an ecoregion, gradients of climate and vegetation attributes are well understood as determinants of fire regimes and their variation. Most significantly, broad-scale spatial variability of fire regimes results from broad spatial variability in long-term climate, annual weather,

[5] The existence of major differences in fire regimes in strongly contrasting ecosystems such as low-elevation, dry pine forests and high-elevation cold forests is relatively non-controversial and well documented in the literature (e.g., Schoennagel et al. 2004; Hessburg et al. 2007, Perry et al. 2011).

environmental and topographic conditions suitable for burning, *and* variability in amounts and spatial continuity of fuels, the nature of fuels, (e.g., forest vs. shrub vs. grass vegetation), and in the history of prior fires.

Many respondents emphasized that the commonly applied classification of fire regimes as “low-, mixed- , or high-severity” adequately describes dominance but inadequately describes variation in fire regimes across the western US (see Topic C). Whereas low- and high-severity fires are at least theoretically well understood endpoints of a continuum, a broad, poorly defined “mixed” category is the source of much confusion and misunderstanding. For example, “mixed-severity” is used to describe both the temporal variability in fire effects over multiple fire events at one site, and the spatial variation in burn severity within a single fire. Even in the case of the two extremes of low-and high-severity, respondents noted that there is often some degree of variability, with under-appreciated ecological impacts. However, there is agreement among respondents that all fire regimes are the product of interactions between varying degrees of top-down climate and weather-forcing and of bottom-up spatio-temporal controls of topography and local fuel, that reflect legacies of past fires and other agents altering vegetation, and hence fuel properties (see also Topic E).

Some respondents questioned whether commonly used vegetation classification schemes are a suitable basis for generalizing about fire regimes, and expressed that known geographic variation in fire regimes within forest types argues for improved forest and fire regime classifications. Many noted that broad classifications such as “dry forest” encompass substantial amounts of variability in historical, current, and future fire regimes, making generalizations at the level of an entire forest type suspect. Numerous respondents emphasized that variability in historical fire regimes within a broad forest type often reflects dominant influences of neighboring forest types and their associated fire regimes.

Areas of Divergence

Key areas of divergent opinion among respondents included:

- The relative proportions of different historical fire severities in particular geographical areas.
- The relative importance of extreme weather events to historical burn severity.
- Desirable proportions of low-, moderate-, and high-severity fire in the future.

Respondents disagreed about the relative proportions of different severities of historical fires for some of the *same geographical areas of study*. While this is a key source of debate, it is noteworthy that most studies conducted in the same study areas find qualitative similarities in historical fire regimes. Some studies stress the quantitative differences in the proportions of a study area interpreted as fitting into various classes of burn severity. Most commonly, such disagreement involves potential inferences from different types and scales of evidence of past fire, or past vegetation attributes. For example, tree-ring evidence sometimes supports conclusions that contrast with those derived from landscape-scale inventory and monitoring data using different sampling frames (see Topic H). Yet these different types of evidence of past fire sometimes also yield overlapping or even similar estimates of past fire activity.

In other cases, disagreements about proportions of low-, moderate-, and high-severity fire are based on findings from studies conducted in one area that were applied to another. In other words, some respondents assumed transferability of research findings across ecoregions, based on similarity of forest type. In certain instances, this may be true, but in others it may be inaccurate. Respondents expressed a fairly high degree of consensus about historical fire regimes within particular forest types and ecoregions. Few fire history researchers have significant field experience in more than one ecoregion, but a few of those with cross-regional experiences articulated support for the occurrence of contrasting fire regimes in similar dry, moist, and cold forest types among differing ecoregions. Certainly a narrow range of field experience can limit the ability to interpret and accept findings that differ from one's own experience.

Respondents exhibited a wide range of opinions, explicit or implied, about the potential importance of extreme weather events in overriding historical fire behavior and burn severities (see Topic F). Respondents noted that historical fires in some areas were mostly low-severity, but some high-severity events were also evident in tree-ring records incorporating stand ages, tree growth changes, and tree mortality dates, consistent with other evidence. Most others emphasized the greater frequency and extent of low-severity events and their role in reducing fuel quantities, creating fuel-limited systems or open canopy forests. Some respondents stressed the importance of long-lasting ecological effects from infrequent, moderate- or high-severity fires in the same study areas. Respondents who emphasized the longer time scales of charcoal records noted that most areas of predominantly low-severity fires also showed some incidence of moderate- or high-severity fire over longer time frames. However, the spatial imprecision of those longer charcoal records relative to particular forest types and their location makes these insights difficult to interpret. Some respondents related the occurrence of high-severity fires to extreme climate/weather conditions (both past and present), whereas other literature stresses fuel accumulation or both climate and fuel as the main explanations for high-severity fire.

Determining what proportions and patterns of various burn severities[6] may be desirable in the future is a question that goes far beyond the information available from either fire history research or elicited in our questionnaire. What is desirable will be based on fire's expected influence on ecosystem goods and services that are valued by people, and the social acceptability of those influences. Thus, the predominant viewpoint among land managers and policy makers is that wherever feasible, fire and fuels management should promote the fuel and successional conditions that will support the natural fire regime going forward. In areas such as wilderness, where commodity production is not a management objective, the goals are much the same. Regardless of the management allocation, heterogeneity of fire effects, including the pattern of patches created by fires and other disturbances, is important to forest resilience to future fires (see Topic E).

Respondents exhibited a wide range of opinions about desirable future proportions of burn severity. Some stressed that fire and forest managers often propose treatments designed to reduce future potential for large areas burned with high severity. In contrast, others explicitly stated the benefits of high-severity fire, generally stressing its role in providing habitats for certain wildlife species, forest successional heterogeneity, and biodiversity. Proponents of this latter viewpoint stressed recognition and agreement that allowing high-severity fires in the Wildland-Urban Interface (WUI)[7] was not socially acceptable. Some respondents noted a

[6] Burn severity is ecological change due to fire, often characterized within the first year or more after fire. In contrast, fire severity refers to effects during the fire. From 1) Morgan et al. (2014). Challenges of assessing fire and burn severity using field measures, remote sensing and modelling. *International Journal of Wildland Fire 23*(8):1045-1060, and 2) Keeley (2009) Fire intensity, fire severity and burn severity: a brief review and suggested usage. *International Journal of Wildland Fire 18*(1): 116-126.

[7] Wildland Urban Interface (WUI): The area where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels. From NWCG glossary of wildland fire terms (https://www.nwcg.gov/glossary-of-wildland-fire-terminology, accessed 8 May 2017).

paradigm shift from a prevalent view in the 1990s that the only acceptable or “good fire” is a low-severity fire, to a growing viewpoint stressing the benefits of some level of moderate- and high-severity fires, as well as the need for societal adaptation to “managing wildfire” and “living with fire.” Many respondents stressed the importance of different management objectives in different settings (e.g., remote areas versus the WUI, general forest versus wilderness management), and of the clearly different historical fire regimes in low-elevation dry mixed-conifer forests versus cold subalpine forests.

Implications

Managers and scientists alike are challenged with overcoming the tendency to simplify historical fire regimes across and within ecoregions and forest types. While managing for the inherent complexity of fire regimes can be daunting and painstaking work, the resulting patterns and effects on processes provide important and compensating benefits. There is no single model of historical fire regimes applicable to all forest types and ecoregions. Managers should exercise care when applying scientific understanding developed in different landscapes, and recognize that this may result in erroneous scientific underpinnings and failure to meet objectives. Thus, management decisions are generally best-informed by area-specific understanding of fire ecology, which in some cases may require new partnerships between managers and researchers, both in implementation and monitoring. Scientists must clarify the importance of place when characterizing and presenting knowledge about historical fire regimes, and would benefit by sharing methodological approaches and collaborating across ecoregions. Stakeholders—from the general public to land managers to society at large—must wrestle with and decide what future proportion and pattern of burn severity might be desirable in each locality, both for the ecosystem, and for the people who live nearby and depend upon their services. Bearing this in mind, stakeholders will need to discuss the ability of various management prescriptions to achieve their desired changes, the social cost and acceptability of the changes, and alternative approaches to accomplishing them (see Topic I).

A logical way forward is to increase cross-regional and in-depth field research experiences within the fire research community. Improved collaboration across research groups, defined geographically or by previous narratives, can overcome some of the current atmosphere of deep distrust and interpersonal acrimony. Cross-regional comparisons of top-down and bottom-up determinants of fire activity is a fertile area of future research, which can examine how differences in seasonality, productivity, surface and canopy fuels, climatic differences, and other factors may explain some of the reported geographical differences in historical fire regimes in broadly-similar forest types. Likewise, inter-regional comparisons of various land-use practices by Native Americans and EuroAmerican settlers would improve our understanding of how these practices have contributed to past and present geographic differences in fire regimes.

Agencies like the US Forest Service and Bureau of Land Management, by virtue of their enabling legislation and Congressionally appropriated annual budgets, are legally required to manage for improved fuel and fire behavior conditions. Actions that can effectively treat large areas over a short period of time often suffer from an oversimplified understanding of the desired conditions. Because there are strong relationships among spatial patterns of surface and canopy fuels, seral stages, expected burn severity patterns, and onsite climate and fire weather conditions, care must be taken to avoid oversimplifying those patterns for the sake of simply reducing expected wildfire severity. Such oversimplifications can have profound effects on habitat patterns resulting from all burn severities, and their spatial complexity and connectivity. Thus, in each geographic area, managers must seek to obtain a clear understanding of the historical spatial patterns of surface and canopy fuels, and of seral stages through focused study and reconstruction of those conditions. Further, they should use modern climate change evaluation tools to assess how these historical patterns would be altered under the 21st century climate anticipated for that area. This larger understanding would enable managers to then consider conditions in this larger context, and develop landscape prescriptions to make the needed adjustments. Tools to be applied would be those that matched the land allocation and the specific needs for change.

Topic B. Human impacts and management history vary with geography

Common Ground

Key points of common ground among respondents to the questionnaire included:

- The influence of humans directly on fire ignitions and suppressions as well as on landscape drivers of fire activity is ubiquitous and important.
- Impacts of humans vary through time, and are not uniform geographically.
- Human influences are pronounced in dry, moist, and cold forests, but impacts vary.
- The role of human ignitions on wildfire prevalence and severity varies markedly in western forests.
- Climate change is a human impact and a strong driver of fire occurrence and effects.

Respondents to the questionnaire strongly emphasized that fire suppression[8], despite its widespread effects, was not the only human activity profoundly affecting fire regimes and fire-prone ecosystems. Most respondents mentioned other activities as influential in altering fire regimes, such as domestic livestock grazing, logging (selective, post-fire, and clearcut), diverse types of anthropogenic ignitions, mining, overly generalized reforestation practices, invasive plants and animals, road and rail construction, and land-use or development changes. Respondents also spoke to the decimation of Native American communities through the introduction of human diseases, and later marshalling onto reservations, which significantly reduced ignitions and cultural fire uses by native aboriginal people. Human impacts vary with degree of access via roads and trails, but even remote areas have been influenced by people. For example, selective and clear-cutting timber harvests have widely affected dry and moist mixed-conifer forests, where the favored commercial species principally grew.

Many respondents noted that the impacts of these different activities are known to have varied over space and time, posing difficulties for generalized characterizations of human impacts over broad geographical areas or forest types. In other words, there was strong consensus that geographical context matters, and this influences the local assortment of human impacts. Some respondents noted that wilderness areas and actively managed forests often have had different human use histories, including Native American influences, and therefore different trajectories. Wilderness areas, along with some national parks and large roadless areas, offer examples of potentially different human influences, and related opportunities for both research and management. A few respondents elaborated on similarities

[8] Fire suppression is the act of extinguishing or fighting fires. Fire exclusion has partially eliminated fires from the landscape using fire suppression and other land uses, such as grazing, settling in valleys, road and railroad building, and agricultural conversion of most native grasslands.

between the effects of some human activities (e.g., fewer fires may be due to active fire suppression, reduced Native American ignitions, and/or grazing that removed surface fuels) in certain ecosystems, while most noted that dense recruitment of shade-tolerant species has been a direct result of nearly-ubiquitous fire suppression efforts, or logging of large, fire-tolerant trees across many western ecosystems.

A notable point of common ground among many respondents and a chord that was detected throughout the literature was that human impacts have been most detectable and pronounced in dry and many moist mixed-conifer forests, where the most commercially desirable species were logged. This logging, along with fire suppression, has resulted in generally altered and often more-homogenous forest compositions and structures. Such homogenization of forests is often due to harvest of larger and older trees and species (like western white pine, sugar pine, western larch, Douglas-fir, ponderosa and Jeffrey pines) followed by regeneration of higher density, young shade-tolerant forests (of grand fir, white fir, subalpine fir, Douglas-fir, red fir, and incense cedar, or mixes of these species), or due to fire exclusion and a variety of other related mechanisms. Less agreement exists on the degree and causes of homogenization with regard to cold subalpine forests. Regardless, this relative consensus about where human impacts have been most pronounced hopefully provides a stepping-stone for further discussion and common ground.

Many also recognized that climate change at broad scales is a dominant human influence affecting fires and fire effects in all ecosystems. We address it here and in sections F and G because it is the one common denominator affecting all forest types and all fire regimes.

Areas of Divergence

Key areas of divergence of opinion among respondents included:

- The general applicability of “thinning and prescribed burning remedies” to offset human influences.
- The significance of human impacts on forest successional conditions in moist and cold forests.

The questionnaire was intended to elicit a wide variety of responses about the generalized applicability of forest thinning and prescribed burning techniques, in response to changes in fire regimes and forest successional and fuel properties that have occurred across different forest types, and in different geographic locations. These topics might have been better separated, which could have made the areas of agreement and disagreement more distinct. Regardless, there was a general pattern among respondents, based on whether they viewed the fire regime of the forest in question as more driven by fuels versus weather and climate (see also Topic F).

For low-elevation ponderosa pine forests and woodlands and to a lesser extent in dry mixed-conifer forests, respondents generally viewed thinning and prescribed burning to have wide utility, both for ecological and social reasons. However, some asserted that, even where such activities may be useful and justified, their effects may be better accomplished primarily through wildfire.

While a majority of respondents agreed with the statement that cold subalpine forests have been little affected by fire suppression, many studies highlight that human impacts on forest successional conditions have been significant in dry, moist, and cold forests in ecoregions of the northern Rockies, Inland Northwest, Pacific Southwest, and Inland Southwest. In particular, there is evidence in these ecoregions that once-complex cold subalpine forest patchworks composed of early, mid, and late-seral forest conditions have been simplified by extensive timber harvesting, fire exclusion and fire suppression, but also to a lesser degree by livestock grazing of the often widespread wet and dry meadows, and road development.

Implications

There is general consensus that human impacts vary widely across western US forests in terms of type of activity and associated ecosystem effects. Although some human activities had similar influences on many forest ecosystems, failure to recognize the heterogeneity of human impacts can lead to overly generalized prescriptions for forest restoration and management. Thus, there is likely no one-size-fits-all management or restoration approach—available to all conditions—due to the importance of locally-coupled human-natural histories, and current social or political considerations. Most fire scientists assume prehistoric Native American influences on fire and forests to have been relatively widespread, but to varying degrees in different landscapes and habitats. However, more clarity is needed about differences in how Native American and more modern human influences shaped forests of today.

The importance of local context in the management of fire-prone landscapes underscores the need to move away from oversimplified narratives that encourage application of fire research beyond its original scope of inference. Nonetheless, a widespread challenge facing land managers is the need to make forest management decisions in the substantial areas of landscape where fire-vegetation history research has not been conducted; this is a major future research need. General agreement about drier forests being the most impacted by human activities could provide a path forward among those disagreeing about the extent of high-severity fire in these ecosystems. Human impacts have been pronounced but with different effects and implications for moist and cold subalpine forests. Additional studies of landscape changes, and of vegetation response to fires and fuel treatments in these forest types, will inform discussions about forest landscape restoration and management.

To apply knowledge of the relative human impacts on local vegetation conditions, managers need to develop a clear understanding of the specific impacts geographically, their period of influence, and some understanding of their relative strength (also see Topic D). Important human impacts to date include:

- domestic livestock grazing, period of grazing, and density and types of animals grazed;
- introduction of non-native plants or animals, their distribution, and influence on herbivory and the local fire regime;
- wildfire suppression, including the number, locations, and timing of wildfires suppressed;
- timber harvest, type of timber harvest, and frequency of harvesting;
- presence of roads and railroads, their density, and the period of road impacts;
- historical frequency of Native American burning and time since that burning ceased;
- other changes in patterns and trends of anthropogenic (e.g., recent EuroAmerican) and natural (lightning) fire ignitions;
- conversion to cropland, exurban, or urban development, other conditions.

Research shows that the presence or absence of even a single one of these human influences can have profound effects on the resulting vegetation and fire behavior conditions. For example, the absence of timber harvest in some studied wilderness areas reveals significant differences in species composition and tree density in comparison with harvested locations growing in similar climatic conditions and forest types. Knowledge of the local human impacts, their period, and relative intensity can help guide the selection of areas needing and not needing restorative treatments, and it can aid in the selection of appropriate management tools.

Topic C. Fire is a keystone process[9] that occurs in almost all western US forest types

Common Ground

Key points of common ground among respondents to the questionnaire included:

- Low-, moderate-, and high-severity fires historically occurred in nearly all forest types.
- Fires of all severities play important ecological roles.
- Since nearly all western US forests are significantly fire-influenced, fire is a key driver of ecosystem patterns and processes.
- Burn severity patterns and resulting successional and fuel bed conditions have changed due to human activities in most forest types.
- In many western forests, a period of fire exclusion persists, reflecting successful passive and active suppression of the vast majority of ignitions (95-98%) over the past century.

There was consensus among respondents that various combinations of low-, moderate-, and high-severity fire occur in nearly all western US forest types, and associated agreement that fires of all severities play important ecological roles in each forest type. Unsurprisingly, there is also consensus that fire has been, is, and will continue to be an essential ecosystem process across nearly all western US forest types. A key challenge for researchers has been to estimate the proportions of fires that could be classified into one of the three commonly-used descriptive severity classes (low, moderate, high), and how those proportions may have changed over time.

An increasing emphasis in fire research conducted over the past 20 years has specifically aimed at estimating proportions of areas historically affected by low-, moderate-, or high-severity fires, but there remain uncertainties about the actual variability of burn severity historically. Some of this uncertainty is due to methodological limitations, especially in the case of high- and moderate-severity fires, where much of the evidence of past fires is destroyed. This renders fire history studies that exclusively use fire scars less useful under these conditions. However, much progress has been made in recent years by combining fire-scar data with extensive tree age data, tree growth release data, and data on tree mortality events, to provide a more nuanced understanding of the history of fire effects. In addition, aerial photographic reconstructions were employed in the interior Columbia Basin and East-side Forest Health Assessment studies, and these have provided expanded insights into the proportion of patches burned with low-, moderate-, and high-severity fires of those studied ecoregions across the 20th century (Topic H).

[9] A keystone process is one upon which other species and processes in an ecosystem largely depend, such that if it were removed or significantly altered, the ecosystem would change drastically.

Varying degrees of increased continuity of forest in all forest types (i.e., loss of early seral grass- and shrublands, and sparse woodlands and savannas) have been observed with implications for increased vulnerability to larger and more continuous crown fire disturbances, particularly in combination with successful suppression of all but the largest fires. A highly promising area of current research is the integration of dendroecological studies with the existing aerial photographic reconstructions currently covering millions of hectares across the northern Rockies and Inland Northwest. Recent research focusing on proportion of area affected by various burn severities and the emergent patterns represents an important improvement over the former focus almost exclusively on past fire frequencies.

There also was consensus that in many western US forests, there has been dramatically less fire activity over the last century than in prior centuries and millennia, tied to intense and pervasive societal efforts to actively suppress and exclude wildfires. Respondents broadly agreed that patterns of fire occurrence have changed in relation to historical patterns, especially in many dry forests, but also in some other forest types and locations. This is a response to changes in climate and/or fuel properties, recognizing that both extreme fire weather and combustible fuels have always existed to some degree (see Topic F).

There are many existing studies of fire history based on stand-origin mapping over study areas of many tens of thousands of hectares. However, a commonly held view in the fire science community is that even larger areas (i.e., many hundreds of thousands of hectares) are required for effective analyses—combining multi-century fire history data with landscape ecological approaches—to understand past fire patterns and simulation of future fire patterns. A fertile area of future research is analysis of large regional and local landscape historical patterns and patch size distributions of burn severity, and how these varied with topography, climate, prior disturbance, and other influences. Such research is needed because inferences are generally drawn from historical fire frequency, rather than pattern analysis.

Areas of Divergence

Key areas of divergent opinion among respondents included:

- Relative proportions of low-, moderate-, and high-severity fire within western US forests historically.
- Magnitude of changes in fire frequency, severity, sizes, and their consequences for various forest types since the 19th century.
- Magnitude of recent changes in forest patterns relative to historical conditions.
- The urgency, scale and overall need for various active and passive management options.

Key areas of divergent perspective among respondents centered on the relative importance of the various fire attributes that everyone agreed were generally important. For example, whereas numerically dominant perspectives can be identified, there was no consensus about the historical proportions and sizes of differing burn severity classes in some forest types, nor agreement about the magnitude of changes in fire frequencies, severities, and sizes; thus changes in the absolute significance and relative importance of different fire regimes in various landscapes is still debated. It is noteworthy that spatial reconstructions of historical proportions and sizes of differing burn severity classes in various forest types are relatively lacking in the literature for some ecoregions, which is likely a key reason for divergent opinions on this topic.

In particular, perspectives on historical patterns and changes in the occurrence and effects of both low-, moderate-, and high-severity fires in dry and moist mixed-conifer forests were a key area of divergence, with most respondents concerned over the negative effects from historical fire suppression, resultant fuel accumulation, and recent increases in high-severity fire. These observations contrasted with some respondents who highlighted climate and extreme fire weather over fuel accumulation as the main driver of high-severity fire, debated the historical relative importance of low- versus high-severity fire, and emphasized the ecological values and importance of past and present high-severity fires in all forest types, but less so in the driest forest types. Notably, respondents did not try to integrate the concomitant effects of weather, climate, topography, and fuel abundance.

We note that many studies use climate covariates to predict trends in annual area burned. These studies generally do not include fuel covariates, and lacking any evidence of the contribution of fuels covariates, conclude that weather and climate drive area burned. More important are area burned by severity class and changes in patch size distributions of severity classes, which lead to changes in patch size distributions of successional conditions. The lack of data on potential changes in the role of fuels may have fostered disagreements regarding the relative urgency and risks of various active (fuel treatment) versus passive (wildfire only treatment, suppression of human ignitions) management options, the appropriate locations and scale of desirable management actions, and the desirability and trade-offs among alternative forest fire management goals and actions.

Implications

Uncertainties associated with relative proportions of different burn severities and patch-size distributions combine to cloud key points of consensus that have important management implications. There is consensus that various combinations of low-, moderate-, and high-severity fire are important to ecological processes in almost all western US forests. Likewise, there is consensus that these combinations of burn severity, and their variability over space and time, contribute to seral stage pattern and complexity, and the future flammability of the landscape. Therefore, given that landscape patterns of successional and fuel conditions aid in controlling and are to a large extent controlled by fire, and that ecosystem function is altered in the absence of fire, the recent reduction of fire activity in many areas has important ecological implications. Managers are open to using fire on the landscape, but they often are unable to use fire alone. They have intimate knowledge of their landscapes and fuel characteristics, and many acres are not amenable to fire-only prescriptions. Managers wish to use combinations of tools, as is appropriate to the fuel conditions and the land management allocations, to restore more natural patterns of burn severity and of successional conditions that will support them down the road. They can use biophysical and topographic templates to tailor desired treatment patch sizes and intensities to their landscapes. And, they will have to accept some uncertainty about the effectiveness of their fire mitigation procedures under different future climates.

Public land managers throughout the western US are concerned with calibrating fire regimes in many forest types. Central to this idea of calibration is geographically pertinent knowledge of historical patch size distributions of seral stages, burn severity patches, and patterns of lifeform and physiognomic conditions. Nevertheless, paleo studies of fire covering multiple centuries to millennia show significant variability in area burned so that expectation of a long-term stationarity in fire patch sizes is unrealistic. Despite the likely lack of long-term stationarity, these landscape conditions and their variability contribute to the patterns and variability of fire regimes. Specific geographic knowledge of these conditions is often lacking and instead managers often apply knowledge of related or nearby systems, often with less than adequate precision. To learn how to better calibrate relative proportions of each burn severity and patch size distributions, managers should work closely with fire and landscape ecology researchers to improve their local characterizations of these historical conditions. Future proportions of low-, moderate-, and high-severity fire will depend strongly on local context, which includes the HRV, societal and political objectives, prior land-uses, climate and weather, topography, vegetation, and other factors.

Topic D. Knowledge of historical range of variability (HRV) is useful but does not dictate land management goals

Common Ground

Key points of common ground among respondents to the questionnaire included:

- Knowledge of the HRV provides essential context for discussion of land management decisions but it does not set management targets.
- There is no single model of the HRV of forest successional and fuel conditions and fire effects that can be applied across the western US.
- Because the HRV differed greatly from place to place, HRV findings from one area may or may not have relevance to another.
- Understanding the determinants of the HRV is useful in assessing future ecosystem responses to climate change and land-use practices.
- Although appropriate time frames of the HRV are often difficult to define, time frames must be specified for the HRV of particular attributes.
- Deep understanding of the HRV may require application of multiple research methods (see Topic H).

The HRV refers to the variation of ecological conditions and processes over spatial and temporal scales that are essential for understanding current ecosystem conditions[10] and their current departures. While historical patterns of fire and associated vegetation patterns are often the focus of HRV studies, comprehensive HRV studies also examine historical variability of many other factors including climate, impacts of forest insects and pathogens, and land uses. Interpretations of changes in fire regimes may thus be related to numerous potential drivers. These interpretations require consideration of climate variability as well as a broad range of land-use practices such as grazing, logging, mining, and management explicitly aimed at altering fire activity.

The HRV describes *a body of knowledge about historical conditions* without any explicit prescription for how that body of knowledge should be applied. In the sense of understanding how current landscape conditions reflect effects of historical biophysical processes and past human impacts, the HRV provides essential insights for how processes create and maintain spatial patterns of forest and non-forest conditions, and how those patterns in turn drive the processes of interest. Examples of the utility of HRV knowledge include understanding of how

[10] This definition and application of HRV is taken from: Hayward et al. (2012) Challenges in the application of historical range of variation to conservation and land management. Chapter 3 in: Wiens et al. (eds). Historical Environmental Variation in Conservation and Natural Resource Management. P. 32-45. Wiley-Blackwell.

past climate change and land-use impacts have affected modern landscape pattern and structure. Teasing apart the effects of land-use impacts such as grazing, logging, and/or fire exclusion on forest conditions from the effects of climatic variation on wildfire activity and forest conditions requires historical ecological understanding.

The respondents' comments reflected a strong agreement among scientists that knowledge of the HRV provides essential insights for decision-making in land management, in the context of current and future ecosystem responses to climate change. Hypotheses about climatic drivers of future ecological change can be developed and tested with HRV data covering a range of time frames.

Retrospective studies of fire are essential for developing a mechanistic understanding of disturbance-mediated ecological changes, including those driven by climate variability, which in turn supports the development of simulation models of future landscape dynamics driven by climate change. Some respondents stressed relatively abrupt or extreme changes in both historical and modern ecosystem conditions under climate variability as a basis for expecting future "surprises" in ecosystem conditions in the face of climate change. Other respondents suggested that future vegetation predictions from regional and global change models are still crude, particularly if those predictions do not consider fire feedbacks from altered fuel complexes and patchworks, and do not represent adequate advances in understanding sufficient to warrant reduced consideration of the HRV of any geographic area.

Respondents emphasized that knowledge of past natural variability is an essential reference for evaluating impacts of modern land-use practices such as grazing, fire suppression, and logging on current ecosystem conditions and processes. They noted the continuing challenge of distinguishing among the relative effects of past logging or grazing from effects of active fire suppression.

Many respondents stressed that the insights synthesized in an HRV assessment are intended to inform discussions of potential management goals that incorporate social values for decision-making. The value judgments involved in a deliberative decision-making process are improved by knowledge of HRV, but adoption of management goals is not dictated by environmental history.

Areas of Divergence

Key areas of divergent opinion among respondents included:

- In practice and in communicating with the public, static representations of the HRV often continue to be inappropriately emphasized.
- The applicability of HRV knowledge from well-studied regions to similar but less studied forest types in other geographical regions.

The areas of divergence reflected in comments of both survey respondents and in broader discussions with stakeholders appear to reflect different views on how HRV information should be applied to management decision-making. HRV studies are increasingly viewed as scientific and analytical tools useful in decision-making, not as the management goal. In that context, some stakeholders and fire scientists assume that the primary purpose of an HRV study is to reconstruct a set of vegetation parameters (e.g., tree sizes, stand densities, tree spatial patterns) as representing past "natural" conditions and suitable "reference conditions." Other fire scientists stress that such reconstructions may only be "snapshots" in time in the sense that their relevance is time dependent, for example possibly depicting conditions that may have existed ephemerally, but are not fully representative of the range of ecosystem conditions over a longer time period. Still others have shown that HRV conditions, when reflected via a space-for-time substitution sampling methodology, can adequately reflect historically extant variation in forest spatial patterns as reconstructed or simulated by state-transition models. These responses highlighted the importance of comparing alternative methods and time periods that may be used to predict or reconstruct variability of an HRV.

Many respondents emphasized that oversimplified models of the HRV are often applied indiscriminately across a diversity of landscapes so that actual ranges of variability are underappreciated. Numerous respondents identified cases where oversimplified models of HRV did not apply either to an entire study area or were inappropriately applied to landscapes where the model had not been tested through sufficient data collection, independent calibration, or observation. Some respondents noted that divergent views of the HRV reflected the transfer of general models and interpretations from regions that had been well studied, to regions lacking any similar studies that might highlight differences related to unique geography. This is often done based on the assumption that an HRV should be similar in broadly defined cover types.

Implications

The HRV is most useful as a guide to management. Although the HRV can provide invaluable insights about how various processes and patterns interacted in the past, each HRV is but one reference range – it can vary widely across different locations and temporal scales. Managers should exercise caution when applying HRV information collected in other landscapes, recognizing that there is no single HRV model that can be generalized across the entire western US or generally to certain forest types. Despite debates about specific methods and applications of HRV, there was widespread agreement that understanding the climatic, land use, and other determinants of past fire activity and fire effects is useful in assessing future ecosystem responses to climate change and land-use practices.

One of the difficulties facing public land managers is their concern about how to address climate change, wildfire area burned, and burn severity predictions for the mid-21st century, given the high uncertainty associated with those projections, especially projections of future vegetation and lifeform changes, which are thought to be some of the most uncertain. This uncertainty forces managers to generally lean on HRV predictions to hedge their bets going forward. Nonetheless, managers have tools to estimate near-future precipitation, water deficit, plant-available water, and evapotranspiration conditions over the next few decades, and these estimates can be used to condition their understanding of desired forest successional, lifeform, and fuel patterns, and patch-size distributions in light of HRV estimates.

Topic E. Forest structure, composition, and fuels have changed, affecting burn severity and fire extent

Common Ground

Key points of common ground among respondents to the questionnaire included:

- Historical landscape and disturbance ecology strongly influence fuel patterns and legacies of live and dead forests.
- Forest structure and composition have been homogenized in many places by timber harvest, fire suppression, grazing, mining, road-building and other activities.
- Fire behavior is patchy in space and time, and resulting patch-size distributions are important to understanding its effects on the landscape.
- Landscape patch configuration (heterogeneity) is important and is a key determinant of fire regimes, fire behavior and ecosystem function; not every configuration will do.
- Several spatial scales and types of vegetation and fuel heterogeneity exist, and each scale has important and different ecological functions.

In the western US, historical patterns of forest structure, composition, and fuels—collectively making up successional conditions—resulted from recurring wildfire, insect, disease, and weather disturbances that kill trees and regenerate forests. Through time, wildfires repeatedly affected most western forests. Burn severity varied with seasonal weather, previous fires and regional climatic conditions, but also topographic, biotic, and geomorphic conditions. Burn severity patches occurred in predictable frequency-size distributions, which captured the spatio-temporal variability of disturbance and effects on local and regional successional patterns. Within this historical context, respondents generally agreed that fires were prevalent and greatly influenced forests, though fire frequencies and effects varied. Further, respondents all agreed that this historical ecology needs to be incorporated into our understanding and management of forest landscapes.

Respondents identified a number of recent studies showing that successional patterns of many western US forests have been altered by 20th-century management. Management actions included timber harvests, wildfire suppression, domestic livestock grazing, mining, and road and railroad building, which generally fragmented successional patchiness, increased forest area and density, and created novel successional and fuel patterns. Chief among these changes was increased abundance and connectivity of dense, multi-layered young forests, with greater proportions capable of supporting crown fire. However, the degree of these changes has varied across forest types and ecoregions. There was general agreement that these changes occurred in many western ecoregions, especially in the dry ponderosa pine, Jeffrey pine, and in some dry mixed-conifer forests (see Topic B).

Several respondents commented on patch and landscape-level feedbacks, noting that landscape-level feedbacks mediated the frequency-size distributions of future low-, moderate-, and high-severity fire, whereas patch-level feedbacks influenced the likelihood of low- and moderate-severity fires. Prior fires were likely complex patchworks of already burned and recovering vegetation, which increased or decreased the size and severity of future disturbances.

Respondents noted that reconstructed historical landscape patterns, fire history studies, and simulation studies show how landscape successional and fuel patterns and their variability may have supported particular historical fire regimes. Unique ranges of vegetation and fuels patterns were the result of interactions among regional climate, topography, landforms, geology, and biotic communities of an area, along with associated meso- to fine-scale pattern heterogeneity. This pattern of heterogeneity was unique and important to facilitating local variation in burn severity patterns, habitat patterns, and was of central importance at all spatial scales.

Areas of Divergence

Key areas of divergent opinion among respondents included:

- The extent to which future fires and forests are constrained by forest and landscape legacies.
- Importance of bottom-up versus top-down variables in fire regimes.
- The relative amount of forest structural change of an area (e.g., increased density and more complex tree layering leading to increased vertical continuity of fuels that can propagate fire upward).
- Costs and benefits of fuel treatments at necessary spatial and temporal scales.

Respondents disagreed about the extent to which structural change and successional forest patterns have been altered by 20th-century management, as well as the relevance of these legacies for future fire regimes. For example, large landscape assessments in the Inland Northwest showed that the increased abundance and connectivity of dense, multi-layered young to intermediate aged forests, with high crown-fire potential, has occurred in dry, moist, and cold forests. In cold subalpine forests this has occurred via the elimination of formerly complex early-, mid-, and late-seral forest patchworks. In dry and moist forests in the Inland Northwest, this has occurred via increased area of forest (as meadows, sparse woodlands, and some shrub vegetation has been encroached upon by forests), and increased density of a once more-complex patchwork of open and closed canopy forests. In contrast to these patterns, respondents and the peer-reviewed literature for the Colorado Front Range, for example, agreed that for the lower elevation areas of dry ponderosa pine forests there has been a substantial increase in woody fuel connectivity. However, respondents noted that the peer-reviewed literature demonstrates a much smaller shift towards increased woody fuel connectivity in mid-elevation dry mixed-conifer forests and even less in the cold subalpine forests. These respondents noted that for dry mixed-conifer forests of the upper montane zone, abundant research does not support a pattern of significant shift towards a higher percentage of the landscape capable of supporting crown fires today in comparison with historical fire regimes, which also included moderate- and high-severity fires.

Overall, divergence of perspectives on the degree of change in vegetation structure and fire potential often reflects studies conducted in similar forest types but different geographical regions, although in other cases, there are fundamental disagreements over the validity or interpretation of evidence for the same landscape using different methods.

Another area of divergence can be traced to a lack of dialogue and theory integration between climate and landscape ecology researchers. A significant body of landscape ecology research shows that “emergent” properties have central importance to ecosystems and their pattern and process regulation, whereas climate scientists are less focused on local-scale feedbacks and emergent patterns. This creates a fundamental problem in linking climate change and landscape ecology research. Climate models assume that top-down climate covariates drive temperature, precipitation, and solar radiation conditions. Landscape ecology research shows that those top-down inputs can be highly modified by meso- and fine-scale bottom-up environmental controls to produce climatic conditions that are strictly speaking neither the top-down or bottom-up inputs, but are influenced by these inputs. Until the processes that produce such emergence are incorporated into downscaled climate modeling, and until landscape ecology studies incorporate the full suite of realistic climate futures, these uncertainties will remain a problem in applying climate change science to landscapes and their restoration.

Implications

There is consensus that landscape pattern, which is influenced by vegetation, topography, climate, and past fire disturbances, is nearly always an important mediator of fire size and burn severity. A variety of management and land-use activities have altered western US forest landscapes at multiple spatial scales, and essentially created a new landscape template for 21st century fire regimes. Successional and fuel patterns will influence future fires, including size and burn severity of patches. When historical patterns are unknown, efforts to create locally representative reconstructions may be needed.

Forest structure, composition, and fuels have changed to varying degrees in different areas, and in some forest types there is broadly shared common ground that these changes are affecting burn severity and fire extent. While changes observed in some dry forests became a prime motivator for agencies to act, and for Congress to focus financing on restorative actions, there is less common ground about the degree of these changes West-wide in other forest types. However, informed dialogue among scientists and managers, and in some cases additional research, can help to improve common understanding concerning the degree of change and appropriate restorative action for other forest types. Monitoring and adaptive management are needed, especially where reconstructions of representative historical patterns and predictions of future patterns are hard to come by. This is a prime opportunity for scientists to work closely with managers in support of resilience-oriented management. In these cases, a significant monitoring component will facilitate learning. Information gained may be used to initiate restoration of forest structure, composition, and fuels, using the tools that best fit the circumstances. Because simply applying the best available science will not always be sufficient to gain assent from stakeholders and interested parties, collaborative dialogue that factors in local social values and emphases tempered by that science may provide an adequate way forward.

Topic F. Climate and fuels both influence current fire sizes and their severities

Common Ground

Key points of common ground among respondents to the questionnaire included:

- Climate and weather are now and will continue to be primary drivers of fire size and annual area burned.
- Surface and canopy fuels are important drivers of burn severity.

Global and regional climates vary over centuries, decades, and between years, including conspicuous oscillations between the relative dominance of warm-dry versus cool-moist weather patterns. As recently as the late 20th century, a sizable portion of the ecological literature assumed relative stationarity in climate, but increasingly abundant and diverse lines of evidence overwhelmingly demonstrate that the Earth's climate, and that of its many ecoregions, has constantly varied over multiple time scales.

Changes at decadal, centennial, and longer time scales have the potential to redefine biophysical settings. Hence, maps of plant associations, environments, existing and potential vegetation, and physiognomic types are now all seen as shifting patchworks. In landscape ecology, this is an accepted view and is wholly consistent with its body of theory. However, in forest, plant, and rangeland ecology, this view of shifting environmental or biophysical settings has stretched thinking for many practitioners and researchers. Relating projected climate changes to anticipated changes in forest fuel conditions and fire regimes adds further complexity (see Topic G).

Operating within this broader context of changing climate and landscapes, respondents agreed that woody fuel quantity, arrangement, and moisture are important to both the current flammability of western US landscapes, and to the ecological effects of fires. Changes in fuels along with topography drive changes in energy release, fireline intensity, flame length, burn severity, and emissions. Respondents agreed that widespread increases in the area that is forested and in the fuel quantity and vertical and horizontal fuel continuity in many ecoregions and forest types have increased the likelihood of large forest fires and higher burn severities via increased likelihood of crown-fire initiation and spread.

Regional climatic variability and extremes also influence wildfire size and burn severity. Based on the last several decades of research, respondents noted that annual, decadal, and multidecadal climate variability has always been important to fire size, and annual area burned. Respondents also agreed that the largest fires have always been driven by extreme fire weather, and they will continue to be. However, within large historical fires, including those burned under extreme conditions, burn severity was often patchy in response to topography and vegetation (i.e., fuels) conditions. The result was variably-sized patches of low, moderate, and high severity within burn perimeters. These patchy burned areas have changed into the 20th and 21st centuries, and more areas are being burned under high severity than is often typical for the forest types. While this view is supported by many respondents and published studies, there are other studies that question its generality. For example, some research based on historical aerial photography in the northern Rockies on burn area and severity from the 1880s to the early 2000s showed that over this long record, the proportion burned with high severity did not increase, despite extensive area burned in recent decades. Likewise, studies based on satellite imagery, while generally showing trends of increasing burn area since 1984 across the western US, do not show increases in burn severity for all ecoregions or even in a majority of regions. However, we note that in pre-1900 low-severity regime landscapes of the southwestern US and low-elevation Colorado Front Range ponderosa pine ecosystems, the most spatially extensive fire years and likely the largest fires occurred in dry years that followed one or more wet years, which apparently supported buildup and broad-scale continuity of fire-spreading fine surface fuels. Smaller fire sizes and low- and moderate-severity fires are generally associated with milder fire weather and moderating climate conditions.

What has changed most significantly since about 1985 is the frequency of large fires in association with warming temperatures and drought. While some of the increase in the frequency of large fires is expected from increased woody fuel continuity, broad-scale studies based on robust research designs are still needed to tease apart the roles of changing climate and changes in fuels in the observed trends in frequency of large fires. Some respondents argued that the loss of the patchwork created by the historically superabundant small fire-affected patches also has contributed to larger patch sizes of recent forests, and in fact this is a key focus of much current research. In many forests, not just dry mixed-conifer forests, some respondents also noted that fire suppression has resulted in loss of the most numerous smaller and most extensive (in some landscapes) lower-severity fires, which has removed an historical resilience mechanism that once had regulated the frequency and severity of the largest fires by controlling fire growth. Expectations under projections of continued climatic warming include more effective fuel drying during years or seasons of reduced precipitation, as well as more extreme short-term events such as heat waves, driving extreme fire activity. This coupling has the ability to significantly alter the size distribution and burn severity of burned patches and functioning of affected landscapes, including their future physiognomic types[11] and patterns of species composition. What is apparently most important is that increasingly extreme fire weather is increasing the frequency of large and severe fires, and quite small increases in the frequency and extent of large high-severity fire patches can result in tipping points for ecosystems.

These points of common ground coincide with increasing evidence that when recent wildfires severely burn large areas of forest, local elimination of conifer tree seed sources and reduced tree regeneration under emergent warmer-drier conditions can occur. As a result, large areas of forest increasingly are converting to persistent grasslands or shrublands post fire in some regions.

Areas of Divergence

Key areas of divergent opinion among respondents included:

- With respect to current fire regimes, the relative importance of landscape changes in vegetation and fuel properties in comparison with weather and climatic changes.
- The degree to which the frequency of large, high-severity fires and large, severely burned patches within fires has increased, and over what time frames.
- The extent to which landscape tipping points have been reached as a result of high-severity fires.

[11] Examples of physiognomic types include evergreen broadleaf forest, deciduous broadleaf forest, evergreen needle-leaf forest, deciduous needle-leaf forest, grasslands, shrublands. From: 1) Kuchler (1949) A Physiognomic Classification of Vegetation. Annals of the Association of American Geographers, 39(3), 201-210; 2) Box (1981) Predicting physiognomic vegetation types with climate variables. Vegetatio 45: 127-139.

One core area of divergent opinion is the relative importance of landscape change to current fire regimes. Empirical research in some landscapes shows that landscape abundance and horizontal and vertical continuity of woody surface and canopy fuels has increased in many western US ecoregions, which when combined with empirical and modeling research on fire behavior, supports an inference of increased fire intensity, longer flame lengths, increased crown-fire ignition and spread potential, and burn severity (i.e., *fuels affect fire behavior and burn severity*).

On the other hand, much recent research concludes that trends in annual area burned or in numbers of large fires are explained by weather and climatic influences on fuel availability. In these latter studies, drought and related time series are used to predict annual area burned. Models generally show fair to good prediction of a positive climate involvement (i.e., *climate drives the recent increase in area burned*). However, more complex statistical models that show multi-way and multi-scale interactions among fuel properties, fire weather, topography, and climatic predictors of fire extent and burn severity are needed.

A critical limitation on this front has been the lack of quantitative data, for some ecoregions, on changing fuel properties geographically and by forest type. Currently, in some ecoregions, we know more about how area burned and fire extent are influenced by climate than how the ecological effects of fires are affected by both changing climate and fuels. We also know that burn severity varies with fire weather, topography, vegetation, and time since fire (or other disturbances), even when large fires are burning under relatively extreme weather. However, there are few studies that show the relative contributions of each of these factors and climate together to burn severity. Recent reports of increasing burn severity for some ecosystem types are mostly, but not entirely, limited to the 1984-present period, due to the limited temporal depth of Monitoring Trends in Burn Severity (www.MTBS.gov) data. In addition, some respondents were concerned about adequate validation of the MTBS data for that period.

A second core area of disagreement hinges on the degree to which the frequency of large, high-severity fires and large, severely burned patches within fires has increased, and how this differs for dry, moist, and cold forest types. Many respondents believe that the frequency of large fires has increased in association with *both* climatic warming and increased woody fuel abundance and continuity, but as noted, broad-scale analyses of the relative contributions of climate parameters versus altered fuels to observed fire trends remains an important research challenge. Nevertheless, for landscapes with documented large-scale increases in woody fuel connectivity, there is a widely shared concern that increased abundance of large high-severity wildfires has expanded the potential for creating broad-scale shifts in dominant physiognomic types.

Implications

There is broad agreement that both climate and fuels are critical regulators of fire regimes in western US forests. In extreme weather, fires are likely to be large and severe, and managers should be mindful that extreme fire weather is expected to become increasingly common in the 21st century. Under milder conditions, however, fire behavior is mediated by complex interactions among climate, weather, topography, vegetation type, and fuel properties that vary spatially due to successional patch structure and patch size distributions. Further, prior fires (both managed and wild) can alter the extent, burn severity, and patch size distribution of subsequent fires depending on time since fire, topography, climate, and other factors.

In many, but not all, portions of the West (including the Inland Northwest and Pacific Southwest, Colorado Front Range, and monsoonal Southwest), scientists and managers have a reasonably large range of studies documenting changes in forest fuel and seral stage patterns of interior forest types, especially those leading to altered fire regimes. It is likely that restoration activities that seek to reduce fuels and restore successional conditions and their altered spatial patterns can be adequately informed, in particular if appropriate attention is paid to the differences in forest type and habitat.

Topic G. The role of changing climatic conditions is increasingly important

Common Ground

Key points of common ground among the respondents to the questionnaire included:

- Climate variability is a key driver of historical and current fire regimes, with distinctive historical patterns of climatic drivers of fire activity evident in different landscapes.
- The western US has recently been affected by a rapidly warming climate, characterized by reduced snowpack, earlier springs, longer fire seasons, hotter droughts, and more frequent periods of extreme fire weather.
- Recent trends in many western forest regions of more large fires and more area burned are linked to recent climatic trends of hotter droughts and longer, more severe fire seasons.
- Projected climate changes toward substantially hotter and drier conditions in the western US are expected to become increasingly significant drivers of amplified forest fire activity and severity; associated climatic interactions with vegetation and fuel conditions will also increase in significance.
- Climate changes, along with other anthropogenic drivers of global change, affect many vital climate-driven forest processes that will interact with changes in fire activity.

Questionnaire respondents noted that climate variability is now accepted as a driver of both historical and current fire regimes in all western US forests. Distinctive historical patterns of fire activity—driven by periods of hot and dry climate—are evident and well-documented in numerous western US landscapes (see Topic F). This important consensus coincides with the broader scientific consensus that the current western US climate has trended hotter and effectively drier in recent decades. This hotter and drier climate has fostered reduced winter snowpacks, milder winters, earlier springs, more rain-on-snow events, longer fire seasons (at times 40 to 80 days longer), drier fuels, and more instances of extreme fire weather—all generally consistent with regional model projections of future climatic change. Some western ecoregions now have nearly year-round fire seasons.

Consensus also emerged from the questionnaire that these recent climatic trends are linked to changes in fire activity since about 1980-85, contributing to larger fires, more area burned, and more moderate- and high-severity fire in some western US forests. Projected future climate changes toward progressively drier fuels and more extreme fire weather conditions in the western US are expected to amplify forest fire size and area burned. Proportion of high-severity fire may follow different trends as burn severity is more affected by topography, vegetation, and fuel beds, and less by climate than area burned (see discussion about the relative importance of fuel treatments; Topic E). We note that climate and fire weather largely determine the moisture content of vegetation and surface fuels, which has a strong effect on the availability of fuels to burn, energy released by the fuel complex, and resulting flame length, fireline intensity, and smoke emissions. Given projected climate warming and drying in the West, current forest fuel accumulations will be reduced through time by anticipated increases in fire activity (although surface fuel loads typically spike within a decade as standing post-fire snags [i.e., dead boles and branches] fall down amidst diverse vegetation regrowth), by constraints on forest regrowth under a hotter and drier climate, and by forest transitions to non-forest vegetation over increasingly large areas. In some of these areas, afforestation due to lack of fire has occurred, which reduces vegetation flammability and rate of spread. Anticipated future changes in forest fire activity and fire effects ultimately will be modulated by these feedbacks among fire, fuels, vegetation succession, and climate.

Respondents also indicated that emerging climatic changes also widely increase tree physiological stress, and adversely affect tree regeneration, growth and mortality losses, and associated insect and disease outbreaks. Thus, ongoing and future climate-induced changes in forest extent, forest fire extent, severity, and effects must be understood in relation to these additional biotic, abiotic, and anthropogenic factors.

Areas of Divergence

Key areas of divergent opinion among respondents included:

- There remains a divergence of opinion over the relative contributions of climate change and fuel accumulation to current patterns and trends of wildfire activity.
- Effectiveness of fuel treatments under projected climate futures and associated more extreme fire weather.

All respondents agreed that climate change is occurring and likely to continue. The main divergence among respondents involved perceptions of the relative importance of climatic versus fuel factors as drivers of changing fire activity, both now and in the future. This basic divergence in perspectives emerged repeatedly in questionnaire responses, as noted in Topics E and F, despite a general lack of scholarly work to explore joint contributions of climate and fuel to fire extent and burn severity.

This divergence in perspectives about the relative importance of climatic versus fuel factors as drivers of changing fire activity also extends to a related divergence in views on the effectiveness of fuel treatments under projected climate futures and associated more extreme fire weather; this area of divergence is presented under Topic I.

Implications

There is wide agreement that climate has long been a principal regulator of wildfire activity and therefore there is broad consensus that climate change via decreased fuel moisture and more extreme fire weather will considerably impact future wildfire activity. There is also wide agreement that fuels are a principal regulator of wildfire activity and fire effects. Divergent opinions emerge with respect to the relative importance of climate and fuel accumulation. Looking ahead, managers should expect climate change to create conditions of declining favorability to historically dominant forest communities, including warmer droughts, reduced snowpack and other phenomena. These general climatic trends are likely to be conducive to longer fire seasons and greater fire activity in the 21st century. Increasingly extensive vegetation transitions to more drought-tolerant and better fire-adapted species and/or lifeforms are anticipated. Although fuel properties directly influence fire behavior and fire effects, managers require in-depth knowledge of all determinants of fire behavior, including expected climate-related effects on fuel moisture and vegetation and other ecological changes, to determine the extent of possible feedbacks with climate change.

Anticipated changes in western US wildland fire activity have the potential to disruptively challenge the sustainability of historical forest ecosystems and our linked human societies. We expect that a broad range of fire-related adaptation measures will be considered in many western forest landscapes, ranging from increased regulation of human land use activities (e.g., disincentives for exurban development, building codes, seasonal recreation restrictions), implementation of diverse vegetation treatments (including managed wildfire, prescribed burning, and strategically-placed mechanical treatments), to management of forest stand structures, tree species compositions, and genetic variability, in order to foster resilience to growing drought stresses and associated disturbances (fire, insect outbreaks, tree regeneration failures). We expect increased societal attention and preference for such adaptation efforts in order to increase the likelihood of favorable forest adjustments to increasingly novel climate and other emerging environmental stresses.

Topic H. Multiple fire ecology and fire history research approaches can be useful to characterizing fire regimes

Common Ground

Key points of common ground among the respondents to the questionnaire included:

- It is desirable to use multiple methods to reconstruct historical fire regimes. More can be learned using multiple approaches and considering data from diverse temporal and spatial scales.
- Integrating and interpreting findings derived from diverse methods, data sources, and different scales of inquiry can be challenging.

The interpretation of any research evidence and the scope of related inferences is limited by scaling and sampling concerns associated with the methods, and these limitations apply to all research methods. Respondents to our survey strongly agreed with the statement that "*New and important insights should be possible through studies that use and compare alternative sources of data, and results may be used to examine fire history and fire effects in the same study areas.*" Respondents disagreed with the statement, "*Even if we find many different study areas where alternative sources of data are available, there are too many uncertainties or incompatibilities among them to make such comparisons useful.*" Thus, respondents recognized the high potential value of using and considering multiple approaches, data sets, and scales of observation to more robustly assess historical fire regimes. Broadly speaking, this reflects widely-accepted scientific views on the general benefits of using multiple lines of evidence when possible, with increased confidence in conclusions when most results are in agreement.

For this project, we decided to focus on the evidence regarding fire regimes of recent centuries, although substantial paleoecological research using sedimentary charcoal and pollen data has been essential in expanding our understanding of long-term variations in fire regimes. All methods for reconstructing historical fire regimes are necessarily indirect. They may include, but are not limited to, interpreting evidence of past fires or the extent of fire-dependent ecosystems from historical documents, land surveys, aerial photographic reconstructions, fire-scar and growth-release data from tree rings, tree age and death dates from tree-ring data, climatic data linked with past fires, charcoal and pollen deposits, current characteristics of stands (i.e., structure, species, and stand age distribution), fire perimeter mapping, historical timber survey data, and use of statistical distributions for modeling stand-replacing fire. In addition to utilizing multiple methods, the use of clear and shared terminology is needed for effectively combining research approaches to characterize fire regimes. Similarly, the use of diverse archaeological, anthropological, and cultural resource research methods that address the extent and impact of aboriginal fire uses in landscapes can provide useful information in support of restoring culturally important landscapes and their fire-maintained cultural resources.

Respondents noted that multiple methods enhance the potential of inferring the severity and other ecological effects of past fire events, which is central to current debates about the relative proportions of fires of different severity in the past. There are diverse examples where western fire researchers have used multiple methods to characterize historical fire regimes. Commonly, there is general agreement among studies about characteristics of historical fire regimes, particularly for ecosystem types that have had a history dominated by either low-severity fires (e.g., leaving scars but not killing many adult trees) or high-severity fires (killing many adult trees).

In recent decades, we have increased our learning about the strengths and weaknesses of diverse methods and data sources for analyzing high-severity fire, and also the scope of spatial and temporal inference limits for reconstructing historical fire regimes and forest conditions in varied western US landscapes. A particular challenge has been elucidating historical spatial patterns, such as patch sizes, shapes and arrangement. Much of this expanded insight has come on the heels of examining relationships between documented fire histories and associated forest successional or cohort conditions. In particular, further developing studies that cross-walk dendroecological fire histories with aerial photo interpretation and cohort age structure analyses offer much promise. These methods too can be combined with simulation studies that may offer additional insights. Respondents recognized that a more productive approach to multi-methods analysis might be for research laboratories that specialize in one method or another to collaboratively join their strengths in designing, implementing, interpreting, and documenting results of such research through joint work in multiple landscapes.

Areas of Divergence

The areas of divergence in opinion among respondents included:

- The introduction of new methods for reconstructing historical fire regimes has, in recent years, resulted in unresolved debates regarding the limits and usefulness of some new and old methods.

  There currently is significant debate about the validity and thus utility of some new approaches using historical (General Land Office, GLO) and current (USFS Forest Inventory and Analysis, FIA) land and timber survey data to infer the amount of high-severity fire, forest species composition, and the density and age structure of historical forests. Similarly, extrapolating from historical tree-ring and fire-scar point data across much larger areas has been a topic of some debate, but the disagreements are quite different. In the former case, disagreements center around the usefulness of the land survey data to the ends applied. This results from doubts regarding differences in interpretations of historical fire regimes based on tree-ring or other data versus historical land survey data. In some cases these differences are large but in other cases the percentages of a landscape classified as having an historical fire regime of mainly low-severity versus mixed (or higher) severity fire are relatively slight. The validity of reconstructing historical forest conditions and fire regimes in particular from all types of historical land or timber survey data has been critiqued. Such scrutiny of the validity of methods is a normal part of the scientific process, and highlights the need for continued research based on cross-validation from multiple types of data and methods.

Implications

The use of multiple methods for characterizing historical fire regimes, combined with increasingly clear and shared terminology, can improve our understanding of HRV patterns and processes in western forests. However, there can be significant challenges associated with bringing together evidence about historical fire regimes from differing methods and data sources. Each line of evidence has a different scope of spatial and temporal inference, and issues about the nature of the data captured in each sample. In addition, there is substantial skepticism about the utility of some methods for HRV reconstruction purposes, which will have to be resolved. Nonetheless, one new frontier of fire ecology research is the exploration of multi-method approaches by collaborating labs toward more-nuanced understandings of diverse fire regimes. For example, in mixed-severity fire regime forests, by combining time series derived from diverse dendroecological data sources (e.g., fire scars, death dates of trees, establishment of postfire cohorts, growth releases on surviving trees), land survey data, aerial photographic interpretations of successional and past fire severity conditions, landscape panoramic photos, and simulation modeling, stronger inferences may be possible about the ecological effects of past fire events.

Topic I. Many existing fire management tools and strategies can be useful for managing fire going forward

Common Ground

Key points of common ground among the respondents to the questionnaire included:

- Many tools can be useful to fire managers for reducing human vulnerability to fires and increasing ecosystem resilience.
- Managed wildfire is underutilized but viable ecologically and socially in many areas.
- Managing fuels is important and fuels are one contributing factor that can be influenced through management.
- Thinning alone without managing the resulting fuels increases surface fuels and does not mimic many of the ecological effects of fire.
- Firefighter and citizen safety, degree of smoke production, financial costs, and effective scales of treatment must all be considered.
- Land-use and financial incentives could be used to reduce human vulnerability to wildfires in and near the WUI.

Many respondents stressed that a wide variety of tools and policies can be useful to increase forest resilience and reduce human vulnerability to future fires. Suppressing fires to protect highly valued resources is important, but managers need a full suite of active and passive management strategies and tools because different management situations often call for different approaches. There was strong support for managing wildfires to accomplish resource benefits and also support for prescribed burning[12]. We agree. However, there was very little discussion of how and where wildland fire use can be effectively implemented to foster desirable patch size distributions, particularly where climate and forest conditions have changed, and surface and canopy fuels have accumulated over the period of fire suppression. Broad-scale landscape planning for wildland fire use will be essential to better understand special circumstances and clear opportunities for its use.

Wildland or prescribed fire use can be effectively complemented with fire suppression strategies and with thinning to reduce vertically and horizontally continuous fuels that contribute to fire hazard. Tools such as the Wildland Fire Decision Support System are used to make effective fire management decisions considering landscape conditions, jurisdictions, fire weather, values at risk and local management objectives.

Increasing education and outreach, managing post-fire to reduce soil erosion potential where values are at risk, decommissioning roads, creating snags where they are in short

[12] Wildfires are ignited by people or lightning. They may be suppressed, either aggressively or with more limited efforts, depending on management objectives, values at risk, costs, firefighter risk, and other factors. Managed fires are those that achieve resource objectives. They are monitored and parts may be actively suppressed while other parts are managed with less aggressive suppression. Prescribed fires are ignited by management actions under certain, predetermined conditions to meet specific objectives, such as reducing hazardous fuels, improving habitat, managing cultural resources, firefighter training, fire behavior experiments, or restoring forests. Prescribed fires are nearly always conducted under written, approved plans.

supply, and other tools can further help accomplish management objectives, while protecting people and property from fire and fire effects. Other strategies for helping communities become more fire-adapted include altering residential development in highly fire-prone environments, and making existing homes safer from wildfires. Land-use (e.g., applying the national WUI building codes proactively and retroactively, zoning to concentrate development in lower fire danger environments) and financial incentives (e.g., tax, insurance, mortgage restrictions, fees, assistance with fuel treatments around homes and towns, support to mitigate structure ignition vulnerabilities) could be used to reduce vulnerability to wildfires in and near the WUI.

Certainly, fire managers must consider financial costs, firefighter safety, public safety, and smoke. These and other societal and operational management constraints vary geographically, so managers must look for opportunities to adapt and use multifaceted strategies. There was widespread agreement among respondents that the suitability of different tools is highly context specific. In discussing strategies, both the often significant beneficial and detrimental consequences of taking no action must be considered.

There is strong consensus that more fire is needed on the landscape, but not all wildfire behavior or extent will do. Managers need assistance and funding to create landscape conditions that favor more desirable fire behavior at spatial scales and extents that can make a difference to current conditions.

Respondents generally indicated that the scale of landscape change in western US forests is quite broad, and that it could be difficult to overcome (i.e., a high level of landscape inertia), especially with the current level of defunding of public land management agencies. The cost of fire suppression has risen from 17 to nearly 60% of the entire Forest Service budget in the last 25 years, greatly limiting the financial capacity of the agency for proactive work at any meaningful scale. Treatments need to be of sufficient scale and pattern to be effective at restoring patch-size distributions of low-, moderate-, and high-severity fire, and at reducing what is seen by many as an increasing risk of unusually large, high-severity patches within fires. Although fuel treatments can be prioritized across very large landscapes to be potentially effective in managing wildfires to accomplish resource benefits, such treatments must be designed consistently with other ecological and management goals including riparian corridors, habitat for listed species, and the like. Restorative treatments likely need to occur at the scale of the landscape changes to change current fire regime conditions. Due to widespread existing habitat reserve commitments, opportunities for strategically allocated treatments are substantially limited.

Given the profound influence of the type and amount of fuel on fire behavior (Topic F), the type, location, timing, frequency, and maintenance of fuel treatments[13] will all influence their effectiveness. Forest thinning is one commonly applied fuel treatment. Most cutting methods that are applied to reduce future burn severity are thinning treatments where emphasis is on removal of the less fire-resistant trees (usually the smaller ones especially of shade tolerant species). The intensity of thinning determines the amount of branches and tree tops (slash) left behind. There is consensus that follow-up burn treatments of this slash are critical, however, this can be logistically and financially challenging because of highly restrictive smoke management policies. Post-harvest slash burning typically involves burning of piled slash concentrations, and in some cases, broadcast burning of remaining fuels. Prescribed burning

[13] Fuels treatments and fuels management include planned prescribed burns, mechanical treatments such as mastication or thinning, and silvicultural treatments and other treatments designed to change or reduce wildland fuel quantity and arrangement, the intensity of future fires, and increase the ease of fire suppression.

can also be done independently of thinning to reduce surface and ladder fuels, and to reintroduce more natural fire to the ecosystem. There are often significant constraints to this sort of prescribed burning though. For example, where surface fuels are too abundant, and where tree density and layering are significant, burn-only treatments are difficult to execute with any certainty. Burn-only treatments are also highly influenced by favorable fire weather (moderate conditions are best to accomplish goals), availability of fire crews, and smoke management restrictions. Respondents support efforts to overcome these roadblocks so that more fire can be reintroduced. Additional prescribed burn considerations for managers include improving public support for them, helping to design fuel treatments that mimic historical fires, using more fire during the fire season, enlarging the number, size, and positive effects of burns, and decreasing undesired effects of slash burning. Prescribed burns also consume less fuel and are far smaller than large wildfires, thus they produce far less smoke and smoke exposure to the particle sizes that are most harmful to human health.

Many respondents noted that managed wildfire is underutilized. It can be a viable tool ecologically, despite operational constraints. Ideally, this will result in more area burned under less than extreme weather conditions, and more moderate-severity fire effects resulting in heterogeneity that can be more consistent with both the historical range of variability and long-term management goals, if only for altering where and how future fires burn. Practically, there are large areas where mechanical thinning is neither allowed nor feasible, for example in wilderness and roadless areas. Managing wildfire may be useful there for reducing fuel quantity and altering vegetation composition and heterogeneity consistent with management objectives and enabling policy.

Wildfires can sometimes be managed at less cost and less risk to firefighters in areas where other fuel treatments are neither feasible nor desirable. Advanced planning is needed, as is accepting long-term risk and smoke when such fires burn for many days. Public lands are sometimes mapped into zones designated for particular management, included allowing fire. Challenges include societal constraints (e.g., smoke, fear of fire, concerns about shifts in weather, and distrust of managers and scientists) and operational constraints (e.g., costs, long-term risks, timing, and suitable weather). Smoke from fires poses human health hazards and visibility issues. Despite best efforts, some managed wildfires will not go as planned. The biggest challenges are the expanding area of WUI, public and political perceptions of fire and smoke, and unpredictable changes in fire weather. When homes burn, the fear of wildfires and their smoke often fuels political support for aggressive fire suppression, which reinforces the current predicament. But there are beneficial aspects of wildfire smoke too. For example, in northwestern California, Mid-Klamath Basin tribes recognize benefits of canyon smoke inversions for reflecting direct sunlight, and cooling air and river temperatures that can benefit native salmonids. Smoke is also a naturally occurring fumigant that reduces nut, seed, and acorn infestations by forest insects, and along with fire, facilitates seed germination of some native plants if smoke occurs during the natural fire season.

Managing wildfires to accomplish resource benefits may be one important way to achieve relatively widespread vegetation change at the spatial scales and in the short time frame needed to make a difference in the short-term. Depending on the situation, this will typically require strategically pretreating a portion of the landscape using prescribed fire—sometimes coupled with thinning—to reduce vertical and horizontal continuity of fuels, and to anchor managed wildfire or prescribed burning treatments. Such strategies can help manage risks and help society be more comfortable with less aggressive fire suppression, especially in or near the WUI. In remote locations far from the WUI and most vulnerable infrastructure, fairly typical mixes (for the fire regime of interest) of low-, moderate-, and high-severity fires may be a desirable and achievable outcome that is compatible with forest resilience, despite the many challenges managers face in managing wildfires.

Where there is a high concentration of values at risk and sensitive human populations within the WUI, aggressive fire suppression and fuel treatments may be the only socially acceptable strategies. In these situations, managing forests abutting the WUI with thinning and prescribed or pile burning, and aggressive fire suppression, will be appropriate.

Areas of Divergence

Key areas of divergent opinion among respondents included:

- Appropriate locations, scale, and effectiveness of thinning aimed at reducing fire hazard.
- The scale of thinning that can be feasibly and repeatedly implemented relative to the scale of the need.
- Advantages and disadvantages of managed wildfires, including acceptable levels of risk.

Communities often feel a strong sense of urgency and need for hope in the face of threats from wildfires. For areas distant from the WUI and municipal watersheds, some respondents disagreed with the degree of urgency and scale of need for thinning and prescribed burning.

Another area of divergent opinion is the role that forest restoration and fuel treatments might play in charting a new course for forest resilience, especially where public lands are considered. Arguments for restorative treatments range from concerns that prescribed burning or other treatments are needed where the condition of many forests before wildfires can result in undesirable burn-severity and patch-size distributions, to the belief that treatments are not restorative because large areas can only be effectively restored by proactively working with wildfires that are assumed to be “natural.” A range of other arguments falls somewhere on this continuum. One challenge is that fuel treatments may not be performed at a necessary pace and scale, especially when coupled with operational maintenance costs over time. Another view is that fuel treatments are less important in areas that would have experienced some degree of high-severity fire, and these areas may have been widespread and have greater positive influence on biodiversity and wildlife than is currently understood. This is underscored by strong opposition to partial to complete post-fire logging (salvage) of fire-killed trees, because some snag forests provide valuable habitat, and there are concerns about ecological integrity. The crux of this disagreement is whether the dead trees are most useful for their commercial or ecological values. Another view shows that some areas of high-severity fire tend to burn again at high severity, and that efforts to treat fuels and re-create more varied successional and fuels mosaics can help break this cycle. Yet another view asserts that in some instances, burned forests would benefit from removing dead smaller trees that could constitute critical reburn fuels.

Some scientists’ opinions diverge regarding the relative importance of climate and weather (fuel moisture and availability to burn), and fuel quantity (Topic F). For example, for some, there is more acceptance of the utility of fuel treatments within dry forests than in cold subalpine forests. Further, many scientists differed on the scale of treatment needed to influence high-severity fire at landscape scales because of questions about treatment effectiveness given the large amount of fire that burns under extreme weather conditions. Indeed, most current large wildfires are not even finding fuel treatments at the current low level of application. There can also be problems with non-native invasive species increasing in abundance following thinning and/or fire, particularly in lower-elevation forests. Many disagreed on the extent to which levels of high-severity fire and landscapes have changed, and the degree to which fuel treatments far from the WUI are a net benefit. The degree of divergence differs by forest type and landscape context, with stronger agreement about landscape change for dry mixed-conifer forests, and less for landscapes dominated by cold subalpine forests. Another argument by some for not actively managing landscapes outside the WUI is that even where there is strong support for treatments, the cost and difficulty of implementing and maintaining existing treatments may already be too great for society to absorb; this consideration is beyond the scope of this report. Of course, societal cost and practicality must be considered in the context of potential loss of forests, fire-adapted biota and other resource and social values. Further, reduced reliance on fuel treatments might imply an increased use of managed wildfire, but there is currently no consensus framework for weighing the costs and benefits of managed wildfire.

Some divergent opinions derive from establishing forest treatment targets, especially when those targets are not yet socially acceptable. For instance, thinning from below (removing many smaller, fire-intolerant trees while leaving older, larger trees) will reduce fire hazard under many circumstances, and can be a first step in ecological restoration treatments in many dry mixed-conifer forests. However, these treatments must be followed by prescribed burning, and a certain amount of smoke production, to reduce fuels and potentially restore ecosystem processes in the short-term. In some cold subalpine forests, however, where fires are more often limited by weather than by fuels, fuel treatments beyond the WUI may be relatively ineffective when and where fires spread by long-range spotting.

Some respondents noted that current landscape conditions reflect suppression of most fires, effects of past logging, and land uses that have often resulted in landscapes that are more homogeneous fuel-wise, notwithstanding widespread fragmentation by roads. Some respondents argued that these more-homogenous landscapes are more vulnerable now to very large patches burned with high-severity fire relative to historical conditions. Others saw less divergence between present and past high-severity fire potential (see areas of divergence Topics B, E). Careful analysis is needed in each unique geographic location.

Another challenge is that treating large areas is difficult when there is strong level of distrust. Collaboration with diverse groups has in many cases strengthened trust, especially when treatment approaches have been altered through a consensus-building process.

Implications

Managers seeking to reduce human vulnerability to wildfire and enhance forest ecosystem resilience should have available to them a flexible set of management options that includes suppression, thinning and other fuel treatments, prescribed burns and managed wildfires, as well as broad education on both the essential roles of fire and on prevention of undesired human-caused fires. The uses of these various tools should depend highly on management priorities and local context, including vegetation structure and composition, legacies of past fuel treatments and land use, the historical range of variability, presence of houses and resources people highly value, and acceptance by people. In the future, prescribed fire and managed wildfire will be useful to increase or maintain forest structural heterogeneity and restore associated ecosystem processes. Fires can limit the extent and severity of subsequent fires.

Fires respond to interacting influences of climate, weather, fuels, topography, legacies of prior disturbances, and management. The relative importance of these factors varies across landscapes and through time. Those who express that increasingly extreme fire weather with climate change will increasingly override the importance of fuels argue that fuel treatments should be focused around the WUI with limited fuel treatment elsewhere. Their logic is that direct protection of human assets is the top priority on which to focus, and that fuel conditions are less important as fire weather becomes more extreme. Those who emphasize the importance of fuels to fire behavior urge strategic fuels management in both WUI and non-WUI forest landscapes, using a variety of tools and prescriptions as needed across dry, moist, and cold forest types. They also assert that fuels are the main landscape characteristic that management can change. Where fuels and vegetation patterns have changed to foster more contagious fire spread, fires will be widespread and often large when fire weather and fuel moisture are conducive, particularly where grass fuels are continuous.

Going forward, monitoring is important to assure that fire management supports long-term vegetation management goals, particularly in the context of climate change, or to modify management to better align it with goals. We need to learn where fuel treatments are effective under different environmental conditions and where they are not, and then we must adapt management informed by monitoring. Scientist-manager partnerships could be particularly useful here to develop useful monitoring frameworks.

Where managed wildfire is not socially acceptable, more aggressive fire suppression and fuel treatments will be appropriate, along with prescribed burning. Many wildfires will occur and some will be large. With thoughtful management, we may be able to influence their severity and spatial extent under many but not all fire weather conditions.

To address future challenges in the face of expanding WUI, longer fire seasons, and altered forest conditions, managers need many different tools to balance ecosystem needs, costs, risk to firefighters and the need to protect people and property from fire. Federal fire policy allows this flexibility, and fire managers need it if they are to reduce societal vulnerability to fire and smoke, while also limiting costs and risks to fire personnel, and managing for ecosystem values. Addressing the vulnerability of the WUI depends on other approaches as well. Thus, policies to make current WUI communities more fire adapted are critical, as are changes in land use policies that influence where and how future WUI areas develop.

Conclusions

We found much common ground that will be useful to scientists, managers, and others for moving forward. There is wide agreement among scientists that fire is one of the most essential and pervasive influences on the forests of the western US. Further, fires can produce more positive benefits and fewer negative impacts when they burn with an ecologically appropriate mix of low, moderate, and high severity, and in patch size distributions that reflect the natural variability of fire behavior and fire effects.

Many questionnaire respondents suggested that the real challenge is to face the twin realities of increased abundance and connectivity of woody fuels and a changing climate. Not surprising, there were differing opinions about trade-offs between social values and the ecological benefits of fire. For example, smoke from wildfires or prescribed fires is a great concern that can have important influences on how various fire treatments are applied. There was wide agreement on the need for land management strategies that reduce societal and ecosystem vulnerability to negative consequences of wildfire, while providing for the essential role and benefits of fire in forests.

Areas of agreement outnumbered areas of disagreement. Respondents agreed that geographical context is very influential and that human impacts vary, and therefore there is no single one-size-fits-all management prescription. There was strong support for utility of the historical range of variability (HRV) for fostering understanding of how and why ecosystems have changed, and how they respond to fires of varying severity. Despite rapidly changing conditions, HRV will continue to be useful as a guide, but not a prescription for future landscapes. From HRV we can learn how ecosystems respond to wildfires, and the HRV of landscapes and ecosystems forewarns about ecosystem capacities and limitations in response to varied climate and disturbance drivers. As a guide for managing future landscapes, history does not provide precise prescriptions, but does offer precautionary principles. We fully recognize that adaptive resilience for the future will require applying what we learn from history to some future range of variability, where fires burn and ecosystems respond in both similar and different ways. There was strong support for prescribed burning, coupling thinning with prescribed burning, and for managing wildfires to accomplish resources objectives. This is common ground.

Forest structure, composition, and fuels have all changed, affecting burn severity and successional patch size distributions. Climate and fuels together with topography will influence future fires and their effects. There was consensus that many fire management tools and strategies will be useful moving forward, and no tools should be excluded.

We challenge managers and scientists to overcome the tendency to oversimplify historical fire regimes across and within ecoregions and forest types: there is no single model of historical fire regimes. Managers should exercise caution when applying scientific understanding developed in different landscapes and recognize that this may result in erroneous scientific underpinnings and failure to meet local objectives. Rapidly changing circumstances suggest that future management should be highly adaptive, incorporating learning from what works well and poorly. To adopt an adaptive management stance though, managers will need to engage in ongoing monitoring to detect and learn more about the best and poorest methods and outcomes. Scientists can work with managers in these practices, and such partnerships could provide a potent resource for managers. Scientists must also clarify the importance of place when characterizing and presenting knowledge about historical fire regimes, and scientists and managers would both benefit from sharing methodological approaches and collaborating across ecoregions. Scientists and managers should work together with science communication experts to create training and reference materials that capture appropriate levels of simplification and complexity.

Broader discussions center on issues where there is less common ground, including:

High-severity fire

There was strong common ground that for dry pine and some dry mixed-conifer forests, there has been either an observed increase in high-severity fires or an increase in the potential for fires of elevated severity. These changes have occurred as the result of increased area and density of forests, and increased connectivity of woody fuels since the late 19th century. In contrast, for cold subalpine forests the majority of survey respondents agree with the statement that these forests have been less affected by fire suppression. Yet, large-scale landscape assessments of forest spatial patterns in the Inland Pacific Northwest show that recent (i.e., post 1984) patterns of high-severity fire and changes in patch size distributions in many moist mixed-conifer and cold, subalpine forests reflect significant departures from longer-term patterns linked to both climate, increased forest area, and increased density, layering, and connectivity of these forests. Expanded woody fuel connectivity is a result of synchronized successional conditions as a consequence of fire suppression and fire exclusion. Suppression of wildfires in moist and cold forests has yielded much lower prevalence of early seral conditions, and increased connectivity of mid- and late seral conditions, which has concomitantly increased landscape connectivity of conditions that are conducive to initiation and spread of crown fires. Conclusions differ for some cold subalpine forests in the Southern Rockies based on published studies and survey responses. Unfortunately, we don't have similar information on landscape change across moist and cold subalpine forests in some other ecoregions. Reasons for these different perspectives on the degree of long-term change in the extent of higher severity fire are varied and complex. Some of the variability in scientific perspectives is empirically attributable to geographical differences in the factors determining historical and modern fire regimes. Others reflect disagreements over methods of examining changes in fire regimes and the interpretation of the evidence of past higher severity fire. Still others reflect the goal of influencing management.

Dry mixed-conifer forests (including areas once dominated by pure or nearly pure ponderosa pine), moist forests, and cold forests have all changed in recent decades. The degree of change is not the same everywhere, yet fires interacting with climate and current forest conditions have the potential to create very large patches and a relatively high proportion of areas burned with high severity. This has implications for post-fire tree regeneration (without which forests convert to non-forest), soil burn severity, and related erosion and watershed change, and other ecosystem services valued by society and affected by varying plant successional processes and trajectories. Non-forest vegetation may be maintained by fire where it is not suppressed; even in the absence of fire, however, forests may not regenerate if seed sources are not available. In some areas, forests have increased and non-forest decreased, due to fire suppression.

Both fuel and climate are important as increased woody fuel connectivity in combination with a warming climate trend is setting large areas of landscapes on fundamentally new trajectories where very large patches burn with high severity. Climate is of increasing importance.

Empirical and simulation studies and landscape ecology theory suggest that even small increases in the frequency of the largest high-severity patches can have a semi-permanent influence on future local and regional landscape habitat configurations and wildfire frequency, severity, and spatial extent. Thus, individual fire events can change the broad-scale resistance of the landscape to future wildfires. How these scenarios will play out under continued warming and more fires is highly uncertain.

We suggest that resolving many disagreements depends on greater consideration of specific geographical context. A logical suggestion is to increase in-depth cross-regional field research experiences of the fire research community. Cross-regional comparisons of top-down and bottom-up determinants of fire activity in similar forest cover types is a fertile area of future research to examine how differences in seasonality, productivity, understory fuels, land use history, and other factors may explain some of the reported geographical differences in historical fire regimes in broadly similar forest types. Likewise, systematic regional comparison of the timing and nature of land-use practices by Native Americans and European settlers on fire regimes would improve our understanding of how changes in anthropogenic ignitions, fire exclusion, logging, ranching, mining, and landscape fragmentation may have contributed to geographic differences in historical fire regimes.

There are several reasons for the disagreements about patterns of past fire severity. First, both scientists and managers often uncritically transfer concepts and findings from one place to another (see Topic A). We know that fire effects at a point depend to some degree on the surrounding landscape and forest composition. Some of the disagreement derives from debates over the relative utility and validity of different scientific methods; nonetheless we believe that application of diverse research approaches is useful in HRV reconstructions. We challenge fire scientists who do not share similar perspectives on historical fire regimes in particular ecosystems to engage in civil discourse to better understand the reasons for their disagreement and to objectively communicate those reasons to managers and other stakeholders. We are heartened by the positive outcomes achieved by some previous attempts when small or large groups work together to find common ground.[14]

WUI and beyond

Respondents strongly agreed on the need for fuel treatments and aggressive fire suppression within and adjacent to the WUI. The strategies for managing wildfire will be quite different within and adjacent to the WUI than in areas far from the WUI. However, what fire managers do beyond the WUI has implications for forest resilience, smoke production and its human impacts, water quality, and many other ecosystem services people value.

Fuels management alone, especially if limited to public land, will not be sufficient to address the vulnerability of WUI communities to fires. Fuels management will be important for influencing the resilience of the future forest, and for influencing the behavior of wildfires that approach the WUI. Thus, policies to make current WUI communities more fire adapted (e.g., implementing current WUI codes) are a critical piece of the puzzle, as are changes in land use

[14] See: 1) Kaufmann et al. (2006) Historical fire regimes in ponderosa pine forests of the Colorado Front Range, and recommendations for ecological restoration and fuels management. *Front Range Fuels Treatment Partnership Roundtable, findings of the Ecology Workgroup.* 2) Romme, et al. (2009) Historical and modern disturbance regimes, stand structures, and landscape dynamics in pinon–juniper vegetation of the western United States. *Rangeland Ecology & Management* 62(3): 203-222. 3) Baker et al. (2017) The landscapes they are a-changin' – Severe 19th-century fires, spatial complexity, and natural recovery in historical landscapes on the Uncompahgre Plateau. Colorado Forest Restoration Institute.

policies that influence where and how future WUI areas might develop, and the spatial extent and arrangement of managed and wildfire fuel treatments.

Pattern and Process for Fires in Forest Landscapes

Heterogeneity of fire effects, including the pattern of patches created by fires and other disturbances, is important to forest resilience to future fires (see Topic E). There are potentially profound implications for forest function and carbon sequestration if the proportion of area burned with high-severity fire changes. Even more importantly, as the patch size distribution changes greatly, particularly with respect to the proportion and size of the largest patches burned with high severity, there are multiple ecological consequences. For instance, the proximity of seed sources from surviving trees of fire tolerant species can affect forest regeneration, and the future flammability of the forest. Wildlife habitat use will change, both for those species dependent on hiding and thermal cover adjacent to more open areas and for those thriving in recently burned forest openings. Similarly, the fire refugia that many species depend upon to bridge fire disturbances will all be greatly affected. Further, soil erosion potential is often higher when large patches burn with high severity.

Fires are essential to ecosystem function. Largely missing from many western landscapes are the historically most numerous small- and medium-sized fires that burn under less-than-extreme conditions of weather and fuels. Even when they don’t burn much area individually, such fires cumulatively shape landscape heterogeneity, the resistance of the landscape to wildfire growth, the frequency of large fires, and landscape capacity to respond to future large fires. Simulation modeling in forested landscapes suggests that even relatively small changes in the proportion of large patches alters system behavior. Thus, the patch-size distribution of low-, moderate-, and high-severity fires is of prime concern to policy makers, scientists, and managers.

Climate, Fuels, and the Implications of Landscape Change

Because fuels, weather, and topography dictate fire behavior, fuels management is important to efforts to mitigate fire behavior. However, mechanical treatment of fuels alone is not enough. Thinning without follow-up prescribed burning will typically worsen the problem. More flexible and extensive management of wildfires and prescribed fires will be essential, depending on local objectives and conditions, to increase the footprint of land areas showing reduced surface and canopy fuel abundance and connectivity. More extensive use of prescribed burning combined with thinning will be helpful, where forest fuel conditions (both surface and canopy fuels) are not currently manageable via wildfires and prescribed fires alone. The influence of prior fires on the extent and severity of subsequent fires, even when those fires burn under extreme weather and fuel moisture conditions, is a reflection of the importance of fuels. In some areas, forest conditions are such that some manipulation of fuels is needed so that key ecosystem elements are not lost in extreme fires. Many respondents accept that a proactive approach to fire and fuels management on public lands will reduce overall costs and improve climate change adaptation in the long-term. Some respondents questioned the practicality and effectiveness of fuel treatments under a changing climate; however the literature is clear that fuel reductions reduce flame length and fireline intensity, which reduce the likelihood of high-severity crown fires. Sound, science-based monitoring needs to be coupled with adaptive management to provide locally appropriate stewardship of our forests.

Decades of research in landscape ecology show that emergent properties have central importance to ecosystems and their pattern and process regulation, whereas many recent studies of climate-driven fire and vegetation change are less focused on local-scale feedbacks and emergent patterns. This creates a fundamental problem in linking climate change and landscape ecology research. Climate models assume that top-down climate covariates drive temperature, precipitation, and solar radiation conditions. Landscape ecology research shows that those top-down inputs can be highly modified by meso- and fine-scale bottom-up environmental controls to produce emergent climatic conditions that are strictly speaking neither the top-down or bottom-up inputs, but are influenced by these inputs. Climatic forcing alone poorly explains the shifts in landscape patterns because lagged patterns of historical disturbances continue to influence emergent patterns, under all but the most extreme events. The path forward to more effective projection of future fire and landscape change includes better integration of feedbacks from landscape ecological models into climate-driven models of future fire and landscape change.

In many landscapes, the increased abundance and connectivity of forests and fuels is favoring larger fires, and larger patches burned with higher severity. This is widely shared common ground for ponderosa pine forests and in some ecoregions is also applicable to dry mixed-conifer forests. This view is also commonly applied to moist and cold forests in the Inland Northwest, Pacific Southwest, Northern Rockies, and the Inland Southwest, whereas much less increase in fuel connectivity is believed to have occurred in the cold forests of the Southern Rockies. Regardless of uncertainties about departures from historical landscape conditions, there is a coherent argument based on first principles of fire spread that increasing forest patch heterogeneity could foster resilience to future fires, even as the climate changes. Thus, encouraging heterogeneity at various scales and in various processes is important for biodiversity, reducing connectivity of woody fuels, and increasing resilience with future climate change.

Effective management will depend on both science and trust

Our understanding of historical fire regimes can inform decision-making; indeed, such evidence-based decision-making can build trust. However, fire science points to complex patterns that vary with local conditions, so no single solution, such as logging or limiting all logging, will accomplish desired objectives in all forests. Further, no intervention also has consequences, so all decisions need monitoring to support the assumptions of management. Effective monitoring can improve knowledge, and through collective learning can build common understanding and trust.

Fire management can become more proactive and strategic. Existing tools, such as mechanical fuel treatments, prescribed fire, prevention of accidentally-ignited human fires, and managing wildfires will all be useful, but adaptation and mitigation responses to climate change and changing fire activity will require using these tools in strategic ways to fit area-specific goals. Some past disagreements about fire and fuel management strategies may be due to lack of clarity about specific goals, such as resident and firefighter safety, cost reduction, biodiversity issues, and ecosystem resilience under a changing climate.

The timing of fires is important, particularly in the context of a changing climate. While recognizing that wildfire seasons are long and getting longer, we must also take advantage of the milder fire weather and associated effects of fires in the “shoulder seasons.” Managers may find that both less-aggressive fire suppression and expanded use of managed wildfire under relatively moderate weather conditions can aid them where reducing the vulnerability of people and natural resources to fires is the objective.

One of the grand challenges of fire management is balancing the reality that wildfires will occur and are needed by western forest ecosystems, yet people, property, and economies need protection from the adverse effects of fire. Another grand and fairly urgent challenge is discovering the tipping points of transformative change for various forest landscapes in their respective geographies, where large, high-severity fires (regardless of whether they are considered unprecedented or not) may tip forest ecosystems into persistent non-forest states by constraining tree regeneration opportunities. Particularly as climate changes, we also need a deeper understanding of which landscapes may not be able to sustain forests in the future and how fast such transitions are likely to occur. It is clear that our western history of substantial forest fire activity will continue, one way or another: many fires will occur in the future and some will be large. Ultimately, we must find ways to sustainably use and live with fires that are well-adapted to both ecosystem and societal needs of local landscapes.