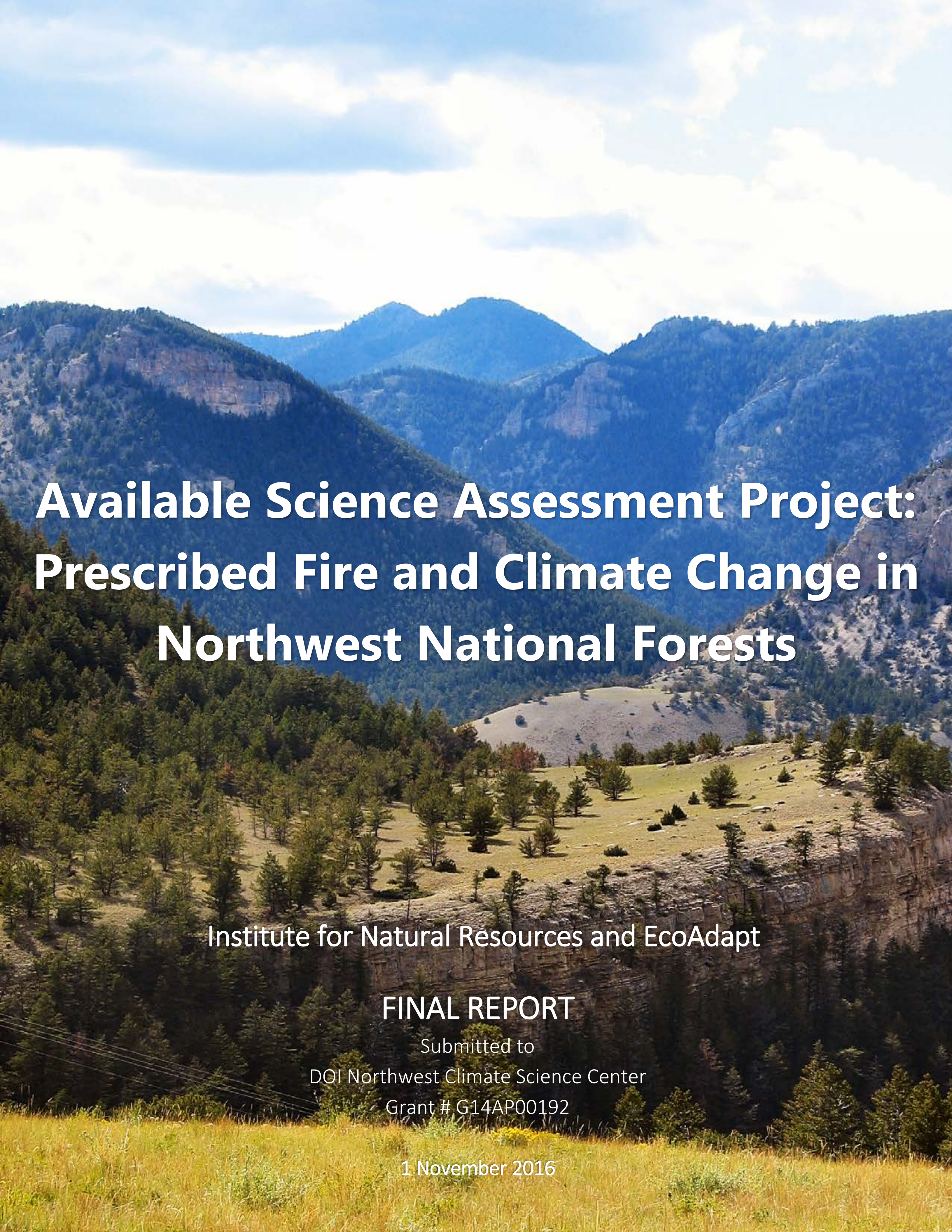

Available Science Assessment Project: Prescribed Fire and Climate Change in Northwest National Forests

Institute for Natural Resources and EcoAdapt

FINAL REPORT

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Available Science Assessment Project: Prescribed Fire and Climate Change in Northwest National Forests

Final Report

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Authors

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Prepared by

THE INSTITUTE FOR NATURAL RESOURCES

Created by the Oregon Legislature through the 2001 Oregon Sustainability Act, the Institute for Natural Resources' mission is to provide access to integrated knowledge and information to inform natural resource decision making and develop solutions in the context of sustainability. The Institute for Natural Resources is an Oregon public universities institute located at Oregon State University and Portland State University.

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More information on the Available Science Assessment Project may be found at: http://ecoadapt.org/programs/state-of-adaptation/asap.

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Disclaimer

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The contents of this report reflect the views of the authors who are solely responsible for the facts and accuracy of the material presented. This report does not constitute a standard, specification, or regulation.

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Executive Summary

Climate change is one of the most pressing issues facing natural resource management. The disruptions it is causing require that we change how we consider conservation and resource management in order to ensure the future of habitats, species, and human communities, whether that means adopting new actions or adjusting the ways in which existing actions are implemented. However, practitioners often struggle with how to identify and prioritize specific climate adaptation actions, which are taken to either increase/enhance resilience or decrease vulnerability in a changing climate. Management actions may have a higher probability of being successful if they are informed by available scientific knowledge and findings. The goal of the Available Science Assessment Project (ASAP) is to synthesize and evaluate the body of scientific knowledge on specific, on-the-ground climate adaptation actions to determine the conditions, timeframes, and geographic areas where particular actions may be most effective for resource managers. This pilot project identified fire-related adaptation actions applied by resource managers, and evaluated the science behind actions that may inform – if not improve – natural resource management.

Project Approach

There is a wide variety of climate response frameworks available to decision makers. In general, an effective framework includes: (1) identifying climate impacts and vulnerabilities of key resources; (2) defining, evaluating, and prioritizing potential adaptation actions; (3) implementing actions on the ground; and (4) monitoring progress and success towards reducing resource vulnerabilities. This project aimed to support Step 2 of such a framework by evaluating the science behind specific climate adaptation actions in order to promote the utility and use of actions that are supported by scientific evidence. The project team derived a methodology that utilizes interviews, a systematic review process, and extensive engagement with natural resource managers and scientists throughout the Northwest Climate Science Center (NW CSC) region. For a test case, we evaluated the science behind specific fire management actions in national forests in the region.

This project was conducted through a series of consecutive phases, each dependent on the results of a previous phase. In consultation with the NW CSC, **Phase 1** was designed to determine the scope and scale of this and future ASAPs by reviewing national and regional climate change strategy documents to identify the most important and oft-cited climate stressors. A review of these documents suggested that projected increases in wildfire frequency and severity were of major concern to management agencies in the Northwest. As a result, we proposed to evaluate the science behind fire-related climate adaptation actions in **Phase 2** through a content analysis of agency plans and interviews with resource managers from 32 national forests within Oregon, Washington, Idaho, and western Montana. This process included the identification of specific actions in use in regional national forests, including thinning, mechanical fuel treatments, prescribed fire, managed wildfire (or wildfire managed for multiple objectives), seeding fire-resistant species, and removal of fire-prone species. Prescribed fire was identified as the climate adaptation action used most broadly in terms of purpose and scale throughout the region. **Phase 3** utilized a hybrid approach of conducting a systematic mapping of the science behind prescribed fire and convening a Science Advisory Panel review workshop. **Phase 4** consisted of outreach on the project, including a workshop to engage scientists and managers in discussions about fire and fuels treatments in a changing climate, as well as a self-evaluation of the processes used throughout the project, including lessons learned and next steps. The emphasis of the project was to develop, test, and evaluate a process for conducting ASAP reviews with Phases 2 and 3 serving as the test cases.

Findings on Prescribed Fire and Climate Change

Prescribed fire is implemented to achieve a range of management objectives. It has been used for decades to reduce fuel loads and wildfire effects, promote more open and diverse forest structure, control conifer regeneration, maintain or increase biodiversity, and preserve defensible space around infrastructure. As a climate adaptation action, prescribed fire reduces the risk of catastrophic or stand-replacing fire by targeting and reducing surface and ladder fuels; allows for the re-introduction of natural fire regimes; and prepares the landscape for the re-establishment of fire-tolerant native species that may be better adapted to projected climatic changes and shifting fire regimes.

Content Analysis of Agency Plans and Managers' Interview Results

Prescribed fire was the top referenced action in the relevant gray literature from regional national forests (e.g., forest and fire management plans and policies), and used by 94% of managers for fire and fuels management in the region to reduce fire risk, and promote fire-resistant species (e.g., ponderosa pine, Douglas fir, western larch) and stand structure (e.g., larger trees, older stands) where appropriate, creating resilient landscapes. Managers noted that there is evidence of decreasing moisture levels, shifting fire seasons, larger and more widespread fires, and increasing disease and insect outbreaks in regional national forests, which impact current management activities and influence the persistence of critical habitat types, forest biomes, and associated ecosystem services in a changing climate. Fire and fuels management therefore requires flexibility and adaptability. Managers noted that prescribed fire has elements of flexibility in that it can be used alone or sequentially with other actions (e.g., thinning, mechanical fuel treatments), and can be applied in several different locations (i.e., wilderness, non-wilderness, Wildland-Urban Interface).

Systematic Mapping Results

The questions for the systematic literature search and screening included:

- In consideration of projected climate-driven shifts in fire regimes, what evidence is there (if any) that could potentially alter established scientific consensus regarding the use and application of prescribed fire? How might the use and application of prescribed fire evolve in response to climate change with respect to implementation conditions, techniques, time frames, scales, and locations?
- Are there any instances where the standard use and application of prescribed fire has been altered specifically in response to climate-driven shifts in wildfire regimes? If so, to what extent/in what way did implementation conditions, techniques, time frames, scales, and/or locations of prescribed fire use change?

There is limited published research directly aligned with, or designed to address, our review questions. The literature search identified studies that were mostly tangentially relevant to these questions. What can be concluded from the literature is that prescribed fire can reduce the intensity and severity of wildfire at the forest stand level. At least in some cases, this finding can probably be extrapolated to climate-related effects on wildfire to the degree that these effects can be differentiated from other human-caused effects on forests. The majority of evidence from the peer-reviewed literature suggests that the rationale and conditions for use of prescribed fire are evolving in response to climate-related shifts in fire regimes. The main issues seem to revolve around where and when to use prescribed fire, and expansion of the reasons underlying decisions to use it, rather than any significant change in how it is used. Anecdotal evidence indicates that there might be opportunity to shift the timing of its application by continuing fuel treatments beyond the traditional burn season, enabling the treatment of more areas.

Most of the relevant literature found summarized how climate change is affecting wildfire regimes and forest ecosystems, and then discussed (and sometimes tested) how established fuels reduction methods and tools, including prescribed fire, could be used to address these effects. Key themes in the relevant literature included:

- The potential for climate-driven vegetation shifts or habitat expansion, contraction, or conversion, and how these events could affect decisions about where to apply fuels treatments.
- The sociopolitical considerations of prescribed fire use in a changing climate, such as how to incorporate climate information into fire planning and management, the costs and benefits of prescribed fire, and public perceptions about prescribed fires (e.g., public aesthetics and smoke health concerns), all of which may restrict the range of management options for managers.
- How to maintain or enhance forest carbon stocks or "carbon carrying capacity" via fuels treatments, including prescribed fire. Western forests currently sequester nearly 100 million tons of carbon each year, but this sink is threatened by predicted increases in wildfire area burned and severity. The literature provides little apparent consensus regarding the potential for active forest management to significantly affect this carbon sink. Findings vary widely depending on spatial and temporal scope of analysis and model assumptions regarding future wildfire probabilities, severity, and extent.

Science Advisory Panel Results

The Science Advisory Panel assessed the project approach and systematic mapping findings, suggested additional literature, and provided expert input on the science on and key research needs for prescribed fire and climate change. The panel largely concurred with the results of the systematic literature, screening and review, but noted that prescribed fire is used for a wide variety of objectives and that there is likely more evidence for some objectives than others. This likely complicated our efforts to locate and assess science explicitly linking prescribed fire and climate change. They therefore recommended simplifying the review question to "What scientific evidence is there (if any) that the objectives for and application of prescribed fire may change with respect to climate-driven shifts in fire regimes?" The panel discussed and identified where there was confidence in the scientific consensus on these objectives. For example, prescribed fire uses with consensus include reducing or maintaining surface fuel loads and reducing stand density and ladder fuels to alter fire intensity; uses without consensus include facilitating fire regime shifts at different elevations and moderating the frequency and extent of large wildfires. The science advisors also suggested areas of research and keywords that might yield additional relevant information, such as terms that might uncover older literature or papers that address climate change and adaptation, but without using those terms.

Scientists-Managers Workshop Results

Thirty-six participants from 30 organizations attended the final workshop in April 2016, including representatives from federal and state agencies, tribal governments, and non-profit organizations, as well as academic and applied scientists. Participants were invited to comment on the ASAP methods and discuss how the literature findings correlated to managers' experiences with prescribed fire, in addition to collaboratively identifying key research and management needs and opportunities for all of the fire-related climate adaptation actions.

Participants indicated that managers are already modifying their use of prescribed fire in responses to changing conditions, such as earlier spring burn windows, reduced snowpack, and phenological shifts in vegetation. However, the scale and scope of prescribed fire use is currently limited by both institutional and sociopolitical constraints, such as a lack of funding and trained staff, liability issues, and public acceptance of smoke, which will likely remain significant challenges in the future. Participants noted some concerns regarding how prescribed fire could continue to garner ecological and sociopolitical benefits in a changing climate, and if altered treatment windows may force a shift away from prescribed fire as a management tool. Opportunities for improving the use of prescribed fire in a changing climate were discussed, including increasing collaborative agreements on prescribed fire application across land management agencies, increasing the amount and flexibility of funding streams (e.g., burn windows do not always match the funding cycle), prioritizing burn times during periods of higher moisture (e.g., wait for forecasted rain, higher humidity, etc.), maintaining fire on the landscape when possible, and altering the public perception of the role of fire on the landscape.

Several themes emerged with respect to critical research and management needs related to fire and fuels management and climate change: (1) existing management frameworks complicate the effective integration of climate science; (2) additional research is needed to fill knowledge gaps on how climate change may affect all of the fire-related climate adaptation actions, especially with respect to public health and safety and liability issues; (3) additional research is needed to inform the effectiveness of fire and fuels treatments; and (4) effective science delivery to managers is constrained by communication barriers, access, time, and funding.

Findings on the ASAP Methodology

The ASAP process has the potential to provide a replicable model for science-based evaluations that can be applied to varying topics, scales, and sectors, and by many agencies and other interested parties. The methodology directly supports the mission of the U.S. Department of the Interior's Climate Science Centers to provide science to support climate adaptation.

This project was primarily focused on learning more about potential approaches to identifying and assessing the science behind specific climate adaptation actions – in this case, the use of prescribed fire in a changing climate. The approach used in Phase 2 successfully helped the project team to identify specific climate adaptation actions recommended in management plans and policies and implemented on the ground by resource managers. In Phase 3, we explored the use of a hybrid process that combined a systematic literature search and mapping process with a Science Advisory Panel workshop wherein subject matter experts commented on the initial results of our literature search and provided insight on the "state of science" on prescribed fire. This phase was conducted under a very compressed timeline, compared to the time typically required to conduct a robust systematic review. The convening of a Science Advisory Panel helped to address some of the challenges that arose from developing and applying explicit criteria (e.g., keyword search terms) to delineate the scope of the review on such a complex, multi-faceted issue. For example, the panel indicated that the process the project team applied represented the state of knowledge on prescribed fire and climate change reasonably well, but also suggested searching other relevant subject matter areas, including the broader fuels reduction and wildfire literature (as opposed to just prescribed fire) as well as climate change impacts on forests. Therefore, there may be additional relevant but diffusely distributed information in the literature on prescribed fire use, fuels reduction, wildfire, and climate change that to date has not been rigorously synthesized, which is a future area of research.

Key lessons learned from this pilot project to improve future ASAPs include:

- **Ground the project with input from managers.** Key to the success of this project was the direct engagement and consultation with resource managers through interviews, informal conversations, and a workshop. Managers provided a level of detail and context that would not have been possible through a content analysis of the literature alone. Generating and promoting "actionable science" – science that can effectively support climate-informed decision-making (Beier et al. 2015) – means that managers need to be engaged and consulted.
- **Engage science experts throughout the project.** The feedback received from the fire science experts during the Science Advisory Panel workshop was helpful in terms of validating the project approach and methods, and refining the review protocol and questions. Engaging with scientists from the beginning of future ASAPs through more formal structures, such as advisory committees, will benefit future projects by building off of scientists' knowledge and experience in a collaborative, efficient, and effective manner. In this pilot project, for example, complementing the systematic mapping with an expert panel provided significant benefits in focusing the review question, expanding the bounds for the literature search, and finding additional literature that the systematic search did not uncover.
- **Using a systematic mapping approach.** A key challenge of this project was identifying criteria that explicitly defined the scope of directly relevant literature with respect to prescribed fire use and climate change, and how to partition off that which did meet these criteria. Our primary literature inclusion criterion was that the publication had to explicitly link climate change (or closely related term, e.g. global warming) with prescribed fire (or closely related term, e.g. prescribed burn) in some way. A traditional systematic review focuses on identifying evidence to

determine the effectiveness of a specific intervention to address a particular problem. Systematic mapping follows the same process and rigor of systematic reviews but instead illustrates the current state and trajectory of knowledge around a particular issue. This approach allows for the discovery of a considerable amount of relevant evidence from the literature as well as the ability to highlight important themes from the collection of studies.

- **Gathering scientists and managers in workshops to facilitate information exchange.** During the systematic mapping, we uncovered anecdotal evidence that managers are taking advantage of reduced snowpack and earlier spring runoff by continuing fuel treatments beyond the traditional burn season. Similar shifts in seasonality of prescribed fire use are likely more widespread than we detected in our survey of primarily peer-reviewed research. This illustrates the advantages of supplementing systematic mapping with workshops that bring scientists and managers together, where it is likely that more evidence and knowledge regarding such practices could be revealed. We added a scientists-managers workshop, *The Future of Fire and Fuels Management: Adapting Fuels Treatments in a Changing Climate*, to the project in order to convene managers and scientists for broader discussions regarding fire and fuels management in the context of climate change, and to gather additional information not currently represented in the literature.

The purpose of this report is to describe and highlight salient features and results of the pilot ASAP. The recommendations presented herein are meant to stimulate discussion, and are not considered by the project team to be definitive or prescriptive in nature.

Introduction

Background and Project Purpose

The ecological, social, and economic impacts of climate change are being experienced worldwide, and decision makers at all levels are faced with choices about how to avoid, minimize, and/or reduce these impacts. Whether or not these impacts are sudden and catastrophic, or slow and chronic, they are requiring that we reconsider many actions, including conservation and resource management tactics that have been successfully used in the past. They also warrant asking whether the science behind conservation and resource management actions of the past adequately supports their usefulness under the new conditions imposed by climate change.

There are two general responses to climate change – mitigation and adaptation. *Mitigation* refers to efforts to reduce greenhouse gas emissions or increase carbon storage potential (e.g., planting trees and vegetation that can absorb carbon) (IPCC, 2014a). *Adaptation* refers to efforts to respond to and prepare for the changes we are already experiencing and/or expect to experience (IPCC, 2014b); this includes both reducing negative effects and taking advantage of potential opportunities afforded by climate change. More specifically, a "climate adaptation action" is any action taken to either increase/enhance resilience or decrease vulnerability in a changing climate. Traditional management actions that explicitly incorporate climate change considerations and aim to alleviate the impacts of climate change by increasing resilience and/or decreasing vulnerability are considered climate adaptation actions. These actions may be anticipatory or responsive; autonomous or planned; and short-term or long-term.

In addition, numerous federal and state statutes call for using the "best available science" to inform natural resource decision making, and stakeholders consistently agree that the best available science may improve the quality of management decisions. Several factors, however, continue to present challenges to natural resource management:

- Managers frequently struggle with how to identify and prioritize specific climate adaptation actions;
- There is an ongoing disconnect between *producing* science and *using* science;
- There are conflicts over what is and is not "good" science and the selective use of studies with different conclusions by competing interest groups; and
- There are questions as to whether or not on-the-ground management actions rely on or are backed up by scientific and research evidence.

These issues point to needing and using a method of synthesizing technical information that relates to particular natural resource management questions or actions in a way that will be more readily accepted as both objective and actionable; a systematic review process provides a mechanism to accomplish this. By evaluating scientific knowledge and findings related to specific management actions, we may be able to increase management effectiveness and efficiency. The goal of the ASAP was to synthesize and evaluate the body of scientific knowledge on specific, on-the-ground climate adaptation actions to determine the conditions, timeframes, and geographic areas where particular actions may be most effective for resource managers. For a test case, we evaluated the science behind specific fire-related climate adaptation actions in Northwest national forests. The emphasis of the project was on developing a process to conduct future ASAP reviews.

Project Approach

The project was conducted through a series of four consecutive phases, each dependent on the results of a previous phase. In consultation with the Northwest Climate Science Center (NW CSC), Phase 1 was designed to determine the scope and scale of ASAPs by reviewing national and regional climate change strategy documents to identify the most important and oft-cited climate stressors. Our preliminary review of these documents suggested that projected climate-induced changes to fire regimes in the Northwest were a major concern to management agencies. As a result, we proposed to evaluate the science behind fire management in national forests in the NW CSC region. In Phase 2, we utilized a content analysis of fire-related forest plans and resources as well as interviews with resource managers, resulting in the identification of specific fire-related climate adaptation actions in use in regional national forests. This phase also identified prescribed fire as the climate adaptation action used most broadly in terms of purpose and scale throughout the region. Based on this prioritization, we took a hybrid approach of conducting a systematic review/mapping of the scientific evidence supporting the use of prescribed fire, followed by an expert Science Advisory Panel workshop (Phase 3). Phase 4 consisted of a self-evaluation of the processes used throughout the project. The project team also hosted a workshop to engage scientists and managers in discussions about fire management and fuels treatments in a changing climate.

The emphasis of the project was to develop a process for conducting future ASAP systematic reviews – with Phases 2 and 3 serving as the test cases. We limited the scope of the project to specific fire management actions in 32 national forests within the NW CSC region – Oregon, Washington, Idaho, and western Montana (Figure 1).

Figure 1. The geographic region served by the Department of the Interior NW CSC.
(Stars show host location and primary academic partner institutions.)

Key Collaborators

The ASAP team worked with key collaborators throughout the project including the NW CSC staff and members of the NW CSC Executive Stakeholder Advisory Committee (ESAC); key informants in the United Kingdom and Arizona who have recognized expertise in systematic evidence review processes; fire scientists and managers who helped us to explore the scope of the project as it related to fire management and climate adaptation actions, national forests, and additional considerations the project team needed to consider; and a Science Advisory Panel. These key collaborators helped to guide the development of an appropriate and documented search protocol; and identify and address any anticipated challenges as early in the process as possible.

Purpose and Organization of the Report

The purpose of this report is to describe and highlight salient features and results of the piloted ASAP. Sections 1 – 3 correspond with each phase of the project, presenting the approaches and results of defining the issues, scope, and framing for ASAP systematic reviews (Section 1); identifying, prioritizing, and selecting specific fire management-related climate adaptation actions around which to develop a systematic review process (Section 2); and conducting a systematic review/mapping of the science behind prescribed fire (Section 3). Section 4 presents integrated conclusions about the work, a self-assessment of the project, and suggestions for future ASAPs. Section 5 presents discussions from the scientists-managers workshop held in April 2016.

The recommendations presented in the report are meant to stimulate discussion, and are not considered by the project team to be definitive or prescriptive in nature for the NW CSC and other stakeholders. The appendices provide the background documents, making the entire project more transparent.

1. Identifying Climate Stressors

1.1 Introduction

The Northwest United States (here defined as Idaho, Oregon, Washington, and western Montana) is well-known for ample rainfall, snow-packed mountains, old-growth forests, sagebrush shrublands, salmon- and trout-laden streams, and large hydroelectricity-producing rivers. Climate change threatens these iconic Northwest features, as projected rising temperatures and changes in precipitation patterns combine to create anomalous conditions across the region. Natural and cultural resource managers from federal, state, and tribal agencies are already seeing the effects of climate change on the lands, habitats, and species that they manage and are struggling with prioritizing conservation or restoration actions.

The NW CSC was created by the U.S. Department of the Interior (DOI) to address the challenges presented by climate change in managing cultural and natural resources in the Northwest. The center's mission is to provide federal, state, and tribal resource managers with the scientific information, tools, and techniques they need to anticipate, monitor, and adapt to climate change. To that end, the NW CSC receives input on the scientific and management needs of regional stakeholders and supports research activities that produce actionable science to meet those needs. The NW CSC's main guiding body is its ESAC, comprised of 23 representatives from DOI bureaus, other federal agencies, four states, three tribal organizations, and three regional Landscape Conservation Cooperatives. In conversations with the ESAC over the past several years, the NW CSC heard three requests in regards to providing actionable science:

1. identify and prioritize the most pressing climate stressors and impacts in the Northwest,
2. develop a repository of on-the-ground climate adaptation actions, and
3. synthesize available scientific data, model, and/or literature to help support the use of particular climate adaptation actions for specific resources, timeframes, or geographies.

The ASAP was born from these requests. The NW CSC intends to repeat the process developed in this ASAP pilot project several times in the coming years. As there are many climate stressors of concern in the Northwest and potentially hundreds of adaptation actions in use by managers, a method to narrow down and aggregate both climate stressors and adaptation actions was required to produce the most useful products to managers.

1.2 Approach/Methods

Many resource management agencies have been tasked in recent years with developing strategies to manage natural and cultural resources in the face of climate change. New strategies are being released regularly; some are broad, general, and applicable to the entire United States, while others are narrowly focused on, for example, individual forests or river basins. These strategies can differ in a number of ways: the conceptual hierarchy and terminology used; the focus on partnerships and capacity building vs. science-based decision making and management actions; or how specifically they describe on-the-ground climate adaptation actions that may be useful in a particular situation or geography. However, a trait shared by most of these documents is a description of the climate change stressors and impacts of greatest concern to the ecosystems or resources that need to be managed.

We used a two-step approach to select climate stressors to focus on for ASAP reviews:

1. **Collect, review, and catalog representative national and regional climate change strategy documents** written by federal, state, tribal, and non-governmental agencies that manage natural and/or cultural resources in the United States. Climate change strategy documents provide agencies' broad view of climate-induced risks to resources managed under their authority, as well as their goals and objectives for managing those resources under climate change. Documents were discovered through Google web searches, EcoAdapt's Climate Adaptation Knowledge Exchange (CAKE), news releases from Department of the Interior bureaus, and periodic federal and tribal newsletters. Documents were catalogued with meta-information, including title, agency, publication date, executive summary, location focus, resource focus, and web URL (Appendix A).
2. From these climate change strategy documents, **identify climate change stressors and impacts to be addressed by the agencies' strategies and action plans.** Those stressors and impacts most commonly referenced and described as being of high importance to management activities in the Northwest are top candidates to consider for future ASAP systematic reviews. Vetting and prioritization of these will be done with assistance from the NW CSC ESAC.

1.3 Findings

A review of 25 national, regional, and local climate change strategy documents (Appendix A) identified seven climate change stressors or impacts as the most frequently cited:

- **Increased wildland fire frequency/severity.** Increased wildland fire frequency and severity was cited by a majority of climate change strategy documents as being a high concern and major challenge under future climate scenarios. As air temperatures increase and summer soil moisture levels decrease, the probability of wide-spread, catastrophic wildfires continues to rise. While wildland fire is a natural part of many healthy, functioning forest, shrub, and grassland ecosystems, anomalous "mega-fires" can destroy important habitat areas, increase soil erosion and sediment load into streams, and create major public health problems.
- **Reduced snowpack (and subsequent changes in water supply).** The most challenging risks to Northwest water supplies posed by climate change include reductions in snowpack, changes in timing and volume of rainfall and runoff, changes in groundwater recharge and discharge, and changes in water demand and consumption within Northwest river basins. These changes will have major ramifications for ecosystems, fish, wildlife, and human communities throughout the region.
- **Sea level rise.** While sea levels are not rising uniformly in the Northwest, areas of both Oregon and Washington can expect higher sea levels that threaten to drown coastal wetlands by the end of the century. Loss of coastal habitat will threaten numerous plant and animal species, as well as the human communities that rely on coastal ecosystems for economic or cultural well-being.
- **Increased frequency and intensity of extreme events (e.g., floods, droughts, heat waves).** Increasing air temperatures, diminishing snowpack, and reduced summer soil moisture are expected to increase the frequency and severity of droughts across the western United States.

The Northwest is already experiencing these conditions: as of August 2015, 100% of land area in Oregon and Washington, 48% in Idaho, and 24% in Montana (all in western Montana) is currently in severe or extreme drought status. These conditions affect over 12 million people in the region (source: U.S. Drought Monitor). Flood risks are expected to increase as more precipitation falls as rain than snow, and projected longer, more intense heat waves will challenge public health agencies.

- **Increased spread and damage from invasive species, pests, and pathogens.** Invasive species, pests, and pathogens already cause extensive environmental and economic damage in the Northwest; warmer temperatures will allow many weeds, pests, and pathogens to expand their ranges and increase the probability of surviving through the winter.
- **Degraded stream habitat (e.g., warmer water temperatures).** Cold-water native salmon and trout are iconic species of the Northwest, however, their persistence under future warming scenarios is severely threatened by warm water temperatures and degraded stream habitat (e.g., increased sediment inputs).
- **Habitat loss and fragmentation.** While not a climate change impact *per se*, the breaking up of habitat into smaller units was cited many times in climate change strategy documents as an impediment to fish and wildlife conservation under future climate scenarios. Creating habitat corridors for wildlife movement and migration is of utmost priority to wildlife managers, as these will allow species to explore and settle in new climatically-suitable habitats in the coming decades.

1.4 Discussion

While there are many variations and nuances to the climate stressors and impacts described above, and every management agency has a different mission and geographic and resource foci, these seven themes represent the broad swath and complexity of challenges facing natural and cultural resource managers in the Northwest. The current ASAP tackles the first climate change impact identified through the Phase 1 process: increased wildland fire frequency/severity. Future ASAPs will focus on the other six stressors and impacts using the process developed through this pilot project.

2. Identifying Climate Adaptation Actions

2.1 Introduction

Climate change is having wide-ranging effects on ecosystems, ecosystem services, and human communities throughout the Northwest, creating major conservation and management challenges and forcing a paradigm shift in decision making. Practitioners may need to adopt new actions or adjust the ways in which existing management actions are implemented. These decisions are compounded at local-to-subregional scales because Northwest communities and ecosystems have been subject to varied land use and ownership histories and management objectives, which may influence vulnerability to current and projected climatic effects.

The purpose of the second phase of this project was to achieve a better understanding of the range of climate adaptation actions being prioritized and implemented on the ground in response to a defined climate stressor/management issue at a particular scale; for this pilot project, we selected to look specifically at those actions being used by national forest resource managers in response to fire. Changes in fire regimes emerged as one of the key climate stressors of concern in the Phase 1 climate change strategies review and was described as a high concern and pressing management challenge by the NW CSC ESAC.

Climate change is projected to exacerbate fire regimes in terms of severity, frequency, extent, and size, causing significant changes to forested ecosystems and the fish, wildlife, and human communities that depend on them. The USDA Forest Service has committed to incorporate these and other climate change impacts and adaptation options into their management goals and objectives through two mechanisms – the 2012 National Forest System Land Management Planning Rule and the Climate Change Performance Scorecard (USDA Forest Service, 2011, 2012). The Planning Rule requires all 155 national forests, 20 grasslands, and one prairie under the Forest Service's purview to explicitly consider climate change in the development, amendment, and revision of all land management plans (77 FR 21161); as a result, several vulnerability assessments and adaptation planning projects are underway throughout the Northwest region. Each forest is also required to complete the Scorecard annually; this self-evaluation allows individual forests to appraise internal organizational capacity to assess and reduce climate vulnerability through adaptation planning.

Climate Change, Forests, and Fire

The USDA Forest Service's mission is to "sustain the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations." The national forests of the Northwest region support a variety of habitats and species, and provide key ecosystem services, such as clean air and water, carbon storage and nutrient cycling, and recreation. Projections for the future of Northwest forests range from widespread expansion to dieback to significant forest community composition shifts, depending on the effects of climate change.

Temperature, precipitation, and water supply all combine to affect vegetation productivity and type, moisture levels, and fire regime characteristics in regional forests. Over the last century, average annual temperatures have increased nearly 1.3˚F in the Northwest; projected changes include an increase in average annual temperatures by 3.3-9.7˚F by 2070-2010 with the largest increases expected during the summer (Mote et al., 2014). Over the last 50 years, the region has experienced a 12% increase in heavy precipitation events (Walsh et al., 2014), although observed regional precipitation trends cannot be considered statistically significant (Mote et al., 2014). Despite some uncertainty in climate models with respect to projected regional precipitation changes, there is consensus that summer precipitation will decrease by as much as 30% by 2100 (Mote et al., 2014); drier summers typically manifest in reduced streamflows and increased wildfire risk across the landscape (Littell et al., 2010). Water shortages also drive increased moisture stress, tree mortality, and fuel flammability in forests. These changes, coupled with climate-driven shifts in forest species and types, are complicated by the cumulative effects of wildfire, insect outbreaks, and tree disease, which have caused widespread die-offs in regional forests (Mote et al., 2014). Projections indicate an increased risk of wildfires and area burned under changing climate conditions, although the extent of this risk varies based on local factors, such as fuel composition and quantity, land use patterns, and management efforts (Figure 2).

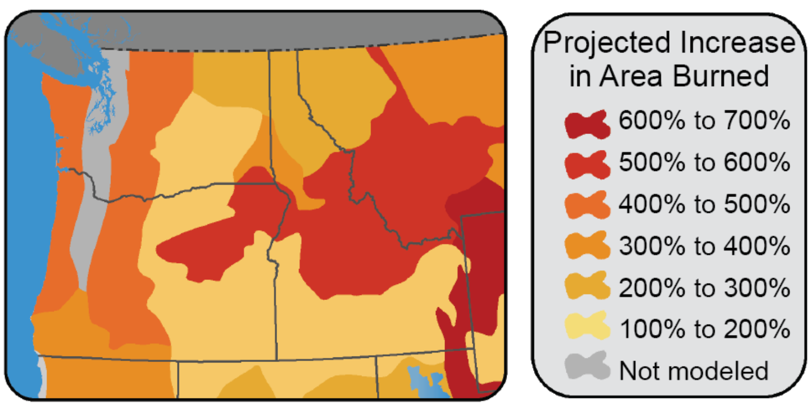

Figure 2. Map of projected increases in area burned with a 2.2˚F overall increase in temperature in the Northwest (adapted from Figure 21.7 in Mote et al. 2014).

2.2 Approach

Our approach for Phase 2 included identifying fire-related climate adaptation actions; categorizing these climate adaptation actions in forest and fire management plans and policies; and cross-referencing the primary actions found in the literature with interviews with fire managers in select regional forests (Table 1).

Table 1. Thirty-two national forests located within the four states comprising the NW CSC region.	
State	*National Forests*
Washington	Colville National Forest Gifford Pinchot National Forest Mount Baker-Snoqualmie National Forests Okanogan-Wenatchee National Forest Olympic National Forest
Oregon	Deschutes National Forest Fremont-Winema National Forest Malheur National Forest Mount Hood National Forest Ochoco National Forest Rogue River-Siskyou National Forest Siuslaw National Forest Umatilla National Forest Umpqua National Forest Wallowa-Whitman National Forest Willamette National Forest
Idaho	Boise National Forest Caribou-Targhee National Forest Idaho Panhandle National Forests (Coeur d'Alene, Kaniksu, and St. Joe) Nez Perce-Clearwater National Forest Payette National Forest Salmon-Challis National Forest Sawtooth National Forest
Montana	Beaverhead-Deerlodge National Forest Bitterroot National Forest Custer National Forest Flathead National Forest Gallatin National Forest Helena National Forest Kootenai National Forest Lewis and Clark National Forest Lolo National Forest

Fire-related Climate Adaptation Actions

Because climate change is projected to affect fire frequency, severity, and extent across much of the western United States (Westerling et al., 2006), forest managers are being required to evaluate and modify their fire and fuels management activities (Bollenbacher et al., 2013; Peterson et al., 2011b). Many climate adaptation actions related to wildfire were identified in our review of peer-reviewed and grey literature, including: thinning, mechanical fuel treatments, prescribed fire, wildfire managed for multiple objectives (hereafter referred to as "managed wildfire"), seeding fire-resistant species, and removal of fire-prone species (Table 2). Many of these actions are currently implemented by resource managers across the Northwest to accomplish a variety of management goals and objectives (Raymond et al., 2014). However, these actions can also be leveraged to enhance forest resilience to wildfire and other climate change impacts (Kershner et al., 2015; Peterson et al., 2011a; Raymond et al., 2014).

Fire-related climate adaptation actions can be used across different time horizons and to meet a variety of different goals. They also represent several different common adaptation approaches (Kershner and Gregg, 2013) (Table 2):

- Resistance strategies: prevent the effects of climate change from reaching or affecting a resource.
- Resilience strategies: help a resource weather the impacts of climate change by avoiding the effects or recovering from changes.
- Response strategies: intentionally accommodate change and enable resources to adaptively respond to changing conditions.
- Realignment strategies: revisit and revise underlying goals and priorities based on new conditions.

Adaptation actions may be explicitly implemented in response to identified climate vulnerabilities, or be implemented in new ways to adapt to changing conditions. For example, aside from generally managing for more fire-tolerant species (Bollenbacher et al., 2013), managers may choose to alter where, when, and how an action is implemented to more specifically target climate-driven wildfire impacts and vulnerabilities on a given landscape. This could include choosing to use fire-adapted species in restoration efforts (Scott et al., 2013), thinning more frequently to reduce fire vulnerability and enhance resilience of remnant trees, or implementing actions in novel places on the landscape based on projected future vulnerability (Peterson et al., 2011a, 2011b). Further examples of how these management actions can be leveraged to minimize wildfire vulnerability under changing climate conditions are described below.

Thinning

Thinning is defined as reducing forest density by cutting and/or physically removing vegetation from the landscape. Thinning has several relevant climate implications (Kershner et al., 2015). Thinning can reduce fuel continuity and biomass, including both ladder and surface fuels, which limits potential fire spread and severity (Kershner et al., 2015; Peterson et al., 2011a, 2011b; Spies et al., 2010). Thinning can also be designed and utilized to increase forest heterogeneity at both the stand and landscape scale through altering stand density, species composition, and size classes (Spies et al., 2010). Heterogeneous forests are typically more resilient to fire and other stressors, such as insect infestations, disease, and drought (Bollenbacher et al., 2013; Scott et al., 2013; Spies et al., 2010). Thinning can also improve the health and vigor of remaining trees, which enhances their resilience to disturbances, including wildfire (Kershner et al., 2015; Scott et al., 2013; Swanston and Janowiak, 2012).

Prescribed fire

Prescribed fire is defined as intentional artificial ignition and subsequent management of fire on the landscape. Prescribed fire is used to meet many different forest management objectives (Scott et al., 2013), but it also has relevance for climate change adaptation (Kershner et al., 2015). Prescribed fire can be used to reduce fuel biomass (Gaines et al., 2012), reducing risk of future catastrophic fire (Kershner et al., 2015; Peterson et al., 2011b; Spies et al., 2010; Swanston and Janowiak, 2012). Reducing fuel biomass

Table 2. Fire-related climate adaptation actions.			
Climate Adaptation Action	*General Description*	*Climate Adaptation Relevance*	*Goals and Timeframes*

Thinning	Reducing forest density by cutting and/or physically removing vegetation from the landscape
	
	• Relevant Practices[1]: commercial and pre-commercial thinning,[2] daylighting,[3] improvement cuts,[4] regeneration practices,[5] salvage[6]
		• Resistance strategy:
		  • Reduces fire risk by reducing fuel quantities and disrupting fuel continuity (i.e., surface and ladder fuels)
		• Resilience strategy:
		  • Increases stand heterogeneity, increasing overall stand and landscape resilience to fire
		  • Improves growing conditions and health/vigor of fire-resistant species, increasing individual tree and overall landscape resilience to fire
			• Anticipatory action: prepares the landscape for climate-driven changes in fire regimes
			
			• Short-term strategy: can be implemented short-term to reduce immediate risk
			• Long-term strategy: can be implemented as long-term resilience strategy and/or as part of broader, climate-informed fuels management strategy

Mechanical Fuel Treatments	Using machines to physically remove dead, downed, and other fuels from the landscape	• Resistance strategy: • Reduces fire risk by reducing fuel quantities and disrupting fuel continuity (i.e., surface and ladder fuels)	• Anticipatory action: prepares the landscape for climate-driven changes in fire regimes

[1] Relevant practices for each climate adaptation action were identified via the peer-reviewed literature; definitions for each practice were derived from several USDA Forest Service glossaries (USDA Forest Service, 2015).
[2] Commercial/Pre-Commercial Thinning: Reducing existing tree density to a target residual density. Typically includes retention of desired species (e.g., fire-resistant, shade-intolerant tree species).

[3] Daylighting: Removing vegetation adjacent to a target tree to increase tree growth and vigor by reducing immediate competition.
[4] Improvement Cuts: Treatments conducted to remove trees of undesirable species, form, age or condition and improve overall stand condition.
[5] Regeneration: Various treatments (e.g., to increase forest stand health and resilience (i.e., by removing disease-prone individuals, maintaining fire-resistant and/or old-growth tree reserves)
[6] Salvage: Removal of dead, dying, or damaged trees.

	• Relevant practices: Thinning, pruning[7]	• Manipulates fire behavior and spread (i.e., can be used to protect valuable resources) • Resilience strategy: • Increases stand heterogeneity, increasing overall stand and landscape resilience to fire • Improves growing conditions and health/vigor of fire-resistant species, increasing individual tree and overall landscape resilience to fire	• Responsive action: can be used to protect critical resources during fire event • Short-term strategy: can be implemented short-term to reduce immediate risk • Long-term strategy: can be implemented as long-term resilience strategy and/or as part of broader, climate-informed fuels management strategy
Prescribed fire	Intentional artificial ignition and subsequent management of fire on the landscape • Relevant Practices: pile burning,[8] broadcast burning[9] (wilderness & non-wilderness, various ignition methods)	• Resistance strategy: • Reduces risk of catastrophic or stand-replacing fire by targeting and reducing surface and ladder fuels • Resilience strategy: • Allows for re-introduction of natural fire regimes on the landscape • Prepares seedbed for planting and/or natural re-seeding of fire-resistant species	• Anticipatory action: prepares the landscape for climate-driven changes in fire regimes • Short-term strategy: can be implemented short-term to reduce immediate risk • Long-term strategy: can be implemented as long-term resilience strategy and/or as part of broader, climate-informed fuels management strategy
Managed wildfire	Allowing naturally ignited fires to burn on the landscape, but actively managing fires (i.e., controlling burn path and	• Resilience strategy: • Regulates forest density and fuel conditions and build-up, preventing uncharacteristic forest conditions and minimizing future risk of catastrophic or stand-replacing wildfire	• Responsive, but anticipatory, action: occurs only with natural fire event, but prepares the landscape for climate-driven changes in fire regimes

[7] Pruning: Removal of lower tree branches to minimize ladder fuels.
[8] Pile burning: Burning of fuels that have been gathered into distinct piles with no fuel connectivity to other piles.
[9] Broadcast burning: Prescribed burns that occur over large(r) areas in both wilderness and non-wilderness. Can include aerial and hand ignition.

	extent) to protect areas of concern (i.e., structures, no-burn areas) • Relevant Practices: wildland fire use[10]	• Facilitates return of landscape to historical fire-resilient structure and composition • Prepares seedbed for planting and/or natural re-seeding of fire-resistant species	• Long-term strategy: will take time to fully implement due to current landscape condition and current policy challenges

Seeding fire-resistant species	Artificially planting and/or creating ideal conditions for natural regeneration of fire-resistant species
	
	• Relevant Practices: reforestation,[11] regeneration treatments, fill plant,[12] improvement cuts, prescribed burning
		• Resilience and Response strategy:
		  • Manipulates species and stand composition to increase stand and landscape resilience to fire
		• Realignment strategy
		  • Becomes a realignment strategy if fire-resistant species are different than historical forest composition
			• Anticipatory action: prepares the landscape for climate-driven changes in fire regimes
			
			• Long-term strategy: can be implemented in the short-term, but due to tree growth times, may take time for benefits to be realized

Removal of fire-prone species	Targeted selection and removal of tree species and/or individual trees that are vulnerable to fire
	
	• Relevant Practices: improvement cuts, regeneration practices, commercial/pre-commercial thinning, salvage
		• Resilience and Response strategy
		  • Manipulates species and stand composition to increase stand and landscape resilience to fire
		• Realignment strategy
		  • Becomes a realignment strategy if fire-prone species represent historical forest composition
			• Anticipatory action: prepares the landscape for climate-driven changes in fire regimes
			
			• Short-term strategy: can be implemented short-term to reduce immediate risk
			• Long-term strategy: can be implemented as long-term resilience strategy to accommodate changing conditions

[10] Wildland fire use: Managing naturally ignited wildfires to achieve natural resource objectives.
[11] Reforestation: Increasing amount of vegetation on the landscape via natural regeneration (i.e., tree reproduction, seeding, and growth) and artificial (i.e., hand-planting) methods.
[12] Fill plant: Planting of trees in previously treated areas to supplement and meet reforestation/regeneration goals and achieve target stand densities.

also allows the re-introduction of natural fire regimes to forested landscapes (Kershner et al., 2015; Swanston and Janowiak, 2012), which can promote regeneration of fire-tolerant species and enhance stand and landscape diversity (Peterson et al., 2011a; Swanston and Janowiak, 2012). Prescribed fire can be also used to create forest conditions ideal for regeneration, including re-establishment of fire-tolerant native species or planting a suite of species or genotypes that are better adapted to projected future climate and fire conditions (Peterson et al., 2011a; Spies et al., 2010; Swanston and Janowiak, 2012).

Managed wildfire

Managed wildfire is defined as allowing naturally ignited fires to burn on the landscape while actively managing those fires (i.e., controlling burn path and extent) to protect areas of concern (i.e., structures, no-burn areas). Similar to prescribed fire, allowing natural fires to run their course on the landscape reduces and regulates fuel biomass and continuity, reducing the likelihood of future catastrophic fire events (Bollenbacher et al., 2013; Peterson et al., 2011b; Spies et al., 2010; Kershner et al., 2015). Natural burns also help restore historical fire-resilient structure and composition by promoting ecological and structural diversity across the landscape (Peterson et al., 2011a; Spies et al., 2010; Swanston and Janowiak, 2012). Resource managers can capitalize on the early successional conditions created by natural fires to establish a suite of species that will be resilient to future fire events and climate conditions (Peterson et al., 2011a; Spies et al., 2010). Managed wildfire is often controversial, but it may be feasible in certain situations, particularly if it aligns with other landscape management objectives and if there is minimal risks to human life and property (Bollenbacher et al., 2010).

Seeding fire-resistant species

Seeding fire-resistant species is defined as artificially planting and/or creating ideal conditions for natural regeneration of fire-resistant species. Planting fire-adapted species may enhance overall stand and landscape resilience to fire (Kershner et al., 2015; Peterson et al., 2011a, 2011b; Swanston and Janowiak, 2012) and minimize overall losses and management costs during future fire events (Peterson et al., 2011b). Seeding fire-resistant species can be paired with restoration efforts (Scott et al., 2013), including in recently burned landscapes, but can also be integrated with other management projects, such as timber plantings and wildlife habitat management activities, or designed as a stand-alone management strategy (Spies et al., 2010).

Removal of fire-prone species

Removal of fire-prone species is defined as targeted selection and removal of tree species and/or individual trees that are vulnerable to fire. This may include targeting fire-prone species, or targeting smaller individuals of fire-tolerant species to enhance the resilience of larger individuals (Peterson et al., 2011b). Removing fire-prone species and individuals can increase stand and landscape resilience to fire (Peterson et al., 2011a, 2011b), and often occurs concurrently with other management actions listed above.

Adaptation Actions in the Gray Literature

After identifying common fire-related climate adaptation actions, staff compiled relevant gray literature from the regional national forests (e.g., forest management plans, fire management plans and policies, climate change strategy documents) written between 1986 and 2015, and categorized the ways in which the aforementioned fire-related climate adaptation actions appear in these documents. We located and categorized 109 documents of relevance (Table 3).

Table 3. Categories and types of relevant documents found.

Categories and types	*Number of documents*
Plans and policies	
– Forest plans & revisions	29
– Fire management plans	15
– Land and resource management plans	8
– Strategy/Strategic plan	6
– Climate change action plan	1
– Policy	1
Reports and handbooks	
– General Technical Report	20
– Report/manual/handbook	8
– White paper	9
Other resources	
– Journal/peer-reviewed article	5
– Tool	4
– Program and project proposals	3

A coding system was created to review and catalog how climate adaptation actions appear in each document. All of these actions are already applied within national forests under varying circumstances, so we aimed to clarify the climate relevance of each action by evaluating whether it was discussed in the context of its ability to contribute to either reducing the vulnerability or increasing the resilience of forests in the face of changing fire regimes. Each document was reviewed and scored based on a 0-2 scale with 0 indicating *no presence* of climate adaptation action(s) within the document, 1 indicating *presence* of climate adaptation action(s) within the document, and 2 indicating climate adaptation action(s) are the *focus/priority* of the document. Where possible, details regarding particular fire regime characteristics were also recorded (e.g., fire severity, frequency, size, intensity, patterns, and season).

2.3 Findings

Literature

Prescribed fire was the action most commonly referenced in the literature review from each of the national forests (Table 4). Nearly 70% of the documents reviewed referenced mechanical fuel treatments and thinning as key actions, while over half identified managed wildfire. Less referenced in the literature were seeding of fire-resistant and removal of fire-prone species.

Table 4. Scoring of fire-related climate adaptation actions in the literature (n=109).					
Prescribed fire	*Mechanical Fuel Treatments*	*Thinning*	*Managed wildfire*	*Seeding fire-resistant species*	*Removal of fire-prone (pyrophytic) species*
102.5	75.5	75	56	14.5	14

Fire size was the most commonly discussed fire regime characteristic in the literature review (Table 5). Fire intensity, frequency, and severity were also commonly discussed, while fire patterns and seasons were discussed less frequently. Twenty-eight documents explicitly linked climate change with varying fire regime characteristics; 14 documents mentioned climate change but not in the context of fire; and 51 documents did not include any mention of climate change (or global warming, changing conditions, etc.).

Table 5. Scoring of fire regime characteristics in the literature (n=109).					
Fire Size	*Fire Intensity*	*Fire Frequency*	*Fire Severity*	*Fire Pattern*	*Fire Season*
71	63	62	60	46	43

Cross-reference with fire managers

Primary actions identified in the literature were then cross-referenced with the top climate adaptation actions used by managers from select forests in the Northwest. Climate adaptation actions used by managers were identified through an interview process, which utilized an interview guide and followed all guidelines and approvals of the Oregon State University Internal Review Board for human subjects research.

Interview questions were designed to gather responses that were both consistent and comparable; a key factor here was to make the distinction between the *intention* to act and the *implementation* of an action itself. Interview questions included:

1. What are some of the ways that you/your National Forest manage for fire?
2. Have you considered climate change and how that might affect what fire actions you take?
3. Do you/your NF use or have you/your NF considered using any of the identified climate adaptation actions [i.e. thinning, mechanical fuel treatments, prescribed fire, managed wildfire, seeding fire-resistant species, removal of fire-prone (pyrophytic) species, other]?
4. What is the primary purpose of the actions you are taking (i.e. fire preparedness, fire response, climate-related changes in fire regimes, other)?
5. What is the scope of these actions? Where are they being used [i.e. wilderness, non-wilderness, Wildland-Urban Interface (WUI), other]?
6. At what scale are these actions being used (i.e. forest plan, program, project, other)?
7. Where do you get your science (e.g., literature, peers, etc.)? Do you have any specific articles or reports that you think we should review?
8. When it comes to climate change and fire, is there anything else that you think we should know? Does a synthesis or another resource(s) exist that we should know about?

This step also included interviewing a representative set of managers from regional forests. Experts were identified based on having some demonstrated interest or experience with climate change, and in whole, provided a range of expertise in fire and fuels management. Starting with a list of 125 individuals, we identified 30 managers that work in diverse settings that represent each of the national forests in the region (Table 6).

Table 6. Work-related demographics of identified managers.

Climate Relevance	*Location*	*National Forests*
27 Yes 3 No/Not sure	9 Non-wilderness 2 Wilderness 2 Wildland-Urban Interface (WUI) 17 (combinations of non-wilderness, wilderness, and/or WUI, or not applicable)	7 Idaho 8 Montana 10 Oregon 5 Washington

Of the 30 managers identified, 18 were interviewed; the map below displays these forests, which represent different geographies, habitat types, and climatic characteristics (Figure 3).

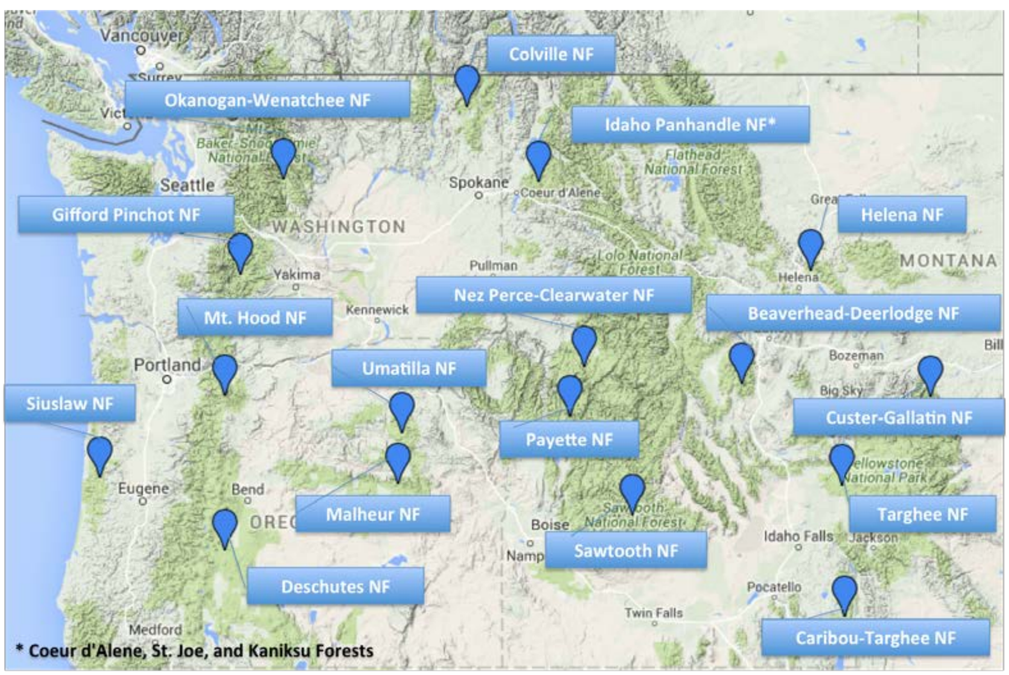

Figure 3. Locations of resource managers interviewed.

Using semi-structured telephone interviews, we surveyed the 18 selected managers to identify the range of management actions applicable to fire and the context (i.e., organizational and stakeholder values) in which the actions are chosen. Responses were documented and qualitatively coded to facilitate tracking and cross-referencing.

Manager Interviews

The majority of managers interviewed use thinning, mechanical fuel treatments, prescribed fire, and managed wildfire (or some combination of these actions) for fire and fuels management (Table 7). Seeding fire-resistant and removing fire-prone species are also used by more than half of the managers; however, according to interviewees, these actions are not broadly applied throughout the Northwest, as managers do not typically try to change the habitat types that appear on the landscape. Other actions used in the forests include:

- suppressing wildfires to protect lives and property in the WUI (e.g., Sawtooth National Forest);
- managing fuel loads by encouraging livestock grazing (e.g., Beaverhead-Deerlodge National Forest) and removing insect-prone species (e.g., Malheur National Forest);
- seeding native species to enhance stand resilience (e.g., Umatilla National Forest); and,
- building capacity through education and outreach efforts on climate change, adaptation, and living with shifting fire regimes (e.g., Okanogan-Wenatchee National Forest).

The exception is Siuslaw National Forest in which managers are not using these actions in response to fire, largely due to the mesic nature of this forest. Instead, managers are implementing restoration treatments (e.g., thinning to restore forest structure for marbled murrelet or using prescribed fire to control invasive species in the Oregon Dunes Recreation Area); these actions may have secondary effects on fuel loads in subsequent years and under a warmer and drier climate, but they are not currently monitored or designed in light of climate change or fire regime challenges.

The following results emphasize actions explicitly taken because of fire and therefore exclude Siuslaw National Forest.

Purpose for implementing actions

We asked *why* the managers implement these actions (i.e., the purposes of fire preparedness, post-fire response/managing landscapes after fire, or climate-related changes in fire regimes) and *where* the managers implement these actions (i.e., wilderness, non-wilderness, or the Wildland-Urban Interface). Understanding the purpose and location of adaptation action implementation, and whether managers have leeway in altering these parameters, can facilitate and inform adaptive management in the context of climate change.

Managers indicated that thinning, mechanical fuel treatments, and managed wildfire are all used to prepare forest landscapes for fire by reducing hazardous fuel loads, and all actions are used to varying degrees for post-fire response and to accommodate climate-driven changes in fire regimes. According to several managers, thinning, mechanical fuel treatments, and prescribed fire are being used to promote fire-resistant species (e.g., ponderosa pine, Douglas fir, western larch) and stand structure (e.g., larger trees, older stands) where appropriate, creating resilient landscapes. This is key for management as several other techniques (e.g., restoration treatments) are unable to keep pace with fire regime changes. In addition, reducing fire risk can help managers preserve timber harvest opportunities, and enhance forest health and wildlife habitat.

Table 7. Climate adaptation actions implemented by National Forest managers interviewed.								
National Forest	State	Thinning	Mechanical Fuel Treatments	Prescribed fire	Managed wildfire	Seeding fire-resistant species	Removal of fire-prone species	Other
Sawtooth	ID	✓	✓	✓	✓	✓	✓	Fire suppression
Payette	ID	✓	✓	✓	✓			
Nez-Perce Clearwater	ID	✓	✓	✓	✓	✓	✓	
Caribou-Targhee	ID	✓	✓	✓	✓	✓	✓	
Caribou-Targhee	ID	✓	✓	✓	✓			
Idaho Panhandle	ID	✓	✓	✓	✓	✓	✓	
Beaverhead-Deerlodge	MT	✓	✓	✓	✓			Use livestock grazing to manage vegetation
Custer-Gallatin	MT	✓	✓	✓	✓	✓	✓	
Helena-Lewis & Clark	MT	✓	✓	✓	✓	✓	✓	
Malheur	OR	✓	✓	✓	✓			Remove insect-prone species
Umatilla	OR	✓	✓	✓	✓			Seeding native species
Siuslaw	OR							
Deschutes/Ochoco	OR	✓	✓	✓	✓		✓	
Mt Hood	OR	✓	✓	✓	✓	✓	✓	
Willamette/Deschutes	OR	✓	✓	✓	✓	✓	✓	
Okanogan-Wenatchee	WA	✓	✓	✓	✓			Education
Colville	WA	✓	✓	✓	✓	✓	✓	
Gifford Pinchot	WA	✓	✓	✓	✓	✓	✓	
	Totals	17	17	17	17	10	11	5

Managers indicated that many of these actions have tradeoffs that affect implementation and scale of use. For example, managed wildfire typically occurs only when cost and safety concerns limit the use of fire suppression techniques; it is situation-specific and depends on risk assessments, which can lead to either a "let it burn" or suppression directive (i.e., fire retardants, water drops). Mechanical fuel treatments and hand thinning can be labor intensive, but allow for more flexibility by allowing resource managers to be highly selective in terms of what vegetation to remove or leave behind. Prescribed fire has a broader application than mechanical fuels treatments or thinning, as it can be used alone or sequentially with other actions. Overall, prescribed fire was noted as the top action taken for most purposes, and particularly for preparing for climate-driven changes in fire regimes (Figure 4).

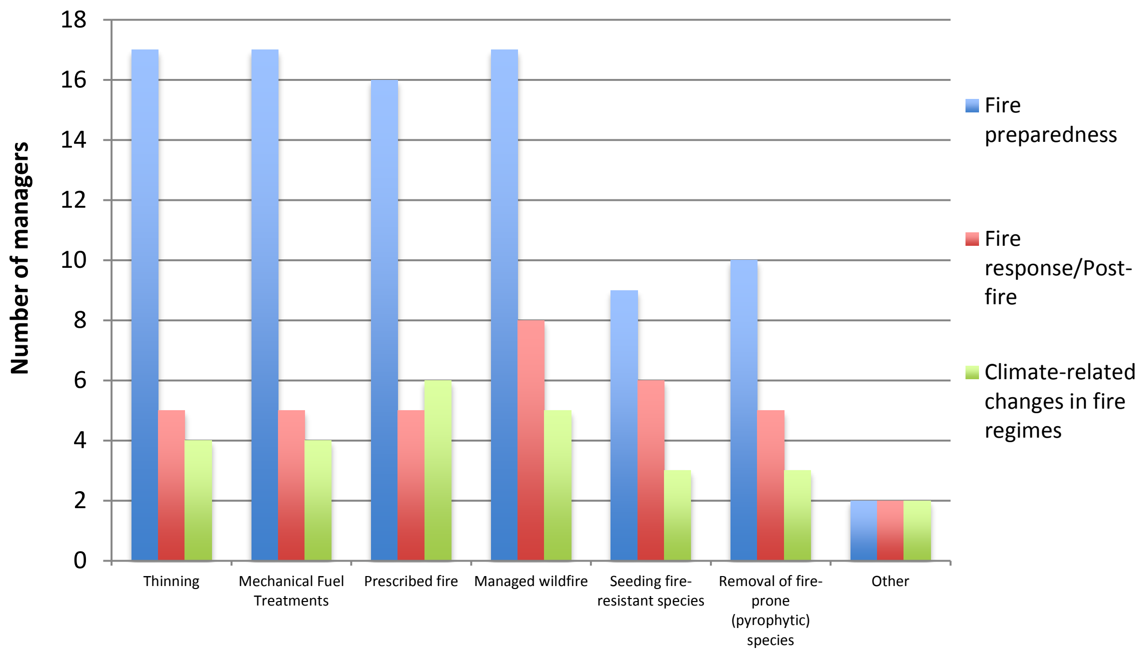

Figure 4. Primary purpose(s) for each of the actions being implemented by resource managers interviewed.

Location of actions

Under Forest Service management guidelines, location classification (i.e., wilderness, non-wilderness, WUI) influences the suite of permitted management actions in that area. For example, managers indicated that mechanical fuel treatments are not used in wilderness areas because of restricted access (i.e., no roads), but are used, along with thinning, in non-wilderness and WUI areas in partnership with local communities. Comparatively, managed wildfire is predominantly used in wilderness regions, while the other actions are more broadly distributed throughout non-wilderness and WUI areas. According to interviewees, managers must also consider societal views and concerns in making decisions, which can restrict the range of actions available for implementation. Social issues and perceptions, such as public aesthetics and health concerns about smoke, may determine what is feasible, especially with respect to prescribed fire. Across all locations, prescribed fire was the top implemented action (Figure 5).

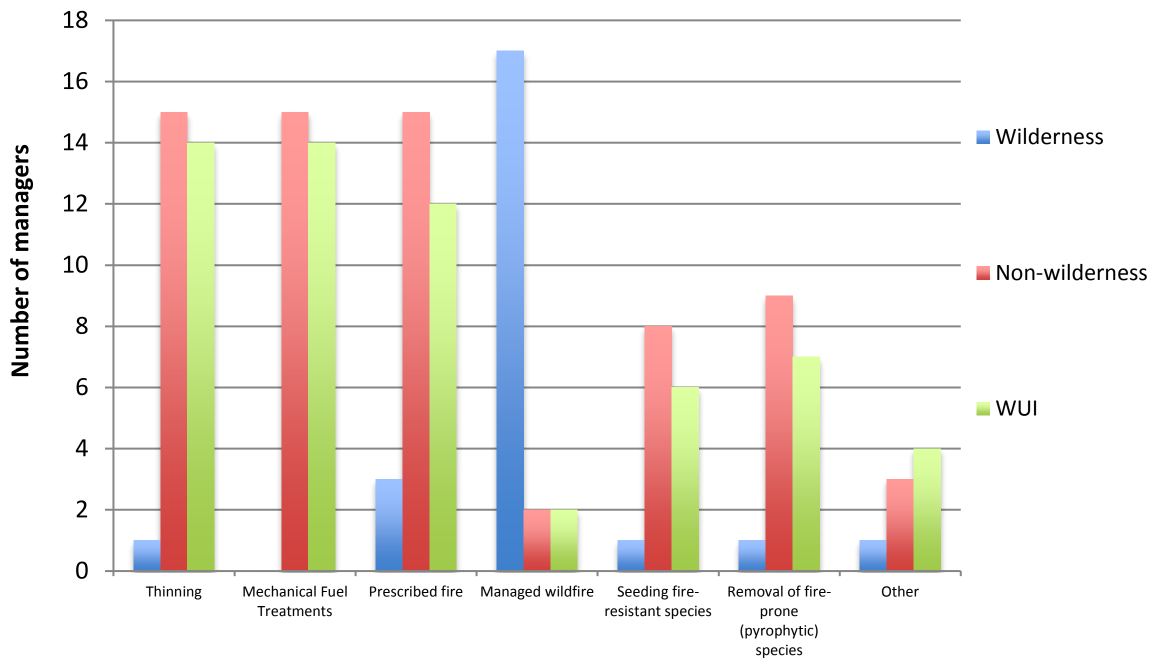

Figure 5. Primary location(s) for each of the actions being implemented by resource managers interviewed.

Comparison: Literature and Interview Findings

Comparing the literature review and the interview results (Table 8), prescribed fire clearly emerged as the top management action referenced and used in practice. In general, resource managers are implementing a suite of approaches to manage fire in Northwest forests; using a variety of options may prove to be important in addressing the uncertainties associated with climate-driven changes in fire regimes.

Table 8. Comparison of adaptation actions – literature and interviews.

	Literature Review (n=109)	*Interviews (n=18)*
Prescribed fire	102.5	17
Mechanical Fuel Treatments	75.5	17
Thinning	75	17
Managed wildfire	56	17
Removal of fire-prone species	14	11
Seeding fire-resistant species	14	10

2.4 Discussion

Prescribed fire is the top climate adaptation action documented in the literature review and implemented by national forest managers in the Northwest region. It is clear that climate change and shifting fire regimes are emerging as significant challenges for forest management decisions in the region. Managers are seeing changes such as decreasing moisture levels, shifting fire seasons, larger and more widespread fires, and increasing disease and insect outbreaks, which impact not only current management activities (e.g., restoration, timber production), but influence the persistence of critical habitat types, forest biomes, and associated ecosystem services into the future. There is a strong recognition that weather and climatic variability may create new management opportunities (i.e., practices and timing) while restricting others. However, managers acknowledge that fire management is always evolving and adapting to changing conditions; climate change simply adds another dimension for consideration.

2.5 Conclusion

Phase 2 helped to identify the fire-related climate adaptation actions most commonly referenced both in the gray literature and by managers; a review of the literature and interviews with managers indicated that prescribed fire is a management action that is broadly applied throughout Northwest national forests. In order to incorporate climate change into fire management, managers need to know when, where, and how existing actions could or should be modified. In terms of the use and application of prescribed fire, Phase 3 aimed to find specific evidence related to:

- conditions (e.g., weather, purpose, monitoring, fuel types, moisture level);
- techniques (e.g., ground ignition, aerial ignition, avoidance techniques);
- time frame (e.g., number of days, time of day, burn period);
- scale(s) (e.g., acreage, forest-wide, etc.); and,
- location(s) (e.g., National Forest, WUI, non-wilderness, elevation).

3. Systematic Mapping/Review

3.1 Introduction

There is little debate that science plays a role in how we think about climate change; however, opinions vary in how science can be and is being used to help guide how we prepare for and respond to climate change impacts. Not all scientific knowledge and research findings for any one area of study are applicable to, or directly address, management- or policy-relevant questions. This is exacerbated by conflicting research results; and, finding, accessing, and interpreting those results is frequently cited as a time-consuming and difficult task (Cook et al., 2013). Pullin et al. (2004) have shown that when scientific evidence is not easily accessible, conservation managers tend to rely on experience-based information and on customary management practices. A more strategic and nuanced approach to making the best use of available science is needed. A systematic evidence review process (also referred to as systematic review) offers one such approach.

A ***systematic review*** is a research process that summarizes available evidence on a clearly formulated question, using systematic and explicit methods to identify, select, and evaluate relevant studies. Systematic reviews were originally developed to help medical researchers and practitioners synthesize results of vast amounts of clinical research and are best suited for single treatment, single outcome issues. The process for conducting systematic reviews (Table 9) differs from traditional literature reviews by focusing on specific, targeted questions, and the use of a documented, repeatable, a priori protocol for identifying and assessing the literature included in the review.

As use and acceptance of systematic reviews continues to expand, practitioners in other fields – including environmental and natural resource management agencies – are taking interest in the process (e.g., the systematic review of the marbled murrelet nesting habitat use and nest success report for the Oregon Department of Forestry, Plissner, et al., 2015). There is broad support for incorporating best available science into natural resource policy- and decision-making processes, there is less consensus on how to identify, review and "package" this information.

Defining the scope of literature that is relevant – and should therefore be included in a systematic review – can be challenging for the more open-ended, complex questions that are common in natural resource management, especially compared to the single-treatment, single-outcome medical questions for which systematic reviews were originally developed. Nevertheless, systematic review techniques – including careful vetting and refinement of review questions, and the development of clearly-specified literature search protocols – show promise for increasing the objectivity, transparency, and utility of the resulting science "package" delivered to policymakers and practitioners.

Table 9. Steps of a systematic review (excerpted from CEE, 2013, p.9).	
Steps	*Description*
Question setting	A process to derive a suitable question both in terms of evidence needs and feasibility of the systematic review
Protocol and search strategy development	A plan for the conduct of the systematic review setting out how each stage will be conducted
Searching	A systematic search is conducted using a repeatable search strategy tailored to the question and likely sources of evidence
Screening criteria (inclusion criteria)	Articles retrieved from the search are examined for relevance to the review question using a priori inclusion criteria and resulting in a collection of relevant studies
Assessment of relevance and/or study quality)	Studies are examined for their design and reporting standards and weighted in terms of susceptibility to bias and validity in terms of the study question.
Data extraction	Appropriate data are extracted from each study and may be subject to further critical appraisal
Data synthesis	Extracted data from individual studies are synthesized to form an overall view of the evidence. Synthesis can be narrative, quantitative, qualitative or a combination of these

For instances when questions around a management action are open-ended (rather than close-ended, which is ideal for a systematic review) and/or when it is not feasible to generate or select a question before a broader review of the evidence is done, ***systematic mapping*** can be a first phase of, or an alternative to, a systematic review (CEE, 2013). Systematic mapping focuses on the current state and trajectory of knowledge around a broad, open-ended question (or a particular area of interest) by charting information on generic variables of the evidence, such as quantity of studies available, the population focus, study design, and the intervention, geographic location, and authors (CEE, 2013).

Systematic mapping follows the same process and rigor of a systematic review, but unlike a systematic review, it does not attempt to fully synthesize the evidence in order to answer the question(s) or to provide a complete and critical assessment of the included studies. However, themes and/or data can be extracted to describe important aspects of the included studies (CEE 2013).

Use of systematic review processes and techniques in natural resources is growing but appears to have more popularity outside of the United States, perhaps spurred by the efforts of the Collaboration for Environmental Evidence. Berrang-Ford et al. (2015) directly address the use of systematic review techniques in climate adaptation research, and concede that assessing and understanding climate change adaptation is “conceptually murky” because climate change adaptation pertains to adjustments in human systems at different scales and by different actors, and because the “success” of any one adaptation action is likely to have different definitions.

The authors note that systematic reviews hold great promise for addressing the need for objectivity and transparency in the synthesis and application of climate adaptation science, but have been criticized for being overly structured and rigid. To address this, Berrang-Ford et al. (2015) suggest that a robust synthesis of science supporting a particular climate adaptation action might combine a review of the existing literatures (i.e., using systematic literature searches) with primary data collection (i.e., interviews, workshops, expert opinion) within a systematic information synthesis framework. Robust reviews of science underlying climate adaptation actions will likely require "…increased engagement with the flexible and creative potential of systematic review approaches…using intentionally designed, transparent, reproducible, and explicitly documented methods of research synthesis" (Berrang-Ford et al., 2015, p. 765).

3.2 Approach/Methods

Phase 1 of the ASAP project identified *increased wildfire frequency and intensity* (and associated impacts) as one of the most pressing climate stressors in the Northwest. In Phase 2, *prescribed fire* was identified by managers as a key tool used in response to this climate stressor. The purpose of Phase 3 was to pilot a systematic review process on prescribed fire as a climate change adaptation action. As suggested by Berrang-Ford et al. (2015), we tested a hybrid approach that combined a systematic literature search with a Science Advisory Panel workshop. Phase 3 had a compressed project timeline with the majority of the search being conducted over a two-month time period.

Framing

The review question(s)

Prescribed fire has been used for decades to reduce fuel loads and wildfire effects, promote more open and diverse forest structure, control conifer regeneration, maintain or increase biodiversity, and preserve defensible space around human infrastructure. The basic questions of relevance for managers, therefore, were whether and how the use and application of this widely-used tool might evolve in response to the effects of climate change on fire regimes in Northwest forests.

Based on the interviews with managers in Phase 2 and discussions with subject matter experts, an initial draft of review questions was produced. Comments on these questions were solicited and the questions were refined (Figure 6).

Iteration 1: Draft questions (March 2015)

Primary Questions: What evidence of climate change effects is there (if any) that could potentially alter established scientific assumptions and consensus regarding the uses of prescribed fire to mitigate wildfire risk and effects? How might uses of prescribed fire evolve in response to climate change?

Secondary Questions: In consideration of projected climate change effects, are there instances (conditions or ecosystems) in which evidence suggests that there may be benefits to modifying the ways in which prescribed fire is currently used to reduce the wildfire risk and effects? If so, what are these instances (conditions or ecosystems) and the modifications in prescribed fire use that the evidence suggests?

Iteration 2: Initial refinement (April 2015)

Primary Questions: In consideration of projected climate-driven shifts in fire regimes, what evidence is there (if any) that could potentially alter established scientific consensus regarding the use and application of prescribed fire? How might the use and application of prescribed fire evolve in response to climate change with respect to implementation conditions, techniques, time frames, scales, and locations?

Secondary Questions: Are there any instances where the standard use and application of prescribed fire has been altered specifically in response to climate-driven shifts in wildfire regimes? If so, to what extent/in what way did implementation conditions, techniques, time frames, scales, and/or locations of prescribed fire use change?

Figure 6: Review question iterations.

Systematic Mapping Search Protocol

Systematic mapping uses a search protocol (Appendix B) that documents how and where the literature will be sought and obtained. A draft protocol was modified following input from the NW CSC, some of the science advisors, and an OSU Libraries Reference Librarian. Due to the potential volume of literature, the strategy was to first search literature with study areas in the Pacific Northwest, then if necessary expand the search to include the western United States, followed by the rest of the United States. Conducting a search of literature outside of the United States was excluded.

Search engines, databases, and organizational websites

To search for peer-reviewed and gray literature, we used a number of databases, search engines, and the websites of relevant organizations.

Peer-reviewed literature. The following databases, supported by Oregon State University Libraries and the University of Idaho Libraries, were searched. These academic databases cover a wide-range of available literature on the topic:

- Web of Science
- Academic Search Premier
- CAB Abstracts

- Treesearch: US Forest Service Research Publications
- AGRICOLA (EBSCOhost)
- Environmental Sciences & Pollution Management
- E.V. Komarek Fire Ecology Database
- JSTPR Plant Science
- GREENR
- Earth and Environmental Sciences E-journals

Gray literature. The following databases were used to primarily seek out relevant gray literature. When available, relevant peer-reviewed literature was also examined.

- Treesearch: US Forest Service Research Publications (www.treesearch.fs.fed.us)
- Climate Adaptation Knowledge Exchange (CAKE) (www.cakex.org)
- Fire Research and Management Exchange System (FRAMES) (www.frames.gov)
- Template for Assessing Climate Change Impacts and Management Options (TACCIMO) (www.taccimo.sgcp.ncsu.edu)
- Joint Fire Science Program Research Database (www.firescience.gov/JFSP_research.cfm)
- Bureau of Land Management: (www.blm.gov/wo/st/en/info/blm-library.html)
- U.S. Geological Survey Library (library.usgs.gov)
- U.S. Geological Survey ScienceBase (www.sciencebase.gov)
- USDA Forest Service Climate Change Resource Center (www.fs.usda.gov/ccrc)
- National Park Service library (www.library.nps.gov)

Specialist sources. The following specialist organizations were searched for relevant gray literature using manual searches of their websites.

- USDA Forest Service Research Stations websites (www.fs.fed.us/research/locations)
- Washington State Department of Natural Resources (www.dnr.wa.gov)
- Washington Department of Ecology (www.ecy.wa.gov)
- Oregon Department of Forestry (www.oregon.gov/ODF)
- Idaho Forest Products Commission (www.idahoforests.org)
- Idaho Department of Lands (www.idl.idaho.gov)
- Montana Department of Natural Resources and Conservation (www.dnrc.mt.gov)
- National Interagency Fire Center (www.nifc.gov)
- U.S. Geological Survey Forest and Rangeland Ecosystem Science Center (fresc.usgs.gov)
- U.S. Geological Survey Western Ecological Research Center (www.werc.usgs.gov)
- Individual National Forest sites
- Landscape Conservation Collaborative Network (LCCNetwork.org)

Internet search engines. GoogleScholar (scholar.google.com) was also used to identify both peer-reviewed and gray literature. The first 50 hits from each GoogleScholar search were examined.

Search terms

Systematic review and mapping processes are designed to allow users to pose very specific questions of scientific literature. The approach outlined above allowed us to specify that only literature explicitly linking prescribed fire use with climate change in some fashion would be included. We did not investigate whether prescribed fire is effective, or whether climate change will alter wildfire regimes in Northwest forests. We were only interested in literature that explicitly addressed how use of prescribed fire might evolve or change under these two assumptions.

To identify relevant literature, we consulted with an OSU Libraries Reference Database Librarian for assistance in refining the search protocol. We explained systematic literature search techniques and how our project was using them, how we had arrived at our review question, the need for an explicit review protocol, and suggested some initial search terms. After test searches of the most promising databases, we settled on a keyword search string with three components: *prescribed fire, climate change*, and *adaptation*.

> “prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn"
>
> AND
>
> "climate change" OR "global warming" OR "global change" OR "climate warming"
>
> AND
>
> "adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation"

Additional test searching was conducted concurrently with these searches. These additional test searches indicated that potentially relevant literature might be missed by requiring an adaptation-related term. In light of this, final searches were run without the adaptation component.

Literature inclusion criteria

The scope of literature related to prescribed fire use is diverse and voluminous. There has also been a rapid increase in the number and range of studies addressing questions regarding projected effects of climate change on Northwest forests. A key challenge was to decide on criteria that explicitly defined the scope of directly relevant literature, and how to partition off that which did meet these criteria. To address our review question we needed to focus tightly on the “subset” of literature that *explicitly linked* prescribed fire use with climate change.

Our approach was to briefly summarize and set aside two categories of supporting science: 1) conventional uses of prescribed fire aside from climate change considerations, and 2) the projected general effects of climate change on fire regimes in Northwest forests. To focus the scope of the review, we accepted as “given” that 1) prescribed fire can be effective in reducing fuel loads and fire effects, and helping promote open forest structure at the stand level, and 2) large areas of Northwest forests are likely to be hotter and drier in coming decades with associated increases in wildfire intensity, severity, and extent. The idea was to briefly summarize these bodies of knowledge (Appendix C) to help explain and establish the rationale for the review question and then, to the degree possible, exclude this subject matter from further review in order to focus on only the most directly relevant literature.

Our primary literature inclusion criterion was that the publication had to explicitly link climate change (or closely related term, e.g. global warming) with prescribed fire (or closely related term, e.g. prescribed burn) in some way. We did not require that the study itself focus on this linkage but, at a minimum, the authors needed to specifically address it in their abstract, discussion, or management implications section; this requirement acted as a coarse filter for searching the relevant databases.

Literature inclusion/exclusion criteria are implemented initially via the *coarse filter*, a key step in a systematic review conducted once the list of references returned by the systematic search is in hand. The coarse filter process involves reading the abstract and enough of the text of each reference to make a reasoned and defensible determination whether it should be included or excluded. The reasons for excluding a reference are documented in terms of the inclusion/exclusion criteria. For questionable references, second opinions from other science advisors can be sought to make these determinations. Science advisors "err on the side of caution" and include references at this point even if there is a chance that, upon closer analysis, they may not be suitable for further review. References included during the coarse filter may be excluded later in the review process, as long as the rationale for doing so is documented.

Systematically Evaluating the Evidence

Systematically evaluating the evidence includes a documented search for the literature, a documented assessment of the relevance of the literature, and creating a narrative synthesis.

Documenting the literature

Systematic methods were used to gather and catalogue only those documents that passed through the coarse filter of explicitly linking prescribed fire with climate change. Documents were entered into an Excel spreadsheet (see https://www.sciencebase.gov/catalog/item/5818c1dfe4b0bb36a4c8806e) and made accessible to the Science Advisory Panel via Google Docs. Fields for each document included study citation, where the document was located, a short summary of the goals or purpose of the study or document, information about the forest type or ecosystem and study location, and another for summarizing key study findings and conclusions. A field was also established to denote four document discovery groups: *Group 1* documents consist of the peer-review literature found through an electronic search of academic databases; *Group 2* is the gray literature; *Group 3* is the peer-review literature found during the gray literature search; and, *Group 4* documents are those that the science advisors suggested that did not show up in any of the previous groups.

Filter and assess the relevance of the literature

In addition to OSU Library databases, some crosscheck searches were conducted on Google Scholar using a few simplified search strings. Keyword combinations of "prescribed fire and climate change" and "global warming and prescribed burning" produced three additional studies that were not identified in OSU Library database searches but passed the coarse filter phase. The sources accessed and search algorithms used by Google Scholar are not transparent, but the additional relevant literature we found using this tool suggests that it should be included in systematic searches even if science advisors have access to a full range of academic databases.

Traditional (non-systematic) searches. In clinical medicine, systematic science advisors access an evidence base that consists primarily of rigorously designed and implemented clinical trials, which are usually conducted in a similar fashion and catalogued using broadly agreed upon keywords. The evidence base available to address natural resource questions tends to be both more limited in extent and more diverse in methodology, with much less consensus on keywords and methods for consistently describing and cataloguing published research. This can make it difficult to develop literature search terms and inclusion criteria that are both objective and comprehensive, especially for more complex, open-ended questions.

Since prescribed fire is a tool that is not specific to climate change per se, it was understood from the start that the range of potentially relevant literature might include documents and studies that did not explicitly mention the keywords we used. Our search terms captured a significant amount of literature where the authors specifically intended to link prescribed fire and climate change, and probably successfully excluded a large amount of tangentially-related literature that did not make this linkage. It is likely that some of this latter category of literature contains information that is relevant to the study question, but it was unclear what other search terms to use that would not result in an overwhelming volume of hits. For these reasons, we used some traditional methods to identify additional relevant literature. The most obvious of these methods is to simply ask subject matter experts to suggest such studies. We solicited input from our Science Advisory Panel via a workshop that was convened to complement our systematic literature search.

Other traditional methods of literature searching include scanning bibliographies of highly relevant papers for additional pertinent references, and checking the websites of recognized experts who are active in the field and authored relevant studies that were already included in the review. There is potential for bias in these methods but that must be weighed against the potential for finding additional relevant studies. We suggest that most, if not all, systematic literature searches and reviews in natural resource fields should be supplemented by such traditional search methods. In short, identifying relevant literature using specific, documented search terms adds substantially to the transparency and objectivity of the review. But in order to be more comprehensive, such methods will usually need to be augmented with traditional techniques for finding relevant literature. This is especially true for more complex, multi-faceted natural resource questions.

Science Advisory Panel Workshop

To complement the systematic literature search, the project team elected to hold a Science Advisory Panel workshop to solicit scientific expertise and input on topics and relevant literature related to prescribed fire and climate change.

Identifying, selecting, and recruiting science advisors

Successful systematic review and mapping processes hinge on qualified science advisors; ideally, scientists in the field under which the review question falls who do not have a vested interest in review outcomes (INR, 2008). The project team utilized a panelist selection process to identify, prioritize, and solicit a diverse group of scientists considered to be experts in their fields (Figure 7).

In consultation with the NW CSC, 23 potential candidates to serve on the Science Advisory Panel were identified within the NW CSC region area, as well as from Arizona and California. The candidates were prioritized based on their expertise. First priority were researchers with experience and expertise in both prescribed fire and climate change. Second priority were those with prescribed fire expertise. Third priority were those with climate change expertise and a scope of work that mentioned fuel treatments and/or management applications.

This approach resulted in 11 potential candidates who were invited to serve on the Science Advisory Panel. Our strategy was to secure five to eight science advisors, and to make their participation in the project as efficient as possible considering the value of their time and efforts, the short-time frame of the project, and the imminent fire season. Via email invitations and follow up conversations, the ASAP team secured 6 science advisors representing each of the NW CSC region states, and a diversity of expertise, affiliation, gender, and race.

Individual Candidates

- The candidate should reside in Oregon, Washington, Idaho, or Montana; or have expertise in the review topic and experience with systematic reviews
- Expertise
  - First priority: Expertise in both prescribed fire and climate change.
  - Second priority: Prescribed fire expertise.
  - Third priority: Climate change expertise with a scope of work that mentions fuel treatments and/or management applications.
- The candidate panelist should not have any conflicts of interest that might prevent a candid and thorough review.

Composition of the Review Team

- In addition to expertise, there should be diversity with respect to geographic distribution, professional workplace (scientists within academia and non-academic settings) gender, race and/or ethnicity of the review team.

Figure 7. Science Advisory Panel selection criteria.

Convening the workshop

The Science Advisory Panel was invited to a workshop held June 3, 2015 at Portland State University in Portland, Oregon (Appendix D). The intent of the workshop was to have a diverse range of experts comment on the topic of prescribed fire in the context of climate change and the findings of our systematic mapping efforts, suggest additional subject matter areas and studies to include in the review, and discuss knowledge gaps and future research needs.

Prior to the workshop the ASAP team was in direct phone and email contact with the science advisors to solicit their input about prescribed fire-climate change as a subject matter of the piloted systematic mapping process. At least two weeks before the workshop, science advisors were also provided a briefing document containing the project overview, the meeting purpose and agenda, panelist biographies, the primary and secondary questions, the search protocol, a brief summary of current knowledge, reference literature, coarse filter references, and annotated bibliography of the peer-reviewed literature (Appendix

E) and written documentation of panelist input, including additional references.

3.3 Findings

Literature Search

Number and type of literature retrieved

The search for relevant literature by the ASAP team took place between 30 April 2015 and 10 June 2015. Figure 8 summarizes the number of articles that were retrieved at each stage of the process, and the number of documents retrieved by source.

An expanded search of the academic databases yielded 314 articles. The articles were given closer scrutiny, at a minimum by reading the abstract for each paper but often scanning the full text for keywords (i.e. prescribed fire and climate change) and/or reading the discussion or management implication sections. The filtering process yielded 40 peer-reviewed publications. The search for gray literature yielded 41 relevant articles plus 16 additional peer-reviewed articles that were not found during the searches of the academic databases, including 3 articles found via GoogleScholar. The web-based search and screening resulted in 100 articles to be considered as part of the systematic mapping. Figure 9 summarizes the years in which the considered articles were published.

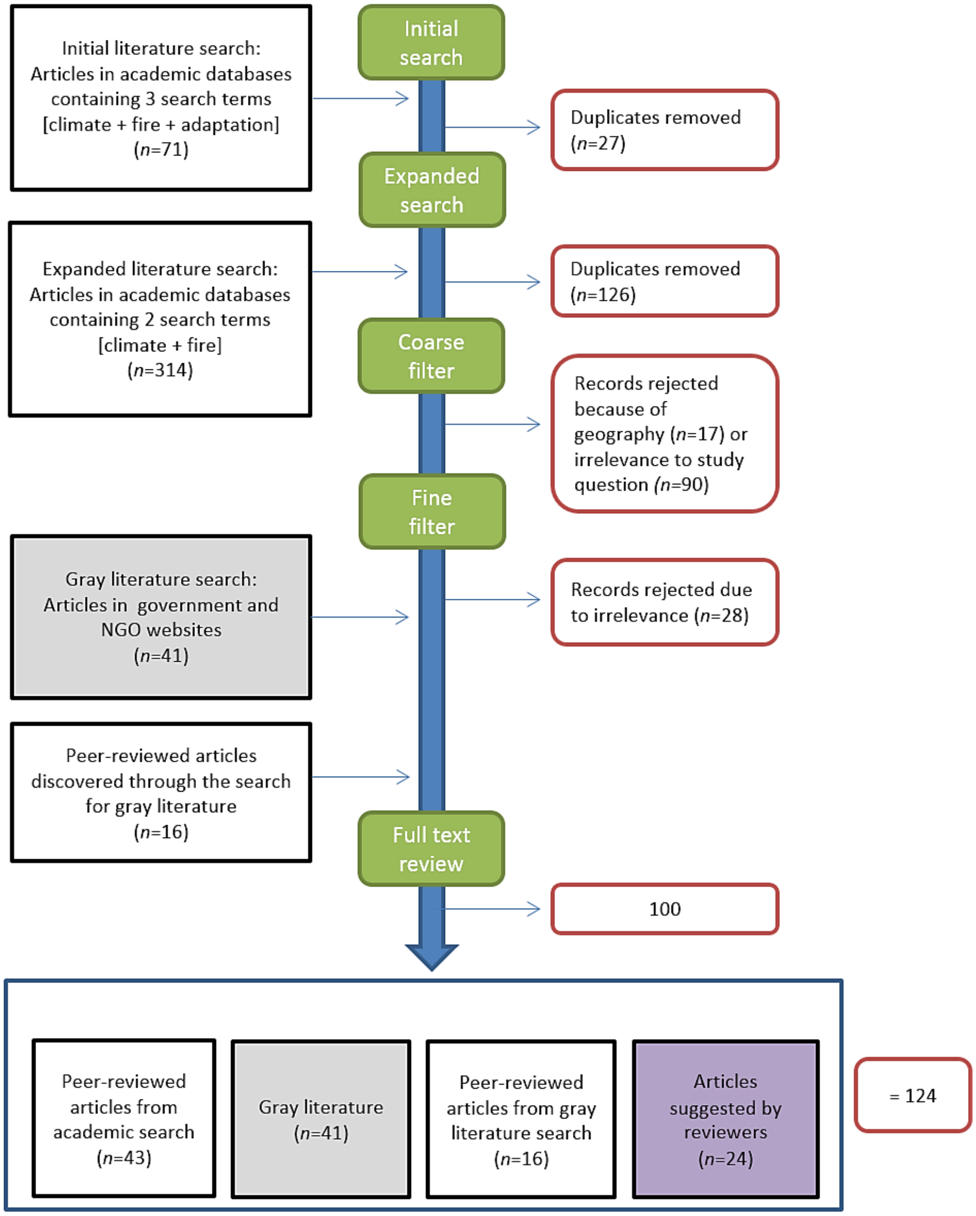

Figure 8. The number or articles retrieved in the search and the number provided by the science advisors.

In addition to the web-based search, the Science Advisory Panel was asked for additional articles. This produced an additional 24 articles, which were added to the database, but did not undergo filtering nor did they undergo review due to the short timeline of the project, but they documented (see https://www.sciencebase.gov/catalog/item/5818c1dfe4b0bb36a4c8806e).

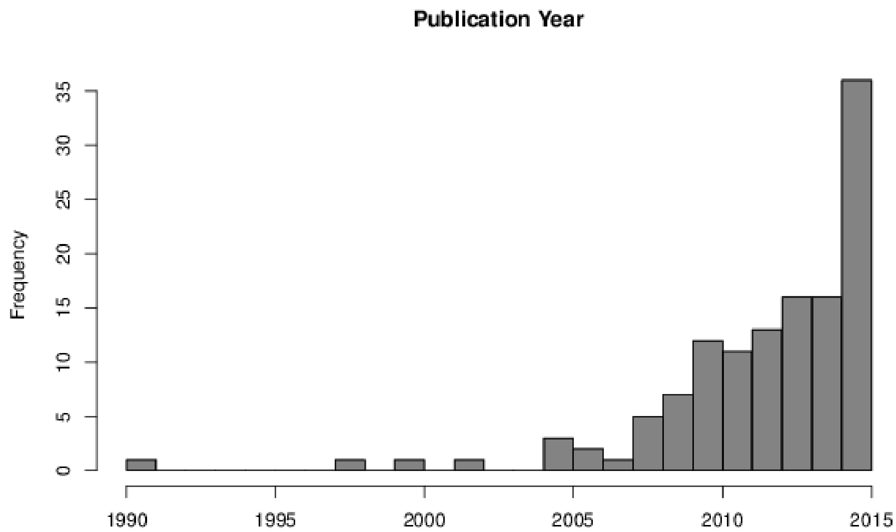

Figure 9. Publication year of relevant articles.

Applicability to the Questions

The search and screening of the literature did not yield a single study that was purposely aligned with the review questions (Figure 6). Instead, relevant evidence had to be deduced from other study findings. Most studies discussed or tested prescribed fire use as part of broader fuel treatment prescriptions (usually in conjunction with thinning) and the effectiveness of these prescriptions in reducing wildfire intensity, severity or extent, or achieving fire-related forest ecosystem maintenance and restoration goals. Studies were often included simply because the study rationale or management implications were couched in terms of climate change whereas similar studies were excluded because climate change was not mentioned.

In general, the screened literature seemed to indicate prescribed fire is likely to continue to be a widely used and important tool, and may become even more important as climate change effects on wildfire regimes intensify. However, we found very limited evidence in the peer-reviewed literature that managers have been consciously altering their use of prescribed fire specifically in response to the effects of climate change. The main issues seem to revolve around **where** and **when** to use prescribed fire, and expansion of the reasons underlying decisions to use it, rather than any significant change in how it is used. Because the question of **where** to apply fuels treatments is an overarching theme of most research on this topic, many of the included studies address this theme to some degree; however, a few peer-reviewed publications seem to have addressed it more specifically (Laughlin et al., 2011; Syphard et al., 2011; LeQuire, 2013; Stanturf and Goodrick, 2013; Clark et al., 2014; Hurteau et al, 2014; Raymond et al., 2014; Shive et al., 2014).

Two studies in Arizona – Shive and Fulé (2014) and Bagdon and Huang (2014) – emphasized the importance of having flexible management approaches in a changing climate. In both studies the researchers modeled the implications of various management scenarios under climate change. Prescribed fire was a treatment used in both studies.

Using the Forest Vegetation Simulator Climate Extension, Shive and Fulé (2014) modeled forest growth in ponderosa pine forests that burned in Arizona's 2002 Rodeo–Chediski Fire. They also compared a no-management scenario with four future management strategies. Amongst their results they found that prescribed burning at 10- and 20-year intervals resulted in basal areas within the historic range and variability (HRV) in low-severity sites that were initially dominated by smaller diameter trees; but in sites initially dominated by larger trees, the range was consistently exceeded. For high-severity sites, prescribed fire was too frequent to reach the HRV's minimum basal area.

Bagdon and Huang (2014) examined dynamics of ponderosa pine stands under three climate change scenarios in Northern Arizona using the Climate Forest Vegetation Simulator (Climate-FVS) model to project changes in carbon pools based on three management scenarios. Both of the active management scenarios involved prescribed fire. Results showed that climate-induced mortality is lowest when treatment is frequent and permitted to remove sufficient volume to reduce BA below 28 m2/ha. However, under the most severe climate change scenario, severe mortality of ponderosa pine appears imminent regardless of treatment. They suggested that decisions about timing, frequency and magnitude of treatments should be evaluated in light of the range of climate change intensities.

In the Northwest, Halofsky et al. (2014) modeled effects of management and natural disturbances on vegetation in two central Oregon forest types (dry–large–open and moist-large-dense) under different future climates. Comparing a fire suppression scenario (no management other than continued wildfire suppression) and an active management scenario (light to moderate thinning and some prescribed fire, planting, and salvage logging), they found that the probability of at least maintaining current dry–large–open forest levels was high with active management, where dense stands were thinned and prescribed fire applied. The probability of maintaining moist mixed-conifer forests was higher with active management, but the probability of maintaining even 75% of current amounts of moist-large-dense forests declined with time under both scenarios. Regardless of management, increased fire frequency with climate change may reduce recruitment of large-diameter trees. Increased use of prescribed fire and thinning in higher-density stands created more fire-tolerant forests with larger trees. But medium-sized trees declined under both scenarios, reducing the number of trees that grow to larger diameters. Opportunities to grow new large-diameter trees in dry forest types may diminish through time, assuming increased mixed- and stand-replacing wildfires. The authors note that this closing window of opportunity places greater importance on reducing stand replacing wildfire potential around remaining older, large-diameter trees currently on the landscape.

Looking at old growth from a western U.S. perspective, Abella et al. (2007) argue that thinning, prescribed fire, or wildland fire use will likely be key options for forestalling continued loss of old growth forests to severe crown fires. For many practical and societal reasons, WUI areas afford some of the best opportunities for re-establishing crown fire resistant old growth forests. They note that prescribed fires require substantial investments of human and financial resources, which may be feasible in WUI areas where social values at risk from unplanned wildfire are high, but not in large, remote forest lands.

In terms of **when** to use prescribed fire, some evidence exists that there might be opportunity to shift the timing of its application. Littell et al. (2012) cited anecdotal evidence that Tahoe National Forest fire managers are taking advantage of reduced snowpack and earlier spring runoff by continuing fuel treatments beyond the traditional burn season. For example, some prescribed fires can now be conducted in winter, enabling the treatment of more land area during expanded seasons (Joyce et al., 2008).

Shifts in season of prescribed fire use of this type are likely more widespread than we detected in our survey of primarily peer-reviewed research. The anecdotal evidence that was referred to in passing in an article illustrates the potential for supplementing a systematic literature review with workshops that bring scientists and managers together, where it is likely that more evidence and knowledge regarding such practices could be revealed.

One study drew our attention because the researchers used prescribed fire data to test how climate relates to fire severity (individual tree mortality probabilities) across coniferous forests of the western U.S. (van Mantgem et al., 2013). The study used prescribed fire data because prescribed fires are conducted over a relatively narrow range of fire weather but over a potentially wide range of interannual climatic conditions. They found that longer term climatic stress (5 years prior to fire) predisposed trees to be killed from short-term fire damage. Although they did not explicitly discuss prescribed fire use under climate change, their findings – especially since they are based on prescribed fire data – have perhaps the most obvious implications for prescribed fire use under climate change that we found, i.e. that managers will increasingly be faced with conditions of moisture-stressed trees when applying prescribed fire. This has important implications for the amount of unintentional tree mortality they can expect from a given prescription.

In summary, our conclusion is that there is limited published research directly aligned with, or designed to address, our review questions. Rather than a smaller number of highly relevant, tightly focused studies well aligned with our review questions – as would be ideal – our search and screening identified some studies that were mostly tangentially relevant to these questions. Further, since prescribed fire is not a new tool nor used specifically for climate adaptation, and is best considered as an integral part of broader fuels reduction efforts, our inclusion criteria likely excluded a significant amount of relevant literature. There may be additional relevant, but diffusely distributed, information in the literature on prescribed fire use, fuels reduction, wildfire, and climate change that to date has not been rigorously synthesized.

Other Themes Identified in the Literature

The scope of synthesis included the categorization of salient, and generally observed, issues and trends. These "themes" are highlighted with key example publications. The themes are not mutually exclusive as some studies address more than one.

Potential for biome shifts or type conversions, ecosystem or species changes or migrations

This theme includes studies that address the potential for vegetation change, or forest structure change in response to climatic changes, or for forests to be replaced by non-forest ecosystems after stand-replacing fire, and how these events would affect decisions about where to apply limited prescribed fire and fuels treatment resources.

Bowman et al. (2013) discuss the potential for *biome conversion* in which forests burn and then are replaced by non-forest ecosystems. They suggest that thinning and prescribed fire can decrease the risk of stand replacement, potentially preventing long-term shifts to low-biomass states after regeneration failure. Krasnow and Stephens (2015) found that prescribed fire may be problematic for aspen revitalization because they are often burned under moderate environmental conditions resulting in reduced fire intensity and severity compared to naturally occurring wildfires that often burn hotter. This is most problematic in aspen stands with competing vegetation that can survive low-intensity fires. They suggest that if aspen regeneration is a management goal, using managed wildfire would be a better action than prescribed fire unless high-intensity prescribed fire is possible.

Forest Planning

This theme pertains to the socio-political considerations of prescribed fire use in a changing climate. Issues within this theme include but are not limited to how to incorporate climate information into fire planning and management at all organizational levels, the costs and benefits of prescribed fire, how decisions are made, public perceptions about prescribed fires, and national narratives of the federal fire management plan versus place-based science.

Engel (2014) noted that air-pollution law and policy is an important factor contributing to the difficulties that natural resource agencies face in implementing prescribed fire. The author argues that decisions about prescribed fires are marred by an outdated, inaccurate distinction between "natural" (unplanned wildfires) and "anthropogenic" (prescribed) fire, and suggests that a "smoke is smoke" rule would ensure that air pollution policy better reflects the true costs and benefits of prescribed fire. Corringham et al. (2006) and Kolden and Brown (2009) examined use of climate information by fire managers. Both studies concluded that there is considerable potential for increasing access to, and use of climate data by fire managers and that doing so would improve planning efforts.

Maintaining and enhancing forest carbon stocks

This theme encompasses maintaining, enhancing, or slowing the reduction of forest carbon stocks (forest carbon carrying capacity). Forest carbon in the context of prescribed fire and other fuel treatments was the primary research area in 16 of the screened studies. A number of studies that addressed this were included because they looked at how fuels treatments – usually thinning followed by prescribed fire – affect forest carbon stocks. There was some evidence of controversy regarding the effectiveness of fuels treatments in enhancing forest carbon stocks. This controversy generally centered on the probabilistic, unpredictable nature of where wildfires occur in relation to fuels treatments, and the temporal and spatial scale of analysis on which conclusions were based. It was suggested that the potential for stand replacing fires to result in biome shifts or vegetation type conversions is often underestimated and that such considerations could, at least in some cases, shift the balance of carbon stock accounting to favor more proactive fuels management, including thinning and prescribed fire, to reduce the chances of forests being converted into non-forest ecosystems with much less capacity for carbon storage.

Science Advisory Panel Results

The Science Advisory Panel largely concurred with the results of the systematic literature, screening and review. In addition to assessing the findings, they were also invited to comment on and assess the approach, suggest additions to the literature search, and discuss the trends and issues at hand and potential research needs going forward.

Assessment of approach

The panel indicated that the systematic review process was a transparent and notable process for documenting relevant literature. With respect to applying the process to prescribed fire, they issued a few comments.

General comments

Prescribed fire and the USDA Forest Service. One suggestion was to expand the scope of manager input to include the National Park Service as their agency typically relies on prescribed fire for fuels treatments and thus has extensive experience with its application. Within the Forest Service, in contrast, prescribed fire is almost always used in conjunction with thinning.

Climate change effects. Changes in wildfire regimes are not the only climate impacts on Northwestern forests that may alter how, where, or when prescribed fire is used. For example, prescribed fire use may be altered to account for ongoing moisture stress on trees and resulting increase in susceptibility to mortality after a fire.

Objectives for using prescribed fire. With respect to the review questions, the panel emphasized the wide variety of objectives for which prescribed fire is used, which likely complicated our efforts to locate and assess the science explicitly linking prescribed fire and climate change. The panel discussed the different objectives for prescribed fire application and noted where there was confidence in the availability of scientific evidence or consensus (Table 10).

The panelists agreed that trying to include all of these objectives in a literature search might not be feasible or practical. One option could be to limit the search to a smaller set of commonly cited or important objectives [e.g., conducting a search of fuel reduction **and** maintain/increase landscape resilience (e.g., heterogeneity, forest health) **and** fire suppression (i.e. ladder fuels) **and** maintain/improve wildlife habitat].

Table 10. Categories of other objectives of prescribed fire uses noted by the advisory panel.	
Uses *with* general consensus on effectiveness	Uses *without* general consensus on effectiveness
– reduce or maintain surface fuel loads (i.e. don't let fuel loads increase) – reduce stand density and ladder fuels to alter fire intensity – enhance or improve habitat – reset the natural cycle (i.e., move system closer to historic range of variability) – promote nutrient cycling – reduce tree seedling regeneration – control species composition	– promote ecological effectiveness and impacts – facilitate fire regime shifts at different elevations – carbon storage, effects on carbon carrying capacity (e.g. live vs. dead biomass) – use in areas with increasing bark beetle populations – ability to significantly affect number and/or extent of large wildfires – fire suppression options (containment/suppression) – understory restoration effectiveness, particularly when invasive species are present, in highly altered systems, and in areas where native or desired seed sources are low – use in areas with threatened and endangered species

Refining the review question

Some participants found the review question ponderous and contested the "established scientific consensus" verbiage. They understood the need to tightly focus the review but noted the difficulty of defining such a consensus, and also that the project synthesis would address this matter in the review background and rationale. The review panel submitted a clearer, more concise version of the review question, which reflects their point that prescribed fire is used for a variety of management objectives: *What scientific evidence is there (if any) that the objectives for and application of prescribed fire may change with respect to climate-driven shifts in fire regimes?*

Scope of the "relevant" literature

A significant portion of the Science Advisory Panel workshop was spent discussing the scope of relevant literature. The reviewers acknowledged the challenge of finding literature in the Pacific Northwest that directly links prescribed fire and climate change. One panelist commented following the workshop:

> In light of the short timeframe and also that this is a systematic review rather than a comprehensive review, it seems to me that you shouldn't need to spend much more time combing the literature for every possible reference. Based on your extensive literature review and the suggestions of the review team, I would think you have the bulk of pertinent literature to allow a balanced assessment of the issue.

During the workshop, some key observations and suggestions pertaining to the literature review were made.

- *Terminology.* The observation that terminology associated with prescribed fire use and goals has shifted over time, as certain 'buzzwords' fall in and out of vogue. While there was consensus that our search efforts yielded the majority of the relevant literature, additional terms were suggested. These generally were thought to target older literature or papers that might deal with issues of climate change and adaptation, but without using that language.
- *Expanding the scope of the search (additional key words).* There was general consensus that the search strategy used initially – i.e. requiring both a climate change and a prescribed fire keyword in the same document – probably excluded a significant amount of potentially relevant science. Science advisors noted that the fuels reduction literature is clearly relevant, but that it would be difficult to bound, especially because prescribed fire is usually used in combination with other treatments. One panelist described two "spheres of thought" – climate change effects on forest ecosystems and wildfire fuels management. This panelist suggested that these areas of research are connected but that the literature often does not make these connections. It was further suggested that making these linkages more explicit would be a worthwhile endeavor. For example, literature on climate-related increases in tree moisture stress or insect and disease outbreaks could be used to modify and improve prescriptions for prescribed fire.

The science advisors did suggest areas of research and keywords that might yield additional relevant information, including the following. Terms in bold seemed to have more consensus:

- **Managed wildfire, wildfire use, wildland fire use**
- **Forest restoration**, **fuel reduction**, fuels management, fuel treatments, global change, dry forest restoration, hazardous fuels reduction, treatment effectiveness, **resilience**, **resistance,** species migration, assisted migration, invasives, restoring forest structures, create **heterogeneity, climatic variability**
- Terms that may help us find older literature: fragmentation, edge effects, gaps, buffer zones, operations research, optimization, risk management, **drought (extensive/intense), moisture stress**

As a follow-up to the workshop, the project team conducted an additional search of the bibliographic database *Web of Science* using some variations of the suggested terms (Table 11).

Table 11. Additional search terms suggested by the Science Advisory Panel.

Search Terms	*Number of Results*
TOPIC: (("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND "forest restoration")	57
TOPIC: (("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND "fuel reduction")	185
TOPIC: (("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND "resilience")	53
TOPIC: (("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND resilienc*)	60
TOPIC: (("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climatic variability") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation"))	0
TOPIC: (("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climatic variability"))	2
TOPIC: (("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND "fuel reduction" AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation"))	17
TOPIC: (("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND "moisture stress"))	3
TOPIC: ((("forest restoration") AND ("fire") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")))	10

Other suggestions included limiting the search to research conducted in the western United States, or perhaps even the Pacific Northwest, unless the paper was directly relevant; and if possible, searching unpublished theses and dissertations for relevant studies. With this last suggestion, the panel acknowledged that these sources are catalogued differently and might be difficult and time-consuming to find.

Assessment of findings

Noting the caveats and suggestions above, the panel found that the review yielded reasonable results in terms of prescribed fire being used to reduce the effects of wildfire risk and effects in the context of climate change. They did, however, offer an additional theme – wildland fire under climate change.

Wildland fire use under climate change

Perhaps the most interesting and significant observation or outcome of the workshop was the discussion of how conventional understanding and use of prescribed fire may evolve and overlap with management of naturally ignited fires. To some degree, this “wildland fire use” is already occurring, especially in protected areas such as national parks and wilderness areas. The definition of prescribed fire in most documents (including this one) is explicitly limited to intentionally ignited fires. But managed wildfire sometimes is included under the definition of prescribed fire, especially in cases where a plan of action (prescription) is in place prior to an unplanned ignition and then implemented after the ignition occurs.

Despite extensive experience with its use and knowledge regarding its effectiveness, intentionally ignited prescribed fires remain logistically complex and require significant financial and human resources. Prescribed fire can also be politically controversial due to smoke emissions and limited understanding of its ecological benefits. This can further limit when and where it is used. Moreover, it is widely accepted that the land area that could benefit from prescribed fire greatly exceeds the resources available to implement treatments. Managers generally agree that as climate change effects unfold, the land area that could benefit from prescribed fire will increase, so this disconnect between the amount of area needing treatment and resources available to get the treatments accomplished is only going to widen going forward. In short, managers faced with these realities may have more incentive to try to have plans in place to manage the inevitable increase in unplanned ignitions.

The science advisors noted that the number of unplanned ignitions and the amount of land area burned will almost certainly rise in the future as a direct result of climate change effects on forests and wildfire regimes. Fire and land managers may have limited control over these ignitions but they will have some options for managing the resulting wildfires to try and achieve objectives they might otherwise address via prescribed burns. Despite the many benefits of prescribed fire use, managers usually face tight constraints on their prescriptions to minimize risk and ensure that the fires remain under control. Operating under these constraints means that prescribed fires are often less intense and encompass smaller areas than would be optimum from a strictly ecological standpoint. Thus, wildfires that burn hotter and over larger areas than would be possible in a prescribed fire may actually help achieve objectives that would be difficult or impossible to address with intentionally ignited fires. Analyzing the effects of naturally ignited fires may also help inform and improve prescriptions for prescribed fires. In any case, managers will have more ignitions to contend with in the future and thus more opportunities to manage some of the resulting fires to achieve ecological and societal goals. In coming decades, prescriptions for managing unplanned ignitions may become just as important of a tool as prescribed fire has been in the recent past.

3.4 Discussion and Conclusions

This project was primarily focused on learning more about potential approaches to identifying and assessing the science underlying climate adaptation actions, in this case the use of prescribed fire under climate change. We explored the use of a hybrid process that combined a systematic literature search and mapping process with a Science Advisory Panel workshop where subject matter experts commented on the initial results of our literature search and provided insight on the “state of science” on prescribed fire. It should be noted that the systematic search and review workshop were conducted under a very compressed timeline, compared to the time needed to conduct a robust systematic review. Therefore, tasks were modified as the project progressed. Aside from overall project goals, we had a short-term goal of finding, filtering and summarizing enough relevant literature with enough specificity to allow for a robust discussion at the review workshop.

This project has shed some light on the challenge of developing and applying explicit criteria to delineate the scope of a systematic review on a complex, multi-faceted issue. It has also shown the promise of complementing systematic review methods with input from subject matter experts.

The question that this effort addressed is largely forward looking. The majority of evidence suggests that there is rationale for the application of prescribed fire as a climate adaptation action, however, whether or not to alter its application (e.g., how or where to apply) in response to changing climatic conditions is still under investigation. Anecdotal evidence indicates that there may be opportunity to shift the timing of application by continuing fuel treatments beyond the traditional burn season. What is known fairly conclusively is that prescribed fire and fuels management can reduce the intensity and severity of wildfire at the forest stand level. At least in some cases, this finding can probably be extrapolated to climate-related effects on wildfire, to the degree that these effects can be differentiated from other human-caused effects on forestlands.

4. Outreach and Evaluation

4.1 Approach

As this was a test case of ASAPs for the NW CSC, it is important to review and evaluate the project as a whole, including what worked and what did not, ways of improving the review process, and lessons learned. The overall ASAP methodology has the potential to provide an adaptive and replicable model for science-based evaluations that can be applied to varying topics, scales, and sectors, and by many agencies and other interested parties.

Evaluation is about communication and reflection, looking not only at the activities and contributions of the project, but its connection to the NW CSC's research strategy. We have primarily used qualitative methods in the evaluation, and where appropriate, quantitative methods. Qualitative methods are best used (1) when there is an established effective model, but there is an interest in replication and the question is about how a program is implemented; and/or (2) when there is an interest in conducting a process evaluation and a desire to seek reasons why a program is not yielding the expected results. Through qualitative analysis we can better understand the frequency, specificity, and extensiveness of the how and the why.

Connection to the NW CSC's Research Strategy

This project directly supports the mission of the NW CSC (and other CSCs throughout the nation) to provide fundamental science to support management and decision-making. The NW CSC's Science Agenda for 2012-2016 emphasizes the identification of key science needs in order to more effectively prioritize funding for research that supports climate-informed actions by natural and cultural resource managers and other decision makers in the Northwest. This project addresses three of the Agenda's seven Research Themes:

1. *Response of Biological Systems to Climate Change.* This project complements the priorities of this Theme, including the understanding of changes in fire regimes and the relationship to land management and adaptation strategies.
2. *Vulnerability and Adaptation.* Methods used in this project identified characteristics of fire-related vulnerabilities and adaptation actions applied by resource managers, and evaluated the science behind actions that may inform (if not improve) management decisions in national forests.
3. *Communication of Science Findings.* This project uses a full suite of engagement methods to communicate scientific information to stakeholders, including interviews, websites, workshops, presentations, and webinars.

Outreach and Stakeholder Engagement

INR and EcoAdapt are committed to creating useful and usable products; as such, we have engaged project sponsors, users, and key stakeholders throughout the project, including NWCSC staff, the ESAC, as well as scientists and managers. Stakeholders were engaged in a variety of ways throughout the duration of this project.

Online

A project-specific webpage (http://bit.ly/ASAPFire) was created to describe the project, inform stakeholders how they could suggest scientific studies for consideration, and provide project contact information, among other necessary information. The site was viewed 258 times between September 2014 and November 2015.

In-person

This project was prominently featured and well received at two conferences in 2015: the National Adaptation Forum and the Northwest Climate Conference.

- During the National Adaptation Forum (May 2015, St. Louis, MO), ASAP was a featured talk during a well-attended session (~50-60 people) entitled "Supporting Climate-Informed Decision-Making in Natural Resource Management: Innovative New Tools and Approaches from Western North America." Conversations with participants afterwards led to suggestions for additional literature to review in Phase 3 as well as a specific request to discuss and potentially incorporate the project's findings into ESSA Technologies Ltd.'s Forest Vegetation Simulator.
- At the 2015 Northwest Climate Conference, ASAP was featured during a session entitled "Adaptation and Working Across Boundaries." Attendees were particularly interested in the final products and how applicable the methods could be for other topics.

ASAP was also presented at three NW CSC ESAC meetings to discuss different aspects of the project, including the project concept and its relevance to the NW CSC agenda, and to present the project's final results. Several committee members expressed interest in the ASAP process, its transferability to other organizations, and its link to actionable science.

2016 Scientists-Managers Workshop

In an effort to share the results of the ASAP and discuss future management directions that may require additional scientific research, the project team hosted a workshop on prescribed fire, fuels treatments, and climate change in April 2016. The workshop summary may be found in Section 5.

4.2 Lessons Learned

General Lessons Learned

A number of lessons came out of this pilot of the ASAP process that inform our thinking about future ASAP processes.

Conduct "Helpful Hint" Conversations

Instrumental to the shaping of the project, once awarded, were a series of "helpful hint" conversations and/or correspondence with numerous climate, fire management, and/or fire ecology experts. These conversations were conducted before the specific fire-related climate adaptation action was identified in planning documents and interviews (Phase 2) and before moving forward with Phase 3, the systematic mapping. These interactions helped to generate interest and involvement in the project; in addition, experts provided feedback indicating:

- Interviews with resource managers would likely yield more than just conducting a content analysis of existing plans and documents;
- The amount of literature available on climate adaptation actions and fire regimes would likely be limited; and
- More literature might be available on post-fire management (e.g., seeding, prevention of soil erosion, etc.), although it would likely be focused more on restoration rather than in the context of climate change.

A colleague, who is a leading expert on systematic reviews in the United Kingdom, indicated that a systematic mapping approach might be more suited to this project rather than a traditional systematic review:

> The climate change angle may be tricky to work in…I suggest the systematic map approach so that you are gathering all the evidence you can without necessarily analysing the effect sizes at this stage. We're using the technique for a number of similar reviews. Like you, we also face the possibility that in at least one of our suite of reviews we will not be able to frame the question in a way that satisfies the purists of systematic review (in that it may not actually measure effect sizes), but we want to apply the rigour of the method of selecting literature to specified criteria and describing that body of literature in terms of what it reports. To us, this is a major contribution to the science – and goes some way (quite some way, I would argue) to reducing bias, which is important.

Throughout the project we carefully documented how and where decisions were made to keep the integrity of the project as a whole, while respecting its time and financial constraints.

Ground the project with manager input

One of the major successes of this project was the direct engagement and consultation with resource managers. These practitioners were able to provide a level of input and context that would not have been possible through a content analysis of the literature alone. Ensuring that science can effectively support climate-informed management decisions means that managers need to be engaged. Meaningful reflection and consultation with managers will advance the practice of creating "actionable science" as defined by the Advisory Committee on Climate Change and Natural Resource Science (Beier et al., 2015):

> Actionable science provides data, analyses, projections, or tools that can support decisions regarding the management of the risks and impacts of climate change. It is ideally co-produced by scientists and decision-makers and creates rigorous and accessible products to meet the needs of stakeholders.

Engage science experts throughout the project

The feedback received during the science expert workshop in June 2015 was incredibly helpful in both validating the project approach and methods, and refining the review protocol and questions. Engaging with scientists from the beginning of future ASAPs through more formal structures, such as advisory committees or panels, will benefit future projects by building off of scientists' knowledge and experience in a collaborative, efficient, and effective manner. In this pilot project, for example, complementing the systematic mapping with an expert panel provided significant benefits in focusing the review question, expanding the bounds for the literature search, and finding additional literature that the systematic search did not uncover.

Use systematic mapping rather than systematic review methods

A "standard model" systematic review focuses tightly on direct evidence for effectiveness of an active intervention to address a particular problem – i.e. does it work or not? Since the goal of this project was to test a process for these reviews, identifying bounds or sideboards for the literature search was challenging. Systematic mapping follows the same process and rigor of systematic reviews, but does *not* attempt to synthesize the scientific evidence in order to answer the question(s). Instead it illustrates the current state and trajectory of knowledge around a particular area of interest. Such a systematic, iterative approach to identifying the review question(s) and an objective, transparent search strategy allowed for the discovery of a considerable amount of relevant literature. Since there was voluminous literature related to our review question, identifying and excluding the "settled" science that frames the question was necessary to make the literature review manageable. In this case, the "settled" science included evidence that (1) prescribed fire can be effective at the stand level in helping reduce fuels and fire effects, and (2) large areas of Northwest forests are likely to be hotter and drier in the future due to climate change with associated increases in wildfire intensity, severity, and extent.

Implications for Future ASAPs

Because this project specifically reviewed fire-related climate adaptation actions in regional national forests, it would be interesting to conduct an additional analysis of these climate adaptation actions as they are applied in other CSC regions as well as how they are used by different land management entities, such as federal, state, and tribal managers.

The next iteration of the ASAP will focus on examining the supporting science behind climate adaptation actions taken to address sea level rise in Washington and Oregon. Using the lessons learned during this pilot project, we have altered our methodology to emphasize expert elicitation by engaging with a Science Advisory Panel throughout the project lifetime through both consultation and co-creation of products. Managers will again be critical in providing the context around the application of climate adaptation actions in response to sea level rise and coastal change, and a scientists-managers workshop will be held to facilitate the discussion of future management directions that may require additional scientific research.

In addition to climate stressor-focused projects, future ASAPs could examine climate adaptation actions aggregated by region, ecosystem, species, and/or relevance to human health and infrastructure.

4.3 Key Findings on Prescribed Fire Use and Climate Change

Climate-driven changes in fire regimes are emerging as significant management challenges in Northwest national forests. Prescribed fire is implemented by forest managers in the region to achieve a variety of management objectives, including climate adaptation, and has a broader application than other fuels treatments as it can be used alone or sequentially with other actions (e.g., thinning, mechanical fuel treatments). As a climate adaptation action, prescribed fire reduces the risk of catastrophic or stand-replacing fire by targeting and reducing surface and ladder fuels; allows for the re-introduction of natural fire regimes; and prepares the landscape for the re-establishment of fire-tolerant native species that may be better adapted to projected climatic changes and shifting fire regimes.

The majority of evidence found suggests that the rationale and conditions for use of prescribed fire are evolving in response to climate-related shifts in fire regimes; comparatively, there is less evidence discussing alteration of the mechanics of the tool itself in light of climate change. Anecdotal evidence indicates that there might be opportunity to shift the timing of its application by continuing fuel treatments beyond the traditional burn season.

Most of the relevant literature found summarized how climate change is affecting wildfire regimes and forest ecosystems, and then discussed (and sometimes tested) how established fuels reduction methods and tools – including prescribed fire – could be used to address these effects. Key themes in the relevant literature included:

a. The potential for forest vegetation or habitat expansion, contraction, or conversion, and how these events could affect decisions about where to apply fuels treatments.

b. The socio-political considerations of prescribed fire use in a changing climate, such as how to incorporate climate information into fire planning and management, the costs and benefits of prescribed fire, and public perceptions about prescribed fires (e.g., public aesthetics and smoke health concerns), all of which may restrict the range of management options for national forest managers.

c. How to maintain or enhance forest carbon stocks or "carbon carrying capacity" via fuels treatments, including prescribed fire. Western forests currently sequester nearly 100 million tons of carbon each year, but this sink is threatened by projected increases in wildfire area burned and severity. We found debate and little apparent consensus regarding the potential for active forest management to significantly affect this carbon sink. Findings vary widely depending on spatial and temporal scope of analysis and model assumptions regarding future wildfire probabilities, severity, and extent.

Managed wildfire is likely to play a larger role in fuels reduction in the future, as the conventional understanding and use of prescribed fire may evolve and overlap with the management of naturally ignited fires. The number of unplanned ignitions and the amount of land area burned will almost certainly rise in the future as a direct result of climate change impacts on forests and fire regimes. Fire and land managers may have limited control over these ignitions but they will have some options for managing the resulting wildfires to try and achieve objectives that would be difficult or impossible to address with intentionally ignited fires. Analyzing the effects of naturally ignited fires may help inform and improve prescriptions for prescribed fires. In any case, managers will have more ignitions to contend with in the future and thus more opportunities to manage some of the resulting fires to achieve ecological and societal goals.

5. Scientists-Managers Workshop Summary

5.1 Introduction

In April 2016, EcoAdapt and the Institute for Natural Resources held a workshop to culminate the pilot ASAP process, and to bring managers and scientists together for broader discussions regarding fire and fuels management in the context of climate change. The workshop was held in conjunction with the 5th International Fire Behavior and Fuels Conference in Portland, Oregon, and hosted in collaboration with the Northwest Fire Science Consortium and Northern Rockies Fire Science Network. The workshop featured a mix of presentations, four large group discussions, and small group discussions held during a "Solutions Room" exercise, wherein participants worked through guided worksheets with group facilitators. Thirty-six participants from 30 organizations attended the workshop, including representatives from federal and state agencies, tribal governments, and non-profit organizations, as well as academic and applied scientists. Participants came from a broad range of backgrounds and expertise, including fire management officers, forestry technicians, ecologists, smoke management coordinators, and more. The workshop participant list and full workshop agenda may be found in Appendices F and G, respectively.

5.2 Goals and Objectives

The workshop was designed to build upon interviews with national forest managers who manage resources under shifting fire regimes, a systematic mapping of relevant literature, and an earlier science review panel discussion of the state of the science behind prescribed fire use under changing climate conditions. The workshop was convened to:

- Document knowledge of how fuels management is changing in response to shifts in climate and fire regimes;
- Explore opportunities for further integration of scientific research and climate-informed management;
- Discuss agency plans and priorities for managing fire (with specific reference to the role of prescribed fire) under changing climate conditions;
- Describe the intended management application of desired future research and products on fire and fuels management;
- Develop partnerships between fire experts and forest/fire managers to ensure future research is addressing specific management needs;
- Explore and develop new methods for managing fire and fuels in a changing climate; and
- Help identify and refine funding priorities in the area of fire regimes and climate change.

5.3 Overview of Presentations

Presentation: ASAP Project Background & Process Review

Rachel M. Gregg, EcoAdapt

Ms. Gregg provided a welcome to workshop participants and an introduction to the ASAP process. This included an overview of climate adaptation planning and a review of the four phases of the project, including:

- **Phase 1** to determine the scope and scale of ASAPs by reviewing national and regional climate change strategy documents to identify the most important and oft-cited climate stressors. This review suggested that projected climate-induced changes to fire dynamics in the Northwest were a major concern to management agencies;
- **Phase 2** to identify specific fire-related climate adaptation actions in use in regional national forests through a content analysis of fire-related forest plans and resources as well as interviews with managers. This phase identified prescribed fire as the climate adaptation action used most broadly in terms of purpose and scale throughout the region;
- **Phase 3** to conduct a systematic review/mapping of the scientific evidence supporting the use of prescribed fire, followed by an expert Science Advisory Panel workshop; and
- **Phase 4** to discuss and ground-truth the findings with managers and scientists, and to evaluate the processes used throughout the project.

Presentation: Reviewing the ASAP findings

Jeff Behan, Institute for Natural Resources

Mr. Behan provided a brief overview of systematic review (SR) techniques as they are used in the medical field to find and synthesize science information that is relevant to specific questions, and considerations when applying SR to questions in ecology and natural resource management. He then explained the systematic search strategy used by to find literature that explicitly linked prescribed fire use with climate change, and summarized the results of the literature search and the feedback received from subject matter experts at the 2015 science review panel meeting. Behan noted that the review question did not encompass a distinct discipline with agreed upon, commonly used keywords knitting it together. Systematic review of complex and diverse literature bases for climate adaptation actions cannot rely solely on strict keyword searches. In addition to augmentation using more traditional methods (e.g. searching bibliographies of relevant literature), applying SR in climate adaptation research requires using the tools in novel ways, especially through supplemental efforts such as workshops, to document institutional knowledge and stimulate participatory learning to complement and expand on knowledge synthesized from literature searches.

5.4 Discussion #1: Prescribed Fire Scientific Consensus

The first large group discussion focused on workshop participants' reflections on the ASAP methods and how the scientific literature findings correlated to managers' experiences on the ground.

Reflections on Methods

Participants discussed alternative literature pools that could have yielded additional literature relevant to the research questions, including those focused on:

- *Risk aversion tactics* used in fire and fuels management;

– *Economic feasibility* and comparison studies of fuels treatments, suppression activities, and managed natural fires (i.e. "let it burn");
– *Institutional policy/legal policy analyses* (specifically for federal agencies) that may help identify institutional constraints that dictate when and where managers can implement certain actions (e.g., air and water quality regulations enforced by the U.S. Environmental Protection Agency); and
– *Invasive species effects,* particularly for rangelands where invasive species distributions may be more tightly linked with fire regime shifts rather than in forests that may experience fuel buildup independent of invasive species presence.

Participants also discussed several aspects of the systematic literature review method used in this project, which may prove useful to consider for future ASAPs. These included:

– *Re-examining the treatment of the "settled science" in the systematic review.* Two categories of supporting or "settled" science were identified in order to focus the review: 1) that prescribed fire can be effective at the stand level in helping reduce fuels and fire effects, and 2) that large areas of Northwest forests are likely to be hotter and drier in the future due to climate change, with associated increases in wildfire. Participants noted that both research areas are subject to uncertainty in the models and data upon which they are grounded, and explicit consideration of data gaps would enhance the findings.
– *Accommodating or documenting uncertainty in studies.* Overall, participants noted that documenting and/or quantifying uncertainty would have made the literature review more robust. Although exploring uncertainty was beyond the scope of this particular project, traditional systematic literature reviews are typically conducted by subject experts, who might help address these considerations.
– *Expanding the bounds of the literature search.* Including research from other geographies (e.g., Australia, rangelands) may have provided more detail and/or clarity in the systematic review findings.
– *Exploring additional literature review methods.* Other literature review methods and frameworks exist that could be used to meet ASAP goals; one attendee suggested the EPA National Center for Environmental Assessment's five-year integrated science assessments.[13]

Reflections on Findings

Managers were asked to reflect specifically on how the literature findings compared to their personal experiences. Participant comments included:

– *Lack of research linking prescribed fire and climate change is not surprising.* Prescribed fire has not been used and studied at the scale and scope necessary to effectively address climate change.
– *Fire regime changes are affecting the use of prescribed fire on the ground.* The seasonality of prescribed fire use is changing across the western United States; spring burn windows are

[13] http://ofmpub.epa.gov/eims/eimscomm.getfile?p_download_id=526136

occurring earlier, while the fall fire season is lasting longer into the early winter because of reduced snowfall. In addition, reduced snowpack, variable weather conditions and stronger wind events, and phenological shifts in vegetation are challenging managers' use of prescribed fire.

- *Evidence of altered management practices in response to a changing climate.* Some managers are treating areas that are more resilient in order to maintain them, rather than focusing on areas with higher fire risk. There also appears to be an interest in shifting the use of various fuels treatments (e.g., increased pile and broadcast burning, managed wildfire), but these options are limited by sociopolitical constraints.
- *Sociopolitical limitations on prescribed fire use.* These limitations include resource constraints, liability issues, and a lack of public acceptance of fire and smoke on the landscape.
    - A lack of financial and institutional capacity (i.e., funding, number of staff, trained staff) constrains the seasonal use and scale of prescribed fire, particularly for federal, tribal, and state agencies. This frequently manifests in a mismatch between ecological burn windows and available staffing and funding; a key need identified was to enable shifts in resource allocations, capacities, and timing to better match suitable fire and treatment conditions on the landscape, which may require agency adjustments to hire a more permanent workforce (e.g., firefighters, burn officers, etc.).
    - Liability issues are a constraint for all land managers.
    - Public acceptance of smoke and large landscape burns limits the scale of prescribed fire and managed wildfire use, including agency permissions to use natural ignitions.

5.5 Discussion #2: Incorporating Climate Change into Prescribed Fire Application

The second large group discussion focused on the implementation conditions behind prescribed fire use in a changing climate. This included discussions of the benefits, risks, and uncertainties associated with prescribed fire application, as well as the most and least suitable conditions –both ecological and sociopolitical – for applying fire under current conditions and future scenarios.

Benefits, Risks, and Uncertainties Associated with Prescribed Fire Use

Participant comments related to the benefits, risks, and uncertainties of prescribed fire application under current and future conditions are provided in Tables 12-14. In general, participants indicated some concerns regarding how prescribed fire could continue to garner ecological and sociopolitical benefits in a changing climate, and if altered treatment windows may force a shift away from prescribed fire as a management tool. Discussions also covered how prescribed fire may be used to maintain carbon stocks, provide silvicultural benefits, and increase firefighter safety by removing hazardous fuel loads.

Table 12. Benefits associated with prescribed fire use under current and future conditions.

Current Conditions	*Future Conditions*
Ecological: • Enhances nutrient cycling • Promotes biodiversity (stimulates unique fire-dependent species) • Creates landscape patchiness and heterogeneity • Mitigates wildfire risk (debatable); reduces surface fuels and wildfire behavior depending on treatment scales (spatial + temporal)	Participant discussion focused on describing how the benefits associated with prescribed fire will be reduced, rather than maintained, under future conditions. *Ecological:* • Possible reduced/altered silvicultural benefits (drier conditions, enhanced tree mortality) • Altered heterogeneity and species composition, particularly with respect to proliferation of non-native species • Possible unintended ecological interactions (e.g., mortality) • Reduced wildlife habitat provisioning • Increased bark beetle infestation altering scale of treatments needed
Sociopolitical: • Tends to be more socially acceptable than natural wildfires, although there are tradeoffs between smoke production (natural vs. prescribed fire); education needed • Acts as a good training tool – controlled environment to meet training objectives • Allows for more controlled conditions to support firefighter safety • Supports medicinal and cultural uses • Economically feasible • Provides silvicultural benefits	*Sociopolitical:* • Continued funding issues – money for treatments lacking • Mismatch in synchronization between natural resources management and funding availability • Rapid expansion of wildland-urban interface (WUI) and increased infrastructure density will change fire interactions, may shift public acceptance/success rate, and will increase the number of WUI resources needing protection (primary and secondary homes)

Table 13. Risks associated with prescribed fire use under current and future conditions.

Current Conditions	*Future Conditions*
Ecological: • Unintended effect of spreading invasive weeds and/or exotic species • Noted increase in bark beetle infestation and associated tree mortality after prescribed fire use in the region • Higher tree mortality associated with mastication treatments due to heat timelag/heat above lethal levels • Often requires mechanical treatments prior to prescribed fire application in order to achieve management objectives, especially in areas that have not burned in a long time	*Ecological:* • Scale of treatments across the landscape will likely continue to be limited by funding, social acceptance, and management capacity • Uncertainty around several issues, including: o Increased mortality o Phenology decoupling o Early green-up o Species composition after large disturbances (primary v. secondary species, invasives)
Sociopolitical: • Prescribed fire action is limited by: o Access to adequate funding o Smoke regulation and management o Air quality regulations, which are variable depending on location, and sometimes result in mismatch with ideal ecological burn windows (spring vs. fall) as well as management capacity o Legal/institutional constraints o Public acceptance o Public trust for agency action • Public education and marketing for prescribed fire use ("marketing the mission") with a location-specific context; currently better communication on fire suppression • Guidelines for using tribal/traditional knowledge (missing from some tribes)	*Sociopolitical:* • Continued funding issues: allocation vs. timing (funding in spring, burn windows in fall, taking risk in allocations) • Multiple land owners and associated competing objectives

Table 14. Uncertainties associated with prescribed fire use under current and future conditions.	
Current Conditions	*Future Conditions*
Ecological: • Effects on species composition shifts • Effects on ecological function (i.e. biogeochemical cycling, cascading effects) • Effects on invasive species presence vs. removal • Effects on ecosystem service provisioning: water production • Long-term impacts of mega-fires • Does prescribed fire fit within historic range of variability?	*Ecological:* • Reduced ability to rely on climate records; how will climate change manifest on the landscape? • Rate and magnitude of change • Is historic range of variability a relevant context anymore? • Moving targets: What is a "desired" future condition? How can that be determined? • Ecological fire effects
Sociopolitical: • Ebb and flow of funding availability: allocation vs. timing (money in spring, burn windows in fall, taking risk in allocations) • Carbon calculations • Smoke quantities • Water availability for suppression • Management turnover • Fire policy keeping pace with landscape changes	*Sociopolitical:* • Public perception: fire suppression vs. advanced treatment, may invest more resources in advanced treatment but have same outcome • Competing management objectives: e.g., water availability for suppression vs. other management goals (fish, water provisioning) during drought periods • Fire policy keeping pace with landscape changes • Effect of increased populations on the firefighting and fire management workforce

Enabling Conditions and Opportunities

Participants also discussed the most and least suitable conditions for applying prescribed fire and if and how climate change may affect these factors.

Management conditions/opportunities

- *Building capacity*
  - *Offering training opportunities to increase qualified staff and leadership*. Management experience with prescribed burning increases the likelihood of fire being used on the landscape. Training will also enable managers to feel like they have the resources and knowledge to make tough decisions, and improve agency/line officer's ability to approve burn plans, which leads to increased willingness to take risks to achieve management objectives.
  - *Increasing cross-jurisdictional work*. Increasing collaborative agreements on prescribed fire use across land facets and ownerships will likely increase successful prescribed fire implementation.
  - *Creating a more permanent workforce with more flexibility in job descriptions*. Position permanency and reduced turnover will help to build public trust in agency decision making around fire. More flexibility in staffing would allow for employees to act as both managers and firefighters to bridge the gap between fire and fuels management and fire suppression.
- *Changing the management paradigm* (i.e., no more "business as usual")
  - *Cultivating a more supportive management environment*. There are currently severe consequences for negative effects of prescriptions, including job loss and/or legal suits, which cascades through all management levels, including burn bosses.
  - *Adapting lessons learned from other management structures*, such as:
    - Australia, which employs prescribed fire depending on resources on the landscape. Responsibility is split between federal and private management (i.e., state and local governments, grape growers, etc.).
    - Alaska, which pursues fire management strategies based on four responses: (1) Critical, (2) Full, (3) Modified, and (4) Limited. **Critical** protection occurs when fire threatens human life, inhabited property, and important structural resources, in order to provide complete protection and control fire at the smallest scale possible, while **limited** protection occurs where fire can help achieve multiple land and resource objectives and/or where monitoring and surveillance of fire response is appropriate (Alaska Department of Natural Resources, 2010).
    - The Tribal Forest Protection Act, which authorizes tribal stewardship, including protection and restoration, of federal lands adjacent to tribal lands to protect tribal forest resources from fire and other threats that emerge from Forest Service or Bureau of Land Management lands (USDA Forest Service, 2005).

Funding conditions/opportunities

- *Increasing amount and flexibility in funding streams*. Prescribed fire is underfunded now and treatments will likely be more costly in the future. Variability in funding availability and when it is needed is and will continue to be an issue (e.g., burn windows do not always match funding cycle), and targeted funding allocation will be needed. Agencies cannot only fund fire suppression/smoke jumpers; they will need to create and cultivate ecological management funding streams for fire.
- *Improving budgeting and monitoring/reporting costs*. Overinflated funding requests are a current problem, which creates funder exhaustion. Managers need to do a better job asking for more accurate amounts to reduce overburdening funders. Better accounting of projected and actual costs, as well as monitoring and documenting accomplishments, could help facilitate this; however, managers need a better idea of the type of data that needs to be gathered to appropriately reflect costs and accomplishments.

Ecological conditions/opportunities

- *Prioritizing burn times*. Prescribed fire application can be prioritized during periods of higher moisture (e.g., wait for forecasted rain, higher humidity, etc.).
- *Maintaining fire on the landscape when possible*. Using natural and prescribed fire, managers can identify areas where fire is functioning in its natural role and not interfere and/or conduct maintenance burning in resilient landscapes and low-risk areas.

Sociopolitical conditions/opportunities

- *Altering public perception of fire*. Prescribed fire use could be enhanced in the region by changing the public discourse on the overall role of fire on the landscape.
  - Fire is an integral component of tribal cultural language and stories of many tribes in the region; historic use of this tool has created resilient landscapes on tribal lands.
  - Managers could aim to create a supportive and/or celebratory culture around burning, similar to the agency acceptance and public perception of fire suppression activities.
  - Increasing the visibility of Prescribed Fire Councils may enhance public acceptance of prescribed fire as a tool to maintain and improve natural resources and aid in public safety.
- *Accounting for increasing risks associated with prescribed fire application*. As population growth increases, the WUI is also expanding, which may lead to increased costs, expanded smoke regulations, and legal concerns with respect to public safety.

5.6 Solutions Room Activity and Discussion #3: Incorporating Climate Change into Fire and Fuels Management

The purpose of the Solutions Room workshop activity was to allow attendees to delve more deeply into specific fire-related climate adaptation actions. The goal was to elicit major barriers, opportunities, and resource and research needs for fuels management practices under changing climate conditions. The process included creating four small breakout groups arranged by management activity:

1. Prescribed Fire
2. Thinning/Mechanical Fuels Treatments
3. Managed Wildfire
4. Seeding/Planting Post-Fire

Attendees were asked to self-select a breakout group. With the help of a group facilitator, each person completed an individual worksheet and then shared their comments within a small group discussion. Each group identified major themes from each worksheet question and selected one participant to report back their findings to the larger group. Tables 15-18 present these major themes by each of the four management activities.

Table 15. Prescribed fire themes identified by workshop participants.	
Purpose(s)	• Restore landscape • Promote/retain wildlife habitat • Reduce hazardous fuels • Reduce crown density
Climate change impacts that affect implementation	• Increased air temperatures and extreme heat events dry fuels • Precipitation changes leading to longer and more intense droughts Drought already causes tree stress; prescribed fire may further stress species • Decreased snowpack and earlier snowmelt – less pile burn time, more opportunities for broadcast burns • Decreased soil moisture leading to species changes • Decreased relative humidity – several occurrences in the teens (too low to burn) • Altered windspeed – experiencing more high winds in fall and spring • Insect and disease outbreaks - burning in areas where there are bug-killed trees is possible, but there are concerns about placing additional stress on trees via burning

Climate-informed actions (± indicates a potential co-benefit or tradeoff)	1. Get more prescribed fire on the ground (e.g., aerial ignitions, bigger blocks, contract firefighting resources)
	    • ± Less experience/more risk associated with contracted resources
	2. Treat more areas at more times of year
	3. Plan for species conversion in some places
	    • ± Reduced wildfire loads
	    • ± Potential increased costs, more activity leading to more conflict with wildlife
	4. Change the time of year burns are conducted (e.g., earlier burn window start/close)
	    • ± Better burn windows under more moderate weather conditions
	    • ± Might have wetter fuels and higher relative humidity when burning later in the year
	5. Do more with less funding by altering management approach (e.g., use aerial platforms/ignitions farther from human communities to treat larger landscapes)

Implementation barriers	• Policy/politics (e.g., smoke management/policy; wildlife conflicts) • Legal issues • Sociopolitical issues (i.e. public perception of smoke is bad) • Economics (i.e. majority of fuels funds go towards non-hazardous fuels projects and not every project pays for itself; fire dollars are also skewed toward fire suppression rather than prevention) • Institutional capacity (i.e. reduced personnel) • Ecological issues • Entire thought process is antiquated and needs to be updated to effectively address climate change

Table 15 (continued). Prescribed fire themes identified by workshop participants.	
Resources needed	*Information/Research* • Understanding of effects of smoke and air quality *Communication* • Linking concept that more prescribed fire leads to less smoke impacts from wildfire • Communication of the benefits of prescribed fire is needed *Collaboration* • More funding specifically for ecosystem management (rather than more suppression) *Education* • More training of staff to become qualified to implement prescribed fires
Opportunities	*Communication* • Social media (i.e. Twitter, Facebook) • Interactive, online prescribed fire maps • Collaborative websites • Large, broad-based marketing strategy coordinated by hired professionals *Collaboration* • Prescribed Fire Councils – utilize their connections and political muscle to influence policy • Use contracts to secure funding that spans fiscal years

Table 16. Managed wildfire/Wildfire managed for multiple objectives themes identified by workshop participants.	
Purpose(s)	• Pursued when and where firefighter safety is a concern • Typically in pre-defined locations and under certain conditions (i.e. preparedness levels, local resource availability, etc.) • Protect life, safety, and property; this natural process can be manipulated to fulfill objectives of land managers, silviculturists, ecologists, and more
Climate change impacts that affect implementation	• All climate change impacts can present problems when referring to management objectives; under climate change, fire behavior will present a big issue, along with firefighter and public safety • Increased temperatures – increase fire behavior/severity and increase risk of fire • Precipitation changes – lower/less precipitation makes fuels more volatile and increases risk • Increased drought – makes fuels more volatile and increases risk; drought-stressed areas exhibit less resilience to fire where under normal conditions fire could be used as an effective tool for control • Reduced snowpack – less moisture available for fuels, more runoff and less storage • Earlier snowmelt – longer burn periods, seasonal staff not yet available • Decreased soil moisture – increased tree mortality, permafrost melt, drier fuels • Decreased relative humidity and altered windspeed – increased fire behavior outside of beneficial parameters (may also occur with increased temperatures, altered precipitation, drought, and changes in snowpack) • Altered windspeed – wind shifts increase danger and may limit resources • Insect and disease outbreaks – may change times when appropriate to use (e.g., late in summer), lead to more volatile fuels
Climate-informed actions (± indicates a potential co-benefit or tradeoff)	1. Increase use of fuels treatments around values/boundaries 2. Increase education to promote use of wildfire managed for multiple objectives
Implementation barriers	• Lack of resources – funding/spending mechanism • Policy/politics – agency/administrator and public buy-in, finding champions in government. Difficulty sharing the vision with a suppression-oriented workforce • Legal issues – burn boss “blamed” if there is a fatality or loss of property. Requires more responsibility, so what is the incentive? • Sociopolitical issues – local public safety, aesthetics associated with fire and smoke. Public view of fire and air quality. Accepting that with more fire on the landscape there will be more smoke in the air • Lack of knowledge – the future is hard to predict • Institutional capacity – preparedness levels limiting resource availability. Line officers are risk adverse. Staffing levels. Not enough qualified personnel to adequately manage • Ecological issues – determining what beneficial is to different resource areas. Fire may kill more trees. Further deviation from natural process

Table 16 (continued). Managed wildfire/Wildfire managed for multiple objectives themes identified by workshop participants.	
Implementation barriers (continued)	• Lack of knowledge – loss of knowledge through retirements/lack of use and practice • Uncertainty – earlier and/or later fire seasons? A lot of unknowns • Existing plans and objectives do not match conditions under climate change • Difficult to explain to public and adjacent land owners
Resources needed	*Information/Research* • Make scientific and gray literature more accessible *Communication* • Engage the public, including adjacent land owners *Education* • Take Congressional staffers on field trips out to fires • Everybody can be a messenger – increase communication training for staff on burn issues in public speaking • Practice line officer rotation – individual officers gain experience, offsets agency exhaustion
Opportunities	*Communication* • Share success stories. If a fire is not engaged due to firefighter safety *and* it meets resource objectives, share that story! • Teach public speaking to burn bosses so they can become ambassadors for fire

Table 17. Thinning/Mechanical fuels treatments themes identified by workshop participants.	
Purpose(s)	• Reduce crown load • Reduce high density stands • Protect the WUI • Reduce surface and ladder fuels and fire access to canopy • Prepare the landscape for prescribed fire or other further treatment • Forest restoration (e.g., favoring fire-tolerant species, creating patch dynamics within and amongst stands)
Climate change impacts that affect implementation	• Decreased snowpack – most mastication is done under "snow-on" conditions • Decreased soil moisture – low soil moisture limits the utility of and increases mop-up effort required for masticated fuels • Warmer and drier conditions, reduced soil moisture, and drought – increases fire risk, rendering risk reduction treatments ineffective; creates uncertainty around ideal thinning density; may shift species composition • Insect and disease outbreaks – uncertain impacts of mastication on insect and disease in remnant trees; need to avoid "drawing" insects to remnant trees

Climate-informed actions (± indicates a potential co-benefit or tradeoff)	1. Start underburning or removal of masticated fuels onsite
	  • ± Fuel for pellet plants
	  • ± Risk of torching in intact trees
	2. Plan these mastication treatments for regeneration – seed trees
	  • ± Cost/lack of knowledge on successional trajectories
	3. Continue mechanical treatments even without snow
	  • ± Enhances fire resilience, but may increase soil disturbance and invasive species risk
	  • ± Reduce long-term management costs
	4. Bundle/bale masticated trees for use as bio-energy for local communities
	  • ± Reduces surface fuels
	  • ± Increased treatment costs
	5. Treat larger acreages
	  • ± Increased cost, particularly if no use/value for slash material

Implementation barriers	• Economics – unknown market for masticated fuels, lack of fuels transportation options • Lack of research – do not have good guidelines for mulch underburning • Sociopolitical – institutional and political barriers for treatments • Management is typically focused single species, not landscapes

Table 17 (continued). Thinning/Mechanical fuels treatments themes identified by workshop participants.	
Resources needed	*Information/Research* • Identify if there is a market for masticated fuels • Ecological research on scaling thinning to landscape scale; ecological research is pretty solid on thinning effectiveness/treatment types at the stand level, but some questions about scaling up to landscape level remain *Collaboration* • Altering sociopolitical paradigms for managing at the landscape scale • Interagency and cross-jurisdictional collaboration
Opportunities	*Collaboration* • Thinning is a very accepted treatment on private lands – create shared objectives and subsequent prescription that will occur with thinning. Great place to build on the story that agencies tell the public. • Technology for bundling/baling fuels exists • Collaborative groups could help with planning and sociopolitical outreach to reduce chances of litigation/appeal with policy changes

Table 18. Seeding/Planting post-fire themes identified by workshop participants.	
Purpose(s)	• Tied to suppression and Burned Area Emergency Response (BAER) funds, weed control and watershed restoration • Typically occurs 10 days to 2 weeks after fires • Aerial seeding of grasses and herbs
Climate change impacts that affect implementation	Seedling success is typically poor and could get worse under climate change. • Increased air temperatures and extreme heat events • Precipitation changes, especially in shoulder seasons: increased precipitation in spring and fall can possibly provide opportunities • Intense storm events – may affect success and timing of seeding, as well as the choice of what species to seed • Increased drought – different species may be appropriate depending on status • Decreased snowpack – may reduce opportunities to seed on snow, which is more effective • Earlier snowmelt – may affect seeding success and appropriate seeding rates • Decreased soil moisture – lower success rates • Decreased relative humidity • Increased fire frequency may reduce success and seed availability over larger burn areas

Climate-informed actions (± indicates a potential co-benefit or tradeoff)	1. Planting climate-adapted species
	  • ± Stabilization of site, long-term restoration
	  • ± Uncertainty – new species may fail
	  • ± Decisions often too hurried (i.e. funding available within two weeks after a fire and needs to be allocated)
	2. Assisted migration
	  • ± Pressure to "do something" but may be the wrong thing
	3. Change seeding windows
	  • ± May mismatch with crew availability
	4. Maintain appropriate seed sources and seed volume

Implementation barriers	• Understanding where seed sources come from and strategically planting species • Access to post-fire sites • Currently planting based on current climate, not necessarily future
Resources needed	*Information/Research* • Seed pillows for drought • Research on projections associated with species migration • Autecology of species • Hybridization of seeds and plants and effects on success • Long-term monitoring

Table 18 (continued). Seeding/Planting post-fire themes identified by workshop participants.	
Resources needed (continued)	*Education* • Connecting the public with research • Linking climate with resources of value (e.g., medicinal plants and animals)
Opportunities	• Funding available right after fire via BAER Program • "Tragic to Magic" app: getting people engaged through an app, demonstrating reforestation success • Public meetings: incorporate climate change communication

5.7 Discussion #4: Identifying Critical Research and Management Needs

The last large group discussion of the workshop focused on management needs and the co-generation of critical research. The following themes emerged.

- *Existing forest and land management frameworks can complicate the effective integration of climate change science*.
    - Managers still struggle to get buy-in on basic forest ecology principles (e.g., treating open ponderosa pine); climate change adds an additional complication to these conversations, limiting management opportunities.
    - There is some disconnect between the availability and integration of climate science and day-to-day management, as the majority of fire management decisions occur on a reactive basis.
    - Landscape successional trajectories are used in forest planning processes, which need to incorporate new science and modeling in plan updates; however, these updates can take several years or more to complete. Attendees agreed that there is a need for more dynamic ways to interject the best available science into management frameworks, including allowing for continual plan and policy updates as new science emerges.
    - Adaptive management may be the best way to incorporate climate science, as it allows for the purposeful accounting of the implementation of specific actions, including monitoring what is and is not working, so any needed adjustments can be made.

- *Additional research could help fill knowledge gaps with respect to how climate change may affect the use of existing fire management actions*. Attendees indicated that more social science research is needed on all of the fire-related climate adaptation actions, especially with respect to public health and safety (i.e. smoke and wildfire risk avoidance/acceptance) and associated legal issues. Within each management activity, more information is also needed on:
    - Prescribed fire: maintenance burns – seasonality and frequency (currently few replicates beyond 2-3 retreatments), fuel density, context of prescribed fire plus climate change and interactions between drought stress, beetle risk, and tree/shrub mortality;
    - Thinning: scaling from stand to landscape levels, appropriate thinning density to mitigate altered fire risk and moisture stress;
    - Managed wildfire: opportunities to let fire burn and consequences at different scales;
    - Seeding/planting: life histories and ecologies, adaptability to current vs. future climates.

- *Additional areas of study could inform new or adjusted actions that are suitable for managing fire under changing climate conditions*. Studies are needed for:
    - Quantifying fuels treatment effectiveness: There is some disconnect between the information yielded by models (i.e. where to put treatments and how) and what managers are seeing or experiencing on landscape (i.e. resilient areas).
    - Tradeoffs analyses: Comparing different scenarios (especially with respect to smoke), economic costs, and agency policies across different treatment types would provide more clarity on the consequences of and justifications for certain decisions.

- Black and brown carbon analyses: Studies examining how fire affects short-term climate forcing (i.e. black carbon reducing glacier albedo) is needed to understand potential effects on future management.
- Carbon sequestration/carbon stock research and accounting: There are significant contradictions in the literature with respect to forest carbon; accurate accounting for carbon stocks – gains and losses – will be an important management requirement in the future.
- Analysis of the effects of wildfire versus prescribed fire on different sectors of the economy.
- Utilization of forest biomass for bioenergy.

– *Barriers to communication between fire scientists and managers can constrain effective science delivery and informed decision making under climate change*.
    - There is a lot of science available to inform management, but typically not enough time for managers to digest the information. It can also be difficult to discern the quality of some scientific research; for example, attendees noted that fire management restrictions might create some complexity and/or bias in scientific experiments, inhibiting random trials.
    - Managers noted that their access to the latest science typically emerges through peer-to-peer exchanges and other networking opportunities.
    - In-person, face-to-face meetings have declined in recent years, resulting in limited manager-scientist interactions. There is a need for funding of in-person meetings to facilitate information exchange.
    - There is a need for comprehensive state of the science syntheses to provide clear direction on fire research that can effectively inform management. The Joint Fire Science Program's Fire Science Exchange Network may be able to help facilitate communicate and science delivery.
    - Additional communication opportunities include webinars, workshops, field trips to examine fire demonstration sites, and social media interactions.

5.8 Conclusion

The workshop convened scientists and managers to discuss how fire and fuels management is changing in response to shifts in climate and fire regimes. This workshop demonstrated that there are concerns from both scientists and managers about the future of prescribed fire and other fuels treatments under climate change. Institutional and sociopolitical paradigms limit current management action and flexibility, and will likely remain significant challenges in the future. Effective science delivery to managers is likewise limited due to funding and time constraints. Additionally, novel ecological challenges are likely to emerge as climate conditions change, including issues related to water stress and tree mortality and insect and disease pressure. Despite these challenges, workshop participants emphasized that collaborative research, public education and outreach, and interagency communication and collaboration may help address ecological uncertainties and pave the way for political and institutional changes to facilitate climate-informed management.

This workshop demonstrated the importance of engaging with practitioners in addition to conducting a review of the scientific literature. Along with confirming, ground-truthing, and building upon systematic mapping findings and methods, the workshop created an opportunity to collaboratively identify key research and management needs and opportunities. Overall, this workshop yielded a clearer picture about how science informs climate adaptation actions being taken, and opportunities to improve the integration of science and management.

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Appendix A

List of Representative National and Regional Climate Change Strategy Documents

This is a list of federal, tribal, state, and non-governmental organizations' climate change strategy documents used to identify high priority climate stressors to examine for the current and future ASAP installments.

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Oregon Department of Fish and Wildlife. 2008. Preparing Oregon's fish, wildlife, and habitats for future climate change: a guide for state adaptation efforts. 20 p. Available at: http://www.defenders.org/publications/oregon_adaptation_efforts.pdf.

Oregon Shores Conservation Coalition. 2015. Adapting to climate change on the Oregon Coast: a citizen's guide. 97 p. Available at: http://www.oregonshores.org/pdfs/ClimateChangeOnTheOregonCoast-March2015.pdf

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U.S. Department of the Interior (DOI) Office of Policy Analysis and DOI Climate Change Working Group. 2014. Department of the Interior climate change adaptation plan, 50 p. Available at: https://www.doi.gov/sites/doi.gov/files/migrated/greening/sustainability_plan/upload/2014_DOI_Climate_Change_Adaptation_Plan.pdf.

U.S. Environmental Protection Agency. 2012. National Water Program 2012 strategy: response to climate change, 124 p.

U.S. Environmental Protection Agency. 2014. U.S. Environmental Protection Agency climate change adaptation plan, Publication Number: EPA 100-K-14-001, 64 p. Available at: https://www3.epa.gov/climatechange/Downloads/EPA-climate-change-adaptation-plan.pdf.

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U.S. Fish and Wildlife Service. 2010. Rising to the urgent challenge: strategic plan for responding to accelerating climate change, 36 p. Available at: https://www.fws.gov/home/climatechange/pdf/CCStrategicPlan.pdf.

U.S. Forest Service. 2014. Climate change adaptation plan. 32 p. Available at: http://www.usda.gov/oce/climate_change/adaptation/Forest_Service.pdf.

U.S. Forest Service Pacific Northwest Region. 2012. Okanogan-Wenatchee National Forest restoration strategy: adaptive ecosystem management to restore landscape resiliency, 119 p. Available at: http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5340103.pdf.

Appendix B

Search Protocol

1. Background

Prescribed fire is a tool widely used by land managers to restore natural ecological processes and functions, enhance ecosystem resilience, reduce fuel loads, and minimize the risk of catastrophic wildfire damage to public and private lands and surrounding communities. There is still some uncertainty regarding the effectiveness of prescribed fire in reducing specific aspects of wildfire (e.g., severity, intensity, frequency, extent) at the landscape level, but there is extensive evidence that prescribed fire can be effective at mitigating them at the stand level.

Experts predict that climate change may alter and/or exacerbate fire regimes and associated risks across much of the western United States. It is likely that prescribed fire will continue to be an important management tool for mitigating these effects. However, the reference ecological conditions that managers often use to formulate goals for prescribed fire use – e.g. historic range of variability – may offer less useful guidance under changing climatic conditions. Anticipating and adapting management practices – e.g. prescribed fire – to account for climate-driven impacts is needed now more than ever.

To incorporate climate change into management planning, forest managers need to know the conditions under which currently held assumptions regarding the effectiveness of prescribed fire will continue to hold going forward. They need to know if there are certain conditions or ecosystems in which they may want to consider modifying the use of prescribed fire to account for projected climate effects and if so, what these conditions or ecosystems, and modifications are. The purpose of this systematic review is to uncover evidence that can shed light on these issues.

2. Review Questions

2.1 Primary question(s)

Iteration 1: What evidence of climate change effects is there (if any) that could potentially alter established scientific assumptions and consensus regarding the uses of prescribed fire to mitigate wildfire risk and effects? How might uses of prescribed fire evolve in response to climate change?

Iteration 2: In consideration of projected climate change effects, are there instances (conditions or ecosystems) in which evidence suggests that there may be benefits to modifying the ways in which prescribed fire is currently used to reduce the wildfire risk and effects? If so, what are these instances (conditions or ecosystems) and the modifications in prescribed fire use that the evidence suggests?

Iteration 3. In consideration of projected climate-driven shifts in fire regimes, what evidence is there (if any) that could potentially alter established scientific consensus regarding the use and application of prescribed fire? How might the use and application of prescribed fire evolve in response to climate change with respect to implementation conditions, techniques, time frames, scales, and locations?

- Conditions: weather, purpose, monitoring, fuel types, moisture level

- Techniques: ground ignition, aerial ignition, avoidance techniques
- Time frames: # of days, time of day, burn period
- Scale: acreage
- Locations: WUI, non-wilderness, elevation

2.2 Secondary questions

Are there any instances where the standard use and application of prescribed fire has been altered to address climate-driven shifts in wildfire regimes? If so, to what extent/in what way did implementation conditions, techniques, time frames, scales, and/or locations of prescribed fire use change?

3. Methods

3.1 Search Strategy

3.1.1 Scope of Search

We will search the following databases for relevant peer-reviewed literature and data:

- Databases supported by the Oregon State University Libraries http://guides.library.oregonstate.edu/subject-guide/Forestry?hs=a
    - Web of Science
    - Academic Search Premier
    - CAB Abstracts
    - Treesearch: US Forest Service Research Publications
    - AGRICOLA (EBSCOhost)
    - Environmental Sciences & Pollution Management
    - E.V. Komarek Fire Ecology Database
    - JSTPR Plant Science
    - GREENR
    - Earth and Environmental Sciences E-journals
- GoogleScholar
- Scopus

For grey literature we will search the following databases and organizations

- Databases
    - Treesearch: US Forest Service Research Publications: http://www.treesearch.fs.fed.us/
    - Climate Adaptation Knowledge Exchange (CAKE): www.cakex.org
    - Fire Research and Management Exchange System (FRAMES): https://www.frames.gov/
    - Template for Assessing Climate Change Impacts and Management Options (TACCIMO): http://www.taccimo.sgcp.ncsu.edu/TACCIMO/tbl_sector_list.php
    - Joint Fire Science Program Research Database https://www.firescience.gov/JFSP_research.cfm
    - Bureau of Land Management: http://www.blm.gov/wo/st/en/info/blm-library.html
    - U.S. Geological Survey Library: http://library.usgs.gov/

- U.S. Geological Survey ScienceBase: https://www.sciencebase.gov/
- USDA Forest Service Climate Change Resource Center: http://www.fs.usda.gov/ccrc/
- National Park Service library: http://www.library.nps.gov

- Organizations
  - US Forest Service Research Stations websites http://www.fs.fed.us/research/locations/
  - Washington State Department of Natural Resources: http://www.dnr.wa.gov
  - Washington Department of Ecology: http://www.ecy.wa.gov
  - Oregon Department of Forestry: http://www.oregon.gov/ODF
  - Idaho Forest Products Commission: http://www.idahoforests.org/
  - Idaho Department of Lands: http://www.idl.idaho.gov/
  - Montana Department of Natural Resources and Conservation: http://www.dnrc.mt.gov/
  - National Interagency Fire Center: https://www.nifc.gov/
  - U.S. Geological Survey Forest and Rangeland Ecosystem Science Center: http://fresc.usgs.gov/
  - U.S. Geological Survey Western Ecological Research Center: http://www.werc.usgs.gov/
  - Individual National Forest sites
  - LCCNetwork.org

Bibliographies of all reviews identified as relevant during the assessment of their full text will be searched for further material. Once all relevant literature has been identified and collected, we will contact key groups publishing on the subject area of our review to determine whether further unpublished data exist that are relevant to the review.

3.1.2 Search terms

We will use the following search terms to retrieve articles from the databases mentioned above. Search terms include all combinations of the following:

- prescribed fire, prescribed burn, controlled burn, planned ignition, broadcast burn AND
- climate change, global warming AND
- adaptation, resilience, alter management, change management, adapt, climate adaptation
- Northwest, Oregon, Idaho, Montana, Washington

3.2 Assessment of study relevance

We will assess studies for inclusion in the review based on a hierarchical assessment of relevance by scanning article titles, followed by reading the abstract of articles with relevant titles and key words, followed by reading the full-text of articles with relevant titles and abstracts. Studies will be deemed relevant based on the presence of the desired subject, exposure and comparator, and outcome measurements. Studies that include information to address the secondary question(s) will also be included. These will be marked as relevant to the secondary question. Decisions will be inclusive when there is doubt as to a study's relevance.

Articles that are errata, commentaries that contain no data will all be excluded.

Repeatability of the article selection process will be determined through the assessment of the same literature database (or subset) by two of the ASAP project team members working independently, via kappa analysis (http://en.wikipedia.org/wiki/Cohen%27s_kappa). If there are significant discrepancies in relevance assessment between investigators, these will be discussed and the inclusion criteria amended for clarity if necessary.

3.2.1 Literature inclusion criteria

Peer-reviewed research investigating the use of prescribed fire under conditions explicitly linked to projected climate changes in fire regimes (note: to distinguish between Rx fire use to ameliorate other climate impacts). Peer-reviewed policy or planning documents that discuss the use of prescribed fire under projected climate scenarios (specific to climate-driven shifts in fire regimes). Literature that discusses how managers are adapting, or could adapt, the use of prescribed fire specifically to address climate change in fire regimes. "Gray" literature (e.g. USFS Gen. Tech. Reports) that addresses use of prescribed fire in the context of climate-driven shifts in fire regimes.

3.2.2 Literature exclusion criteria

Research on the effectiveness of prescribed fire in reducing or mitigating wildfire risk that does not explicitly include climate change. Articles that mention prescribed fire and climate change only in passing, e.g. a sentence or two in the discussion section. If time allows, such references could be scanned to see if they add anything substantive to the review.

3.3 Recognized limitation

The approach in this review protocol has a few known limitations:

- We are operating under a constrained timeline.
- We may have to approach the assessment of the literature, though systematically, in a way that varies from the traditional systematic review approach.

3.4 Knowledge transfer strategy

On completion of the review, we will also produce a summary document. The summary document and the completed review will be made available on the internet, and will be distributed to those individuals and organizations collaborating on the project.

In communicating the systematic review and the ASAP goal to develop a process for systematic reviews, we will aim to clearly communicate the potential limits and pitfalls in interpreting the results.

4. Potential Conflicts of Interest and Sources of Support

The ASAP team and reviewers declare that they have no competing conflicts of interest.
This review is funded by the Department of the Interior's Northwest Climate Science Center.

NOTE: *To establish the timeliness and importance of these questions (previous pages), the review introduction will BRIEFLY summarize generally accepted science in two areas: 1) prescribed fire use to mitigate wildfire hazard, severity, intensity, extent (aside from specific climate change considerations) and 2) projected climate change effects on western US wildfire regimes. To the extent possible, we want to exclude these broad, supporting bodies of knowledge from further review, in order to focus tightly on the review question.*

Appendix C

Summary of Current Knowledge

Climate change effects on wildfire in the western US: Brief summary of current knowledge

Wildfire trends under climate change

Today, prescribed fire is used with increasing recognition of the likelihood that climate change will alter and/or exacerbate fire regimes and associated risks across much of the western United States. In this section, we attempt to briefly summarize current projections and expert consensus regarding the effects of climate change on wildfire occurrence and management in the western US.

In a synthesis of fire history and climate change science knowledge, Sommers, Coloff and Conard (2011) explain that fire regimes and ecosystems will undergo substantial change in response to ongoing 21st Century climate change, with major implications for fire managers: "climate in the 21st Century will differ significantly from the 20th Century [when] modern fire management developed…climate change is modifying the envelope within which managers conduct fire business…fire regimes will change, fire seasons will be longer, peak season periods of heat and drought will amplify, and fuel conditions and ignition patterns will change in varying ways." Moreover, they say, "…fire will become even more important in natural resource management as climate change mitigation and adaptation responses count on the benefits of carbon sequestration and ecosystem resiliency that fire can rapidly alter."

Sommers, Coloff and Conard (2011) conclude that "we now realize that climate change considerations will be prominent for all aspects of fire management [and] for many other aspects of natural resources management impacted by fire…" and that "…the option of restoring future ecosystems to what they once were will simply not exist in the 21st Century. Instead, adapting ecosystems to be fully functional within the bounds of future climate, and getting them there with likely increased fire accelerating the transition, is the challenge to be addressed. Fire and fuel management will be critical components for climate change adaptation, for both traditional fire management objectives and for new climate related emphases such as carbon sequestration."

Results from several different lines of research support these conclusions. For example, Liu, Goodrick and Stanturf (2013) investigated trends in wildfire potential in the continental US under a changing climate. They measured fire potential by the Keetch–Byram Drought Index (KBDI, determined by daily maximum temperature and precipitation) and the impact of relative humidity and wind speed by comparing KBDI with the modified Fosberg Fire Weather Index (mFFWI). Present (1971–2000) and future (2041–2070) daily regional climate conditions were obtained by dynamical downscaling of the HadCM3 global projection using HRM3 regional climate model. Results showed that 1) fire potential is expected to increase in the Southwest, Rocky Mountains, northern Great Plains, Southeast, and Pacific coast, mainly caused by future warming, 2) most pronounced increases occur in summer and autumn, 3) fire seasons will become longer in many regions, 4) future fire potential increases will be less pronounced in the northern Rocky Mountains due to changes in humidity and wind and, 5) present fire potential has been increasing across the continental U.S. in recent decades.

Collins (2014) points out that among the components of the “fire triangle” - fuels, weather, and topography - weather is most likely to be directly influenced by climate change. He analyzed 40 years of daily fire weather observations from five northern Sierra Nevada weather stations to investigate potential changes or trends in the frequency of high- to extreme-fire weather. The analysis demonstrated fairly strong upward trends in high- to extreme-fire weather occurrence, particularly since the mid-1990s, suggesting that there is more opportunity for fires to grow rapidly and overwhelm initial suppression efforts, likely resulting in more frequent large fires in the northern Sierra Nevada region.

Littell and others (2009) showed that wildfire area burned (WFAB) in the American West was controlled by climate during the 20th century. They found that most mountainous ecoprovinces had strong year-of-fire relationships with low precipitation, low Palmer drought severity index (PDSI), and high temperature. Grass- shrub ecoprovinces had positive relationships with antecedent precipitation or PDSI. Observed fire–climate relationships were attributed to climatic preconditioning (by summer drought) of large areas of low fuel moisture via drying of existing fuels in forest ecosystems, or fuel production (by winter precipitation) and subsequent drying in shrub/grasslands. These findings indicate that impacts of climate change on fire regimes will vary with the relative energy or water limitations of ecosystems. Differences in climate–fire relationships among ecoprovinces point to the need to consider ecological context - vegetation, fuels, and seasonal climate - to identify specific climate drivers of wildfire. Littell and others (2009) conclude that despite possible influences of fire suppression, exclusion, and fuel treatment wildfire is still substantially controlled by climate and “…future WFAB and adaptation to climate change will likely depend on ecosystem-specific, seasonal variation in climate. In fuel-limited ecosystems, fuel treatments can probably mitigate fire vulnerability and increase resilience more readily than in climate-limited ecosystems, in which large severe fires under extreme weather conditions will continue to account for most area burned.”

Westerling and others (2006) compiled comprehensive data on large wildfires in western United States forests since 1970 and compared it with hydroclimatic and land-surface data. They found that large wildfire activity increased suddenly and markedly in the mid-1980s, with higher large-wildfire frequency, longer wildfire durations, and longer wildfire seasons. The greatest increases were in mid-elevation, Northern Rockies forests (where land-use histories have relatively little effect on fire risks) and were strongly associated with increased spring and summer temperatures and earlier spring snowmelt.

Westerling and others (2006) allow that “land-use history is an important wildfire risk factor in specific forest types (e.g. some ponderosa pine and mixed conifer forests)” but maintain that “the broad-scale increase in wildfire frequency across the western US has been driven primarily by sensitivity of fire regimes to recent changes in climate over a relatively large area.” They argue that “the importance of climate in wildfire activity underscores the urgency of ecological restoration and fuels management to reduce wildfire hazards to human communities and to mitigate ecological impacts of climate change in forests that have undergone substantial alterations due to past land uses. At the same time, however, large increases in wildfire driven by increased temperatures and earlier spring snowmelt in forests where land-use history had little impact on fire risks indicate that ecological restoration and fuels management alone will not be sufficient to reverse current wildfire trends.” They also point out that “Regardless of whether the changes observed in western hydroclimate and wildfire are the result of greenhouse gas–induced global warming or unusual natural fluctuation virtually all climate-model projections indicate that warmer springs and summers will occur over the region in coming decades. These trends will reinforce the tendency toward early spring snowmelt and longer fire seasons, accentuating conditions favorable to the occurrence of large wildfires."

Westerling and others (2006) conclude by articulating potential carbon implications of increasing western US wildfire: "If the average length and intensity of summer drought increases in the Northern Rockies and mountains elsewhere in the western US, an increased frequency of large wildfires will lead to changes in forest composition and reduced tree densities, thus affecting carbon pools. Current estimates indicate that western US forests are responsible for 20 to 40% of total U.S. carbon sequestration. If wildfire trends continue…the forests of the western United States may become a source of increased atmospheric CO2 rather than a sink, even under a relatively modest temperature-increase scenario. Hence, the projected regional warming and consequent increase in wildfire activity in the western US is likely to magnify the threats to human communities and ecosystems, and substantially increase the management challenges in restoring forests and reducing greenhouse gas emissions."

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Appendix D

Science Advisory Panel Workshop Agenda and Panel Biographies

Workshop Purpose

Purpose

The purpose of the science panel meeting was to help develop a process for and to conduct a review of the body of science and/or gaps in the science behind climate adaptation actions.

Objectives

- Solicit thoughts on articles for systematic review (inclusion and exclusion)
- Solicit expert opinion on the use and application of prescribed fire under changing climatic conditions
- Determine concrete steps for writing the review and any publications

Desired Outcomes/Outputs

- Have a better understanding of prescribed fire as a "climate adaptation action"
- An increased understanding of the knowledge gaps and research opportunities
- Concrete steps for writing up the review (and any other publications/op ed pieces) based on the combination of the found literature and the expert deliberations

Review Questions

Primary Review Question

In consideration of projected climate-driven shifts in fire regimes, what evidence is there (if any) that could potentially alter established scientific consensus regarding the use and application of prescribed fire? How might the use and application of prescribed fire evolve in response to climate change with respect to implementation conditions, techniques, time frames, scales, and locations?

Secondary Review Question

Are there any instances where the standard use and application of prescribed fire has been altered to address climate-driven shifts in wildfire regimes? If so, to what extent/in what way did implementation conditions, techniques, time frames, scales, and/or locations of prescribed fire use change?

Agenda

Overview		
9:00-9:20	**Welcome, meeting objectives, and introductions**	Lisa Gaines Rachel Gregg
9:20-10:00	**Background Presentations: Teeing up for the Sessions** – ASAP Overview and Phase 2 (*Rachel*) – The science review: what we are doing and where we are in the process (*Jeff*)	Rachel Gregg Jeff Behan
10:00-10:45	**Session 1: Participant reflections and questions**	All
10:45-11:00	*Break*	
11:00-12:15	**Session 2: Scope of relevance – knowledge and literature sources** *Given our review questions, what would the "relevant" literature encompass? How you would go about finding it?*	All
12:15-1:00	*Lunch*	
1:00-2:30	**Session 3: What does the evidence say?** *Where and how do we use prescribed fire in the context of climate change?*	All
2:30-2:45	*Break*	
2:45-3:45	**Session 4: Research gaps and opportunities**	All
3:45-4:00	**Closing and Next Steps**	
4:00	**Adjourn**	

Panel Biographies

Ernesto Alvarado, University of Washington

Ernesto is a Research Associate Professor of Wildland Fire Science at the University of Washington. His teaching and research interests include a wide variety of topics in the forest fire sciences -- biomass combustion, fire ecology, fire management, prescribed fire, smoke emissions, climate change, tropical forestry, landscape, international forestry, and modeling. He is a member of the Fire and Environmental Research Applications Research Team (FERA) of the U.S. Forest Service Pacific Wildland Fire Sciences Laboratory in Seattle, Washington. His research has been conducted across the Americas from the boreal forests of Alaska to the western United States, protected areas in Mexico, and the tropical forests of Brazil, Bolivia, and Paraguay. He has been a visiting scientist at Brazil's National Institute of Space Research, Mexico's National Autonomous University, the University of Guadalajara in Autlan, Mexico, and at the Bolivian Forest Research Institute.

Sharon Hood, U.S. Forest Service Rocky Mountain Research Station

Sharon is an ecologist with the University of Montana, which collaborates with the Missoula Fire Sciences Lab. The primary focus of her research is on how fire affects trees and ultimately forest dynamics. My past and current research falls into four broad categories: (1) investigate the causes and mechanisms of tree mortality after fire to model changes in forest composition and structure under climate change and after disturbance in temperate coniferous forests of the U.S.;(2) study the effects of fire on tree susceptibility to bark beetle attack to understand how this disturbance interaction scales up to affect bark beetle outbreaks at the landscape level in the western; (3) quantify the impact of fuel treatments on vegetation and fuels to evaluate fuel treatment effectiveness and longevity in the western U.S.; and (4) develop and test methods to quantify ground, surface, and aerial fuel in the U.S. for inputs into fire behavior and effects models.

Morris Johnson, U.S. Forest Service, PNW Research Station (Washington)
Morris is a Research Fire Ecologist with the Pacific Wildland Fire Sciences Laboratory. He studies fuel treatment effects on fire hazard in forest ecosystems in the western United States. He is working to develop and test scientific principles for effective use of thinning and surface fuel treatments—such as prescribed burning, pile and burn, and mastication—to help remove fuels and to reduce the risk of crown fires. His research interests include fire ecology, fire effects, silviculture, fuel treatments and fire behavior, simulation modeling, bark beetles, and climate change.

Becky Kerns, U.S. Forest Service, PNW Research Station (Oregon)
Becky is an ecologist specializing in disturbance and restoration. She helps define the role and impact of fire, grazing, exotic invasive plant species, and other disturbances on forests and rangelands. Kerns studies disturbances and their interactions and how they structure vegetation and plant communities. Her research interest include: (1) Determining the effects of restoration and management activities (prescribed fire, fuel reduction, seeding) on forest plant communities and exotic invasive plant species, including interactions with and among biotic and abiotic factors; (2) Developing understanding and theory about fire and large herbivore interactions and feedbacks, and effects on forest vegetation and exotic species; and (3) Exploring potential mid- and broad-scale vegetation response to future climatic variability and change.

David W. Peterson, U.S. Forest Service, PNW Research Station (Washington)
David is currently focused on improving our understanding of how forest and rangeland vegetation responds to wildfire; how trees killed by wildfire decay and contribute to wildlife habitat, coarse woody debris, and fuels; and how post-fire management treatments can best be used to reduce threats (e.g., post-fire flooding and erosion, future high severity wildfires) and promote long-term ecosystem recovery. I am also working to evaluate the effectiveness of common forest restoration treatments (e.g., mechanical thinning and prescribed fire) for increasing resilience to fire and climatic variability and promoting biodiversity in fire-prone forest and savanna ecosystems. His primary research interests are in the areas of fire ecology, forest ecology, restoration ecology, and climate change. He is interested in understanding how forest, savanna, and grassland ecosystems respond to and influence natural fire regimes, especially fire frequency and intensity/severity.

Carl Seielstad, University of Montana
Carl is the Fire and Fuels Program Manager at the Fire Center and Associate Professor at the College of Forestry and Conservation, University of Montana. Carl's research interests are in forest & range management in wildfire and prescribed fire settings. His research integrates innovative fuels inventory methods, fire monitoring, fire weather, and technology development and transfer. Current projects include measurement of fuel bed properties beneath close-canopies using laser altimetry, development of cost-effective, low power, ad hoc wireless weather sensor networks with fault tolerance, and exploration of new, real-time fire intelligence gathering/delivery capacity. His technical expertise is concentrated in the

geospatial technologies of remote sensing and geographic information systems. Carl remains active in operational fire in an effort to link academic activities and fire management.

Appendix E

Annotated Bibliography of Peer-reviewed Literature (Science Advisory Panel)

Available Science Assessment Project:

Prescribed Fire and Climate Change

Annotated Bibliography: Peer-Reviewed Literature

Science Review Panel Meeting Portland State University

Market Place Building, Room MCB 123 1600 SW 4th Street,

Portland, Oregon

3 June 2015

Past, present, and future old growth in frequent-fire conifer forests of the western United States

Abella, S. R.; Covington, W. W.; Fulé, P. Z.; Lentile, L. B.; Meador, A. J. S.; Morgan, P.
2007

Conservation and restoration of old growth in frequent-fire forests of the American West 12(2) art.16

Source	CAB Abstracts, 05/01/2015 (Steve Van Tuyl)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")
Type of reference	Peer-reviewed journal article
Study type	synthesis and policy
Location	
Ecosystem type	Frequent fire conifer forests
Stated aim of study	Understanding past changes and anticipating future changes to old-growth trees and forests under different potential management scenarios are fundamental to developing ecologically based fuel reduction or ecological restoration treatments. This paper summarizes changes since Euro-American settlement in coniferous, old-growth, frequent- fire forests in the western US and explores anticipated changes in old growth that may result from potential management and policy scenarios, including explicit discussion of prescribed fire use.
Broad outcomes	Evidence exists for large variation in presettlement characteristics and current condition of old growth across this broad forest region, although there are many examples of striking similarities on widely distant landscapes. Exotic species, climate change, unnatural stand-replacing wildfires, and other factors will likely continue to degrade or eradicate old growth in many areas. As fire exclusion is proving to be unsustainable, mechanical tree thinning, prescribed fire, or wildland fire use will likely be key options for forestalling continued eradication of old growth by severe crown fires. For many practical and societal reasons, the WUI may afford some of the most immediate opportunities for re-establishing old growth typical of presettlement forests resistant to crown fires. PF is likely to remain a tool, but a financially costly one, for reducing fuel loads in old growth forests. As PFs burn when and where managers choose, within the "window" of appropriate weather conditions, managers can meet goals of burning particular places at particular times. But PFs require a substantial investment in people to ignite the burn and prepare and secure control lines. Such costs are often acceptable for forests in the WUI, where social values at risk from unplanned wildfire are high. They may not be acceptable for large, remote forest lands, however.

Carbon stocks and climate change: management implications in Northern Arizona ponderosa pine forests

Bagdon, B.; Huang, C. H.
2014

Forests 5(4): 620-642

Source	Web of Science, 05/01/2015 (Steve Van Tuyl)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")
Type of reference	Peer-reviewed journal article
Study type	modeling
Location	Northern Arizona USA
Ecosystem type	Ponderosa pine
Stated aim of study	Examined dynamics of ponderosa pine stands under 3 climate change scenarios in Northern Arizona using the Climate Forest Vegetation Simulator (Climate-FVS) model to project changes in carbon pools. Ninety stands were grouped according to 3 elevational ranges: low (1951-2194 m), mid (2194-2499 m), and high (2499-2682 m.) elevation stands. Growth, mortality, and carbon stores were simulated in Climate-FVS over 100 years. Also simulated 3 management scenarios for each elevational gradient and climate scenario: 1) no management, 2) intensive management- thinning from below with prescribed burn every 10 years, and 3) moderate management- less intensive thinning from below with prescribed burn every 20 years.
Broad outcomes	Climate change has a far greater effect on carbon (C) stocks than does management or elevational grouping. Carbon stores on our study area were particularly vulnerable to catastrophic losses under almost all climate change scenarios and all elevational groupings when compared to no climate change. As expected, C stocks are lower for the two managed scenarios when compared to no-management. However, fire-excluded, overstocked, C-rich ponderosa pine forests of the SW US may be beyond their C-carrying- capacity (broadly defined as maximum C storage obtainable while maintaining acceptable hazardous fire risk) and in need of C removal. Intensive management appears to be most effective for bringing conditions closer to theoretical C carrying capacity. Climate-FVS may serve as an important tool for evaluating effectiveness of proposed treatments. Decisions about timing, frequency and magnitude of treatments should now be evaluated in light of the range of climate change intensities. For instance, results showed that climate-induced mortality is lowest when treatment is frequent and permitted to remove sufficient volume to reduce BA below 28 m2/ha. However, under the most severe climate change scenario, severe mortality of ponderosa pine appears imminent regardless of treatment. Our simulation results also uncover consequences of inaction, especially under a drier future climate. E.g., if management does not occur or is of inadequate intensity, fuels will accumulate to potentially unprecedented high levels under several scenarios. If forest

managers are faced with these climatic conditions in the future, they will have to re- evaluate management objectives and conduct earlier, more frequent and more intensive treatments to avoid increased fire risk and potentially catastrophic wildfires. Under these climate scenarios, inaction by forest managers in the near term will likely result in a missed opportunity to perform treatments that could prevent devastating losses of forest cover.

Implications of spatially extensive historical data from surveys for restoring dry forests of Oregon's eastern Cascades

Baker, W. L.
2012

Ecosphere 3(3) art23

Source	CAB Abstracts, 05/14/2015 (Rob Fiegener)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article
Study type	historical reconstruction
Location	Eastern Oregon
Ecosystem type	Ponderosa pine and mixed conifer
Stated aim of study	Dry western forests (e.g., ponderosa pine; mixed conifer) were thought to have been historically old and park-like, maintained by low-severity fires, and to have become denser and more prone to high-severity fire. In the PNW, early aerial photos (primarily in Washington), showed that dry forests instead had variable-severity fires and forest structure, but more detail is needed. This study used pre-1900 General Land Office Surveys, with new methods that allow accurate reconstruction of detailed forest structure, to test eight hypotheses about historical structure and fire across about 400,000 ha of dry forests in Oregon's eastern Cascades. Results are discussed in the context of increasing forest resiliency to future global change.
Broad outcomes	Reconstructions show that only ~13.5% of these forests had low tree density. Forests instead were generally dense (mean=249 trees/ha), but density varied by a factor of 2–4 across about 25,000-ha areas. Shade-tolerant firs historically were 17% of trees, dominated about 12% of forest area, and were common in forest understories. Understory trees and shrubs dominated on 83.5% and were dense across 44.8% of forest area. Small trees (10–40 cm dbh) were 50% of trees across 72.3% of forest area. Low-severity fire dominated on only 23.5%, mixed-severity on 50.2%, and high-severity on 26.2% of forest area. Historical fire included modest-rotation (29–78 years) low-severity and long-rotation (435 years) high-severity fire. Given historical variability in fire and forest structure, an ecological approach to restoration would restore fuels and manage for variable-severity fires, rather than reduce fuels to lower fire risk. Modest reduction in white fir/grand fir and an increase in large snags, down wood and large trees would

enhance recovery from past extensive logging and increase resiliency to future global change. These forests can be maintained by wildland fire use, coupled, near infrastructure, with prescribed fires that mimic historical low-severity fires.

Forest fire management, climate change, and the risk of catastrophic carbon losses

Bowman, David MJS; Murphy, Brett P; Boer, Matthias M; Bradstock, Ross A; Cary, Geoffrey J; Cochrane, Mark A; Fensham, Roderick J; Krawchuk, Meg A; Price, Owen F; Williams, Richard J
2013

Frontiers in Ecology and the Environment 11(2): 66-67

Source	Google Scholar, 05/21/2015 (Jeff Behan)
Search terms	global warming and prescribed burning
Type of reference	Peer-reviewed journal letter
Study type	
Location	western USA, Australia
Ecosystem type	
Stated aim of study	Approaches to management of fireprone forests are undergoing rapid change, driven by recognition that large scale fire suppression is ecologically and economically unsustainable. However, our current framework for intervention excludes the full scope of the fire management problem within the broader context of fire-vegetation-climate interactions. Climate change may already be causing unprecedented fire activity, and even if current fires are within HRV, models predict that current fire management problems will be compounded by more frequent extreme fire-conducive weather conditions. Discusses potential for "biome conversion" in which forests burn and then are replaced by non-forest ecosystems; suggests assessing carbon implications of fuels treatments in this context
Broad outcomes	Main points: "A paradoxical feature of the debate about PF as a GHG mitigation tool is the limited consideration given to irreversible climate and fire-driven conversion of high biomass forests to low-biomass, nonforest states." Forests (e.g. ponderosa pine) adapted to frequent, low-severity fire, with historical fire suppression increasing small tree density and risk of stand-replacing fire generally have limited regenerative capacity after stand- replacing fires. Thinning and PF can decrease the risk of stand replacement, potentially preventing long-term shifts to low-biomass states after regeneration failure. "For vulnerable forests, the real value of mechanical thinning and subsequent prescribed burning, as proposed by Hurteau and Brooks (2011), may be to resist biome switching, assuming that the 'expenditure' of C associated with these interventions is substantially less than the avoided C losses associated with a biome switch."

Minimal persistence of native bunchgrasses seven years after seeding following mastication and prescribed fire in southwestern Oregon, USA

Busby, Laura M.; Southworth, Darlene
2014

Fire Ecology 10(3): 63-71

Source	Web of Science, 05/14/2015 (Rob Fiegener)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article
Study type	experiment
Location	southwestern Oregon
Ecosystem type	interior valley shrublands of southwestern Oregon
Stated aim of study	Seeding of native grasses is widely used to restore plant communities and prevent establishment of introduced species following wildfire and prescribed burns. However, there is a lack of long-term data to evaluate the success of native grass seeding. In this study, plots in the interior valley shrublands of southwestern Oregon that had been masticated and burned, and then seeded with bunchgrasses seven years previously, were resurveyed. Results are interpreted in the context of climate change.
Broad outcomes	The prescribed fires had resulted in bare ground that increased opportunities for bunchgrass germination as well as for invasion by introduced plants. After two years, native grass seeding was successful, with increased bunchgrass cover that correlated with decreased cover of introduced species. However, five years later, bunchgrass cover had declined by 80%, and the frequency of plots with bunchgrasses had declined by 60%. Cover of surviving bunchgrasses in year 7 correlated positively with bunch grass cover in year 2 (R2 = 0.34; P = 0.003). Seven years after prescribed fire and seeding, native over, introduced cover, and species richness were unchanged, and bunchgrass persistence was minimal. Basically, seeding following mastication and prescribed burning had a minimal effect. This study highlights the importance of longer-term monitoring to determine the efficacy of seeding treatments. Climate change is likely to interfere with attempts at restoration of native plant communities, particularly at lower elevations and on south facing slopes with little summer rainfall.

Climate change and fire management in the mid-Atlantic region

Clark, K. L.; Skowronski, N.; Renninger, H.; Scheller, R.
2014

Special Section: Fire, forests and climate change: an assessment of the continental US. 327: 306-315

Source	Web of Science, 05/01/2015 (Steve Van Tuyl)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")
Type of reference	Peer-reviewed journal article
Study type	
Location	
Ecosystem type	
Stated aim of study	Summarizes potential impacts of climate change on wildfire activity in mid-Atlantic region, then considers how beneficial uses of prescribed fire could conflict with mitigation needs for climate change, focusing on patterns of carbon (C) sequestration by forests in the region. Used synthesis of field studies, eddy flux tower measurements, and simulation studies to evaluate how use of prescribed fire affects short- and long-term forest C dynamics.
Broad outcomes	Climate change may create weather conditions more conducive to wildfire activity, but successional changes in forest composition, altered gap dynamics, reduced understory and forest floor fuels, and fire suppression will likely continue to limit wildfire occurrence and severity throughout the region. PF is the only major viable option that land managers have for reducing hazardous fuels in a cost-effective manner, or ensuring the regeneration and maintenance of fire-dependent species. Field measurements and model simulations indicate that consumption of fine fuels on the forest floor and understory vegetation during most PFs is equivalent to <1–3 years of sequestered C, and depends on pre-burn fuel loading and burn intensity. Overstory tree mortality is typically low, and stands have somewhat reduced daytime C uptake during the next growing season following burns, but may also have reduced rates of ecosystem respiration. Net ecosystem productivity is negative the first year when consumption losses are included, but then positive in following years, and stands can reach C neutrality within <2–3 years. Field data and model simulations suggest that increases in PF in fire-prone areas would have little appreciable effect on long-term forest C dynamics in some fire-prone forest types. [From abstract.]

Exploring use of climate information in wildland fire management: a decision calendar study

Corringham, T. W.; Westerling, A. L.; Morehouse, B. J.
2008

Journal of Forestry 106(2): 71-77

Source	CAB Abstracts, 05/14/2015 (Rob Fiegener)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Chapter in symposium proceedings; peer-review process unclear
Study type	survey of fire managers
Location	
Ecosystem type	
Stated aim of study	Significant potential exists for enhancing the use of climate information and long-range climate forecasts in wildland fire management in the western US. Written surveys and interviews of fire and fuels managers at local, regional, and national levels provide information and insights into the decision processes, information flows, and decision nodes used in wildfire planning and management, and allow the construction of decision calendars showing how climate information needs vary seasonally, over space, and through the organizational network.
Broad outcomes	Found that potential exists for fostering use of climate information, including seasonal to inter-annual climate forecasts at all organizational levels, ultimately opening possibilities for improved targeting of fuels treatments and prescribed burns, more effective positioning and movement of initial attack resources, and improved staffing and budgeting decisions. Longer-term (decadal) forecasts could be useful at the national level in setting budget and research priorities. Study examines the kinds of organizational changes that could facilitate effective use of existing climate information and climate forecast capabilities.

The effect of fire on microbial biomass: a meta-analysis of field studies

Dooley, S. R.; Treseder, K. K.
2012

Biogeochemistry 109(1/3): 49-61

Source	Google Scholar, 05/21/2015 (Jeff Behan)
Search terms	global warming and prescribed burning
Type of reference	
Study type	
Location	
Ecosystem type	
Stated aim of study	Soil microbes regulate transfer of carbon (C) from ecosystems to the atmosphere and in doing so influence feedbacks between terrestrial

ecosystems and global climate change. Fire is one element of global change that may influence soil microbial communities and, in turn, their contribution to ecosystem C dynamics. To improve understanding of how fire influences belowground communities, a meta-analysis was conducted of 42 published microbial responses to fire. Hypothesis was that microbial biomass as a whole, and fungal biomass specifically, would be altered following fires. Results include discussion of PF contrasted with wildfire.

Broad outcomes Across all studies, fire reduced microbial abundance by an average of 33.2% and fungal abundance by an average of 47.6%. But responses differed significantly among biomes and fire types. For example, microbial biomass declined following fires in boreal and temperate forests but not in grasslands, and wildfires lead to a greater reduction in microbial biomass than prescribed burns, differences likely attributable to differences in fire severity among biomes and fire types. Changes in microbial abundance were significantly correlated with changes in soil CO_2 emissions. Results suggest that fires may significantly decrease microbial abundance, with corresponding consequences for soil CO_2 emissions.

Perverse Incentives: The case of wildfire smoke regulation

Engel, KH
2013

Ecology Law Quarterly 40(3): 623-672

Source Academic Search Premier, 05/14/2015 (Rob Fiegener)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")

Type of reference Peer-reviewed journal article

Study type policy

Location

Ecosystem type

Stated aim of study The US is witnessing a spectacular increase in catastrophic wildfires, fed by hotter and dryer conditions associated with climate change. Prescribed burning reduces vegetation built up from years of wildfire suppression. But the total area subject to prescribed burns falls far short of that needed to restore ecosystems and reduce damage from unplanned wildfires. Air-pollution law and policy is an important factor contributing to under provision of prescribed fire that has so far escaped in-depth treatment in the law and policy literature. After setting forth the relevant air quality framework, this article argues that decisions regarding planned wildfire are marred by an anachronistic and inaccurate distinction between "natural" and "anthropogenic" fire. Rationalizing that unplanned wildfires are "natural," the federal government excludes pollutants from such fires from air quality compliance calculations while at the same time encouraging states to vigorously control pollutants from "anthropogenic," prescribed fires.

Broad outcomes	Rationalizing that unplanned wildfires are "natural," the federal government excludes pollutants from such fires from air quality compliance calculations at the same time it encourages states to vigorously control pollutants from "anthropogenic," prescribed fires. This contributes to undervaluation of necessary, planned wildfire. Wildfire air pollution policy is also hindered by governance structures that place air quality and resource agencies at odds with each other, and by state nuisance authorities that enable narrow local interests to shut down prescribed fire, all of which trump the broader public interest in reduced wildfire risk and healthier forests. This article suggests several solutions to remove these distortions, including a default rule whereby all wildfire smoke, of whatever origin, "counts" in air quality compliance. Together with adopting mechanisms to require air pollution and resource agencies to both participate in planned burning decisions and de-emphasize the influence of nuisance standards, this "smoke is smoke" rule will ensure that air pollution policy better reflects the true costs & benefits of prescribed fire.

Old Pinus ponderosa growth responses to restoration treatments, climate and drought in a southwestern US landscape

Erickson, Chris C.; Waring, Kristen M.
2014

Applied Vegetation Science 17(1): 97-108

Source	Web of Science, 05/14/2015 (Rob Fiegener)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article
Study type	experiment
Location	northwestern Arizona, USA
Ecosystem type	ponderosa pine
Stated aim of study	Do landscape-scale thin and burn restoration treatments have a long-term, landscape- scale impact on old ponderosa pine growth? Is there a relationship between old ponderosa pine growth and climatic factors, in particular, drought, before and after restoration treatments? This study looked at old ponderosa pine growth across the landscape in northwestern Arizona, USA, in both an area 'treated' by thin and burn restoration treatments, and a neighboring untreated area.
Broad outcomes	Found significant differences in precipitation and temperature between treated and untreated areas, indicating a drier, less advantageous climate in the untreated area. Old trees in the treated area responded less negatively in diameter growth to treatments; both treatment and abiotic site factors were important in predicting post-treatment growth. All old trees grew slowly during drought years; however, old trees in the treated area grew better after three recent drought years than old trees in the untreated area. Conclusions: Old P. ponderosa diameter growth increased following restoration, though not

immediately. Old trees in the treated area also grew better in the years after drought than old trees in the untreated area. Restoration, or similar treatments removing small, neighboring trees may be critical in maintaining old P. ponderosa in the landscape, particularly under future climate change and increasing drought frequency in the western USA.

Management of forest fires to maximize carbon sequestration in temperate and boreal forests

Guggenheim, DE
1997

World Resource Review 9(1): 46-57

Source	Env. Science & Pollution Management, 05/01/2015 (Steve Van Tuyl)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")
Type of reference	Peer-reviewed journal article
Study type	modeling
Location	
Ecosystem type	
Stated aim of study	Examines prescribed burning as a forestry-based climate change mitigation alternative. The basic rationale underlying this analysis is that prescribed burns prevent catastrophic wildfires. The JABOWA-II forest growth model was modified to simulate forest fire effects. Three measures of carbon offset achievement were developed that consider how long CO_2 is held out of the atmosphere and that the value of removing CO_2 from the atmosphere is greater now than in the future.
Broad outcomes	

Dry forest resilience varies under simulated climate-management scenarios in a central Oregon, USA landscape

Halofsky, J. S.; Halofsky, J. E.; Burcsu, T.; Hemstrom, M. A.
2014

Ecological Applications 24(8): 1908-1925

Source	Web of Science, 05/01/2015 (Steve Van Tuyl)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")
Type of reference	Peer-reviewed journal article
Study type	modeling

Location Central Oregon, USA

Ecosystem type Dry conifer forests. Moist mixed-conifer forests also addressed.

Stated aim of study Used a set of climate-informed state-and-transition models to explore effects of management and natural disturbances on vegetation composition and structure under different future climates. Models were run for dry forests of central Oregon under 1) a fire suppression scenario- no management other than continued wildfire suppression and, 2) an active management scenario- light to moderate thinning from below and some prescribed fire, planting, and salvage logging.

Broad outcomes Probability of at least maintaining current dry–large–open forest levels was consistently high with active management, where dense stands were actively thinned and PF utilized. The probability of maintaining moist mixed-conifer forests was greater with active management, but probability of maintaining even 75% of current amounts of moist-large- dense forests declined with time under both scenarios. Management at levels modeled may not affect overall trends in vegetation change under climate change; trajectories of forest change were similar across management scenarios. But results suggest management actions can dampen the magnitude of change. The active management scenario mitigated potential loss of both dry and moist mixed conifer forests. Yet trends in size classes within forest types suggest that regardless of management actions, increased fire frequency with climate change may result in a longer-term reduction in recruitment of large-diameter trees. E.g, increased application of PF and thinning from below in higher- density stands created more fire-tolerant forests with large tree diameters. However, under both scenarios, there were declines in medium-sized trees, diminishing the pool of trees that can be recruited into the large-diameter size class. Opportunities to grow new large-diameter trees in dry forest types may diminish through time, assuming increased mixed- and stand-replacing wildfire events. This closing window of opportunity places greater importance on reducing stand replacing wildfire potential around remaining older, large-diameter trees currently on the landscape. [From text.]

Climate change, fire management, and ecological services in the southwestern US

Hurteau, M. D.; Bradford, J. B.; Fulé, P. Z.; Taylor, A. H.; Martin, K. L.
2014

Special Section: Fire, forests and climate change: an assessment of the continental US. 327: 280-289

Source Web of Science, 05/01/2015 (Steve Van Tuyl)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")

Type of reference Peer-reviewed journal article

Study type synthesis & review

Location Southwestern USA

Ecosystem type	
Stated aim of study	Reviews current understanding of relationship between fire and climate in the SW, both historical and projected. Discusses potential implications of climate change for fire management and examines potential effects of climate change and fire on ecosystem services. Assesses the role of fire management in an increasingly flammable SW. Severe fire can be mitigated with fuels management including prescribed fire, thinning, and wildfire management, but new strategies are needed to ensure effectiveness of treatments across landscapes.
Broad outcomes	Where tree density and fuels have increased substantially, research indicates that thinning coupled with PF is the most effective means of reducing high-severity fire risk. Structural manipulations alone are much less effective. Research in mixed-conifer forests suggests that multiple PF treatments can reduce forest density, with preferential survivorship of large trees, and retention of heterogeneous overstory spatial patterns. Reintroduction of fire also provides numerous ecological benefits. Reducing high severity wildfire risk through restoration of forest structure and regular PF also provides a level of stability to forest carbon stocks. Restoration of fire regimes is also expected to build system level resistance and resilience to climate change. Reducing forest density adds a level of drought tolerance, allowing sustained tree growth and carbon sequestration during periods of reduced precipitation. However, with uncertainty associated with tree species-specific responses to changing climate, thinning efforts in mixed-species forest types should consider a strategy that restores evenness where appropriate. In historically frequent-fire forests, stand replacing fire can result in conversion to alternative vegetation types through regeneration failure or by creating conditions that prevent tree re-establishment because of increased fire frequency or competitive exclusion. While re-vegetation issues can be overcome with human intervention, the rapid pace of climate change suggests that restoring fire as a process to increase resistance to high-severity wildfire could provide a viable option for slowing vegetation change, and associated impacts to carbon cycling and biodiversity, over larger areas.

Carbon recovery rates following different wildfire risk mitigation treatments

Hurteau, M. D.; North, M.
2010

Forest Ecology and Management 260(5): 930-937

Source	Web of Science, 05/01/2015 (Steve Van Tuyl)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")
Type of reference	Peer-reviewed journal article
Study type	modeling

Location Teakettle Experimental Forest, southern Sierra Nevada Mountains, California, USA

Ecosystem type Sierra Nevada mixed-conifer forest

Stated aim of study To estimate the time needed to recover carbon removed and emitted during treatment, compared 7-year post-treatment carbon stocks for five different mechanical thinning and prescribed fire fuels reduction treatments in Sierra Nevada mixed-conifer forest and modeled annual carbon accumulation rates.

Broad outcomes Within our 7-year re-sample period, burn only and understory thin treatments sequestered more carbon (C) than had been removed or emitted during treatment. Understory thin and burn, overstory thin, and overstory thin and burn continued to have net negative C stocks when emissions associated with treatment were subtracted from 7- year C stock gains. However, the size of the C deficit in the understory thin and burn 7 years post-treatment and live tree growth rates suggest that remaining trees may sequester treatment emissions within several more years of growth. Overstory tree thinning treatments resulted in a large C deficit and removed many of the largest trees that accumulate the most C annually, thereby increasing C stock recovery time. Our results indicate that while there is an initial C stock reduction associated with fuels treatments, treated forests can quickly recover C stocks if treatments do not remove large, fire-resistant overstory trees. [From abstract.]

Modeling the influence of precipitation and nitrogen deposition on forest understory fuel connectivity in Sierra Nevada mixed-conifer forest

Hurteau, M. D.; North, M.; Foin, T.
2009

Ecological Modelling 220(19): 2460-2468

Source Academic Search Premier, 05/14/2015 (Jeff Behan)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")

Type of reference Peer-reviewed journal article

Study type modeling

Location Sierra Nevada Mountains, California, USA

Ecosystem type Sierra Nevada mixed-conifer forest

Stated aim of study Climate change models for California's Sierra Nevada predict greater inter-annual variability in precipitation over the next 50 years. These increases in precipitation variability coupled with increases in nitrogen (N) deposition from fossil fuel consumption are likely to result in increased productivity levels and significant increases in forest understory fuel loads. Higher understory plant biomass contributes to fuel connectivity and may increase future fire size and severity in the Sierra Nevada. The objective of this research was to develop and test a model to determine how changing precipitation and N deposition levels affect shrub and herb biomass production, and to determine how often prescribed fire would be needed to counter increasing fuel loads.

Broad outcomes Model outputs indicate that under an increasing precipitation scenario significant increases in shrub and herb biomass occur that can be counteracted by decreasing the fire return interval to 10 years. Under a scenario with greater inter-annual variability in precipitation and increased N deposition, implementing fire treatments at an interval equivalent to the historical range of 15–30 years maintains understory vegetation fuel loads at levels comparable to the control.

Modeling climate and fuel reduction impacts on mixed-conifer forest carbon stocks in the Sierra Nevada, California

Hurteau, M. D.; Robards, T. A.; Stevens, D.; Saah, D.; North, M.; Koch, G. W.
2014

Forest Ecology and Management 315: 30-42

Source Web of Science, 05/01/2015 (Steve Van Tuyl)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")

Type of reference Peer-reviewed journal article

Study type modeling

Location Lake Tahoe Basin, CA

Ecosystem type mixed conifer

Stated aim of study Used a growth-and-yield model, modified for climate sensitivity, to quantify effects of altered climate on mixed-conifer forest growth in the Lake Tahoe Basin, CA. Estimated forest growth and live tree carbon stocks for low and high emission scenarios using 4 downscaled general circulation model (GCM) projections. The climate scenarios were coupled with a range of commonly-used fuels reduction treatments to quantify the combined effects of these factors on live tree carbon stocks.

Broad outcomes Recursive partitioning analysis indicated that GCM, forest composition, and simulation period most influence live tree C (C) stock changes. Comparison with the late 20th century baseline period shows mixed C stock responses across scenarios. Growth varied by species, often with compensatory responses among dominant species that limited changes in total live tree C. The influence of wildfire mitigation treatments was relatively consistent with each GCM by emission scenario combination. Treatments that included PF had greater live tree C gains relative to baseline under the scenarios that had overall live tree C gains. However, across GCMs the influence of treatments varied considerably among GCM projections, indicating that further refinement of regional climate projections will be required to improve model estimates of fuel manipulations on forest C stocks. Also, had these simulations included effects of projected climate changes on increasing wildfire probability, effects of management treatments on C stocks may have been more pronounced due to the influence of treatment on fire severity. [From abstract.]

Mixed-conifer understory response to climate change, nitrogen, and fire

Hurteau, M.; North, M.
2008
Global Change Biology 14(7): 1543-1552

Source	Academic Search Premier, 05/14/2015 (Jeff Behan)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article
Study type	experiment
Location	Sierra Nevada Mountains, California, USA
Ecosystem type	Sierra Nevada mixed-conifer forest
Stated aim of study	Climate change models predict greater variation in annual precipitation for California's Sierra Nevada Mountains, while nitrogen deposition from pollution continues to increase. These changes may significantly affect understory communities and fuels in forests where managers are attempting to restore historic conditions after a century of altered fire regimes. This research experimentally tested the effects of increasing and decreasing snowpack depth, increasing nitrogen, and applying prescribed fire to mixed-conifer forest understories at two sites in the central and southern Sierra Nevada Mountains, California, USA.
Broad outcomes	Understory response to treatments significantly differed between sites with herb biomass increasing in shrub-dominated communities when snowpack was reduced. Fire was a more important factor in post-treatment species richness and cover than either snowpack addition or reduction. Nitrogen (N) additions unexpectedly increased herbaceous species richness. These varied findings indicate that modeling future climatic influences on biodiversity may be more difficult than additive prediction based on increasing the ecosystem's two limiting growth resources. Increasing snowpack and N resulted in increased shrub biomass production at both sites and increased herb production at the southern site. This additional understory biomass has the potential to increase fuel connectivity in patchy Sierran mixed-conifer forests, increasing fire severity and size.

Fuel treatment effects on tree-based forest carbon storage and emissions under modeled wildfire scenarios

Hurteau, M.; North, M
2009
Frontiers in Ecology and the Environment 7(8): 409-414

Source	CAB Abstracts, 05/14/2015 (Rob Fiegener)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")

Type of reference Peer-reviewed journal article

Study type modeling

Location Teakettle Experimental Forest, southern Sierra Nevada Mountains, California, USA

Ecosystem type Sierra Nevada mixed-conifer forest

Stated aim of study Forests are viewed as a potential sink for carbon (C) that might otherwise contribute to climate change. It is unclear, however, how to manage forests with frequent fire regimes to maximize C storage while reducing C emissions from prescribed burns or wildfire. This study modeled the effects of eight different fuel treatments, including some with prescribed fire, on tree-based C storage and release over a century, with and without wildfire.

Broad outcomes Model runs show that, after a century of growth without wildfire, the control stored the most C. However, when wildfire was included in the model, the control had the largest total C emission and largest reduction in live-tree-based C stocks. In model runs including wildfire, the final amount of tree-based C sequestered was most affected by the stand structure initially produced by the different fuel treatments. In wildfire-prone forests, tree-based C stocks were best protected by fuel treatments that produced a low-density stand structure dominated by large, fire-resistant pines.

Short- and long-term effects of fire on carbon in US dry temperate forest systems

Hurteau, Matthew D.; Brooks, Matthew L.

2011

Bioscience 61(2): 139-146

Source Web of Science, 05/14/2015 (Rob Fiegener)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")

Type of reference Peer-reviewed journal article

Study type policy

Location US dry temperate forests

Ecosystem type US dry temperate forests

Stated aim of study Forests sequester atmospheric carbon (C) and in so doing can mitigate climate change effects. Fire is a natural disturbance process in many forests that releases C back to the atmosphere. In dry temperate forests, fires historically burned with greater frequency and lower severity than now. Frequent fires consumed fuels on the forest floor and maintained open stands. Fire suppression has increased understory fuel loads and tree density; a change in structure that has caused a shift from low- to high-severity fires. More severe fires, resulting in greater tree mortality, have caused a decrease in forest C stability. Fire management actions can mitigate risk of high-severity fires, but

	often require a trade-off between maximizing C stocks and C stability. Article discusses fire effects on forest C stocks, including prescribed fire use.
Broad outcomes	Forests provide a suite of ecosystem services, including carbon (C) sequestration for mitigating human-caused climate change. Regarding C sequestration, forests offer a bridging strategy and are only part of the climate change mitigation portfolio. Although forest C sequestration does carry a risk of reversal, even impermanent C offsets generated by increasing above ground forest C stocks can serve to reduce compliance costs in a cap- and-trade system, and in the case of fire, this risk can be reduced. However, mitigating fire risk in dry temperate forests requires periodic C emissions from PF or allowing natural fires to burn under certain circumstances (i.e., managed fire). In addition to improving aboveground forest C stability, managing these forests in ways that maximize their resilience to fire also provides for a fully functioning ecosystem, which is consistent with a wide array of other land-management goals. As such, we recommend managing forests on the basis of their specific ecologies, with the view that C sequestration is one of many ancillary ecosystem services.

Response of Arnica dealbata to climate change, nitrogen deposition, and fire

Hurteau, Matthew; North, Malcolm
2009
Plant ecology 202(1): 191-194

Source	Agricola, 05/14/2015 (Rob Fiegener)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article
Study type	experiment
Location	Yosemite National Park
Ecosystem type	Mixed-conifer forest, 2100 m elevation, five principal overstory species: Abies concolor, Ab
Stated aim of study	Predicted changes in climate and increasing nitrogen deposition are likely to have significant impacts on species that have limited distributions or are already experiencing diminished population size. Arnica dealbata, a listed sensitive species in Yosemite National Park, is endemic to California and has limited distribution within park boundaries. The objective of this research was to examine the effects of altered precipitation resulting from climate change, increasing nitrogen deposition resulting from pollution, and prescribed fire on A. dealbata in a full factorial design to 72 plots at two locations.
Broad outcomes	A. dealbata cover significantly increased with increasing snowpack and prescribed fire. Increasing nitrogen deposition negatively affected cover. Our results suggest Yosemite's A. dealbata populations can thrive even under a changing climate if prescribed fire is frequently applied coupled with increased moisture

availability. However, if a general decreasing trend in precipitation occurs, A. dealbata abundance may diminish further.
Regardless of the trend in precipitation, a prudent hedge against uncertainty for A. dealbata would be managing for increased soil moisture availability by restoring a more open historic forest condition.

The efficacy of fire and fuels reduction treatments in a Sierra Nevada pine plantation

Kobziar, L. N.; McBride, J. R.; Stephens, S. L.
2009
International Journal of Wildland Fire 18(7): 791-801

Source	Web of Science, 05/01/2015 (Steve Van Tuyl)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")
Type of reference	Peer-reviewed journal article
Study type	experimental
Location	Groveland Ranger District, Stanislaus NF, Sierra Nevada Mountains, California, USA
Ecosystem type	Ponderosa and Jeffrey pine plantations established following the stand-replacement Grani
Stated aim of study	As wildfires continue to increase due to fire suppression or climate change, establishment of forest plantations will likely also increase. Plantations' structural characteristics- dense, uniform spacing and abundant ladder fuels- present significant wildfire hazards. Large- scale fuels reduction may be necessary to attenuate potential fire behavior in plantations and to protect surrounding forests. This study compared four different fuels treatments aimed at reducing potential fire behavior in a Sierra Nevada pine plantation.
Broad outcomes	Fire behavior modeling showed that mastication is detrimental whereas prescribed fire is effective in reducing potential fire behavior at moderate to extreme weather conditions. Predicted fire behavior was compared with actual values from the prescribed burns in an effort to explore the limitations of fire modeling. Fire behavior predictions were similar to field observations in the more structurally homogeneous stands, but differed greatly where mastication created forest openings and patchy fuels distributions.

Beyond wildfire: perspectives of climate, managed fire and policy in the USA

Kolden, Crystal A.; Brown, Timothy J.
2010
International journal of wildland fire 19(3): 364-373

Source	Agricola, 05/14/2015 (Rob Fiegener)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")

Type of reference Peer-reviewed journal article

Study type survey of fire managers

Location

Ecosystem type

Stated aim of study Climate–wildfire relationships have been widely addressed by the scientific community over the last 20 years. However, the role of climate in managed fire in the US (i.e. prescribed fire; wildland fire use) has not yet been addressed. Hypothesis for this study was that if climate is an important component of managed fire, the fire community would already be aware of this and using climate information to mitigate risks associated with managed fires. Researchers conducted 223 surveys with fire managers to ascertain how climate information is utilized in managed-fire decision-making.

Broad outcomes Found that wildland fire use managers consider climate to be an important aspect of managed fire and use various types of climate information, but prescribed-fire managers do not generally consider climate or use climate information in their planning activities. Survey responses also indicate a lack of agency training on climate information and decision-support tools. This is partly attributed to obstacles in US fire policy that inhibit widespread utilization of climate information. We suggest these results are indicative of a broader conflict in US wildfire policy, which does not directly address climate despite two decades of scientific research showing climate plays a key role in wildfire regimes.

Evolving paradigms of aspen ecology and management: impacts of stand condition and fire severity on vegetation dynamics

Krasnow, K. D.; Stephens, S. L.

2015

Ecosphere 6(1) art12

Source Web of Science, 05/01/2015 (Steve Van Tuyl)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")

Type of reference Peer-reviewed journal article

Study type experimental

Location Lake Tahoe Basin, eastern Sierra Nevada Mountains, California, USA

Ecosystem type aspen, mixed conifer-aspen forests

Stated aim of study It is highly uncertain if aspen will accommodate future climate warming via migration through seedling establishment, which has been assumed to be extremely rare. This study compared regeneration dynamics of aspen revitalization strategies (conifer removal and prescribed fire) to unplanned wildfires of low, moderate, and high severity in the Sierra Nevada, and related multiple components of pre-fire stand composition to post-fire aspen regeneration. To better understand the viability of aspen migration to accommodate future climate warming, recent events of aspen seedling establishment were also examined.

Broad outcomes PFs can be problematic for aspen revitalization because they are often burned under moderate environmental conditions resulting in reduced fire intensity and severity compared to naturally occurring wildfires that often burn hotter. Most problematic in aspen stands with competing vegetation that can survive low-intensity fires. If aspen regeneration is a management goal, it will likely be better met by using managed wildfire rather than a PF, unless high-intensity PF is possible. Found substantial evidence that greater disturbance severity yields increased aspen sprout density and growth rates, and that live conifer and/or dead aspen basal area in a stand before a fire reduces post fire sprout density. Also found evidence that aspen seedling establishment is more common than has been assumed, and represents a viable means for aspen migration. Future climate changes will present both challenges and opportunities for aspen. Increased temperatures and drought will stress existing populations but increased high severity fire in forested areas may provide opportunity for successful aspen migration and genet establishment. In addition to revitalizing existing aspen stands, future management should include establishment of new stands in more suitable habitat.

Latent resilience in ponderosa pine forest: effects of resumed frequent fire

Larson, Andrew J.; Belote, R. Travis; Cansler, C. Alina; Parks, Sean A.; Dietz, Matthew S.
2013
Ecological Applications 23(6): 1243-1249

Source Suggested by Carl Seilstad, 05/26/2015

Search terms Not found via keyword search. Included as an example of research that does not explicitly reference PF but informs the use of PF in changing environments.

Type of reference Peer-reviewed journal article

Study type

Location Bob Marshall Wilderness, MT, USA

Ecosystem type ponderosa pine & mixed conifer

Stated aim of study Ecological systems often exhibit resilient states that are maintained through negative feedbacks. In ponderosa pine forests, fire historically represented the negative feedback mechanism that maintained ecosystem resilience; fire exclusion reduced that resilience, predisposing the transition to an alternative ecosystem state upon reintroduction of fire. We evaluated the effects of reintroduced frequent wildfire in unlogged, fire-excluded, ponderosa pine forest in the Bob Marshall Wilderness, MT, USA.

Broad outcomes Initial reintroduction of fire in 2003 reduced tree density and consumed surface fuels, but also stimulated establishment of a dense cohort of lodgepole pine, maintaining a trajectory toward an alternative state. Resumption of a frequent fire regime by a second fire in 2011 restored a low density forest dominated by large-diameter ponderosa pine by eliminating many regenerating lodgepole pines and by continuing to remove surface fuels and small-diameter lodgepole pine and Douglas-fir that established during the fire suppression era. Our data demonstrate that some unlogged, fire-excluded, ponderosa pine forests possess latent resilience to reintroduced fire. A passive model of simply allowing lightning-ignited fires to burn appears to be a viable approach to restoration of such forests. The apparent generality of these results suggested by [recent] studies from other regions is especially important because the available resources, and social and political will, are insufficient to restore fire-excluded forests with thinning treatments and prescribed fire alone. Espousing the position that most or all fire-excluded forests require intervention before reintroducing fire—a position contradicted by increasing scientific evidence—carries the risks of misspent resources, non-target negative ecological effects, and erosion of public trust.[From abstract and conclusions]

Effects of a second-entry prescribed fire in a mixed conifer forest

Laughlin, Daniel C.; Roccaforte, John Paul; Fule, Peter Z.
2011
Western North American Naturalist 71(4): 557-562

Source	Web of Science, 05/01/2015 (Steve Van Tuyl)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")
Type of reference	Peer-reviewed journal article
Study type	before-after study design
Location	Swamp Ridge, Kaibab Plateau, Grand Canyon National Park, Arizona, USA
Ecosystem type	Mixed conifer forest, Grand Canyon, AZ
Stated aim of study	Analyzed effects of a 2nd-entry prescribed fire in a mixed conifer forest in Grand Canyon National Park, Arizona 14 years after the initial burn to assess whether restoration and management goals and objectives- i.e. maintain old-growth forest structure so that the forest could tolerate low-intensity surface fires by 1) minimizing mortality of large trees, 2) maintaining low seedling and sapling densities, and 3) further reducing surface fuel loading- were achieved.
Broad outcomes	PF had little effect on large overstory p. pine, Douglas-fir, and white fir trees and did not change total tree density or basal area. It reduced density of conifer seedlings <30 cm tall by 87%, but had a smaller effect on seedlings >30 cm tall and on sapling density. The fire reduced litter depths 33%, duff depths 23%, fine woody debris 21%, coarse woody debris 44%; effects mostly consistent with restoration goals in mixed

conifer forests that continue to move this forest toward reference conditions. Grand Canyon NP staff now considers this forest to be in "maintenance burning", i.e. they plan to allow natural ignitions to maintain forest structure in the future. Forest is now more resilient to projected increases in fire size and/or frequency under warming climate conditions.

Illustrates that use of prescribed fire in a p. pine–dominated mixed conifer forest can be consistent both with restoring historical conditions and with managing for resilience under altered disturbance regimes accompanying a changing climate.

U.S. National Forests adapt to climate change through science–management partnerships

Littell, Jeremy S.; Peterson, David L.; Millar, Constance I.; O'Halloran, Kathy A.
2011

Climatic Change 110(1-2): 269-296

Source	Google Scholar, 05/21/2015 (Jeff Behan)
Search terms	prescribed fire and climate change
Type of reference	Peer-reviewed journal article
Study type	focus group, policy
Location	Olympic NF (WA) and Tahoe NF (CA)
Ecosystem type	
Stated aim of study	Developing appropriate climate change adaptation options is a new challenge for land managers and integration of climate change concepts into operational management and planning on US national forests is just starting. This paper reports on science-management partnerships on the Olympic NF (WA) and Tahoe NF (CA), the first effort to develop adaptation options for specific national forests. A focus group process was used to establish scientific context necessary for understanding climate change and its anticipated effects, and to develop specific options for adapting to a warmer climate. Climate change scientists provided the scientific knowledge base on which adaptations could be based. Resource managers developed adaptation options based on their understanding of ecosystem structure, function, and management.
Broad outcomes	General adaptation strategies include: 1) reduce vulnerability to anticipated climate induced stress by increasing resilience at large spatial scales, 2) consider tradeoffs & conflicts that may affect adaptation success, 3) manage for realistic outcomes; prioritize treatments that facilitate adaptation to a warmer climate, 4) manage dynamically and experimentally, and 5) manage for structure and composition. Specific adaptation options include: 1) increase landscape diversity, 2) maintain biological diversity, 3) implement early detection/rapid response for exotic species and undesirable resource conditions, 4) treat large-scale disturbance as a management opportunity and integrate it in planning, 5) implement treatments that confer resilience at large spatial scales, 6) match

engineering of infrastructure to expected future conditions, 7) promote education & awareness about climate change among resource staff and local publics, and 8) collaborate with a variety of partners on adaptation strategies and to promote ecoregional management. Focus group process can quickly elicit much information relevant for climate change adaptation, and can be emulated for other public lands. As adaptation options are iteratively generated for additional administrative units on public lands, management options can be compared, tested, and integrated into adaptive management. Science based adaptation is imperative because increasing certainty about climate impacts and management outcomes may take decades. DETAILED OUTCOMES: Tahoe NF fire managers are taking advantage of lower snowpacks and earlier spring runoff by continuing fuel treatments beyond the time when historically these treatments could be done. For example, some prescribed fires can now be conducted in winter. This enables treating more land area with adaptive practices than if only summer were available.

Topographic variation in structure of mixed-conifer forests under an active-fire regime

Lydersen, Jamie; North, Malcolm
2012
Ecosystems 15(7): 1134-1146

Source	Web of Science, 05/14/2015 (Rob Fiegener)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article
Study type	
Location	Sierra Nevada Mountains, California, USA
Ecosystem type	mixed-conifer
Stated aim of study	Management for forest resiliency as climate changes often uses historical forest structure and composition as general guidance for fuels and restoration treatments. But historical reconstructions usually include accurate estimates only of large, live tree density and composition. Information for other stand features- smaller trees, dead wood, understory structure, regeneration, fuel loads- is usually lacking, making it difficult to accurately assess how these features would be affected by fire under current climate conditions. In this study, data for these parameters were gathered from old-growth, mixed-conifer forests with at least two low-intensity fires within the last 65 years by sampling in 150 plots at 48 sites over 400 km of the Sierra Nevada. Results are interpreted in the context of prescribed fire use under climate change.
Broad outcomes	Recent fire history had the strongest influence on understory conditions with small tree density decreasing and shrub cover increasing with the increased intensity and frequency of fire associated with upper-slope and ridge-top locations. In contrast, stand structures associated with large, overstory trees

such as total basal area, canopy cover, and the abundance of large snags and logs increased in topographic locations associated with more mesic, productive sites regardless of fire history. In forests with restored fire regimes, topography, fire and their interaction influence productivity and burn intensity, creating the structural heterogeneity characteristic of frequent-fire forests.

Climate change and forests of the future: managing in the face of uncertainty

Millar, Constance I.; Stephenson, Nathan L.; Stephens, Scott L.
2007

Ecological Applications 17(8): 2145-2151

Source	Suggested by Jeff Behan, 05/30/2015
Search terms	Not found via keyword search. Found cited in several included papers. Included because it appears to be seminal & widely-cited. Lays out oft-cited resistance/resilience/response framework. Discusses PF in passing, PF use implicit in several of the suggested strategies.
Type of reference	Peer reviewed journal article
Study type	
Location	
Ecosystem type	
Stated aim of study	Conceptual framework for managing forested ecosystems under assumption that future environments will be different from present but that we cannot be certain about specifics of change. Encourages flexible approaches that promote reversible and incremental steps, and that favor ongoing learning and capacity to modify direction as situations change. Resources managers will be challenged to integrate adaptation strategies (actions that help ecosystems accommodate changes adaptively) and mitigation strategies (actions that enable ecosystems to reduce anthropogenic influences on global climate) into overall plans.
Broad outcomes	Suggests that no single solution fits all future challenges, especially in context of changing climates, and that the best strategy is to mix different approaches for different situations. Adaptive strategies include resistance options (forestall impacts and protect highly valued resources), resilience options (improve the capacity of ecosystems to return to desired conditions after disturbance), and response options (facilitate transition of ecosystems from current to new conditions). Mitigation strategies include options to sequester carbon and reduce overall greenhouse gas emissions. Priority-setting approaches (e.g., triage), appropriate for rapidly changing conditions and for situations where needs are greater than available capacity to respond, will become increasingly important in the future.

Forest fuel reduction alters fire severity and long-term carbon storage in three Pacific Northwest ecosystems

Mitchell; Harmon, ME; O'Connell, KEB

2009

Ecological Applications 19(3): 643-655

Source	Env. Science & Pollution Management, 05/14/2015 (Rob Fiegener)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article
Study type	modeling
Location	Pacific Northwest forests, USA
Ecosystem type	1) east Cascades ponderosa pine, 2) west Cascades western hemlock-Douglas-fir, and 3) Coast Range
Stated aim of study	Two forest management objectives debated for federally managed PNW landscapes involve perceived trade-offs between 1) fire restoration and 2) carbon sequestration. 1) would reduce fuel (and C) accumulated through a century of fire suppression and exclusion. 2) would manage forests for enhanced C sequestration to reduce atmospheric CO2 and associated threats from global climate change. This study explored trade-offs between these two strategies using forest ecosystem simulation model STANDCARB to examine effects of fuel reduction on fire severity & long-term C dynamics in 3 PNW forest ecosystems: 1) east Cascades ponderosa, 2) west Cascades western hemlock-Douglas-fir, and 3) Coast Range western hemlock–Sitka spruce.
Broad outcomes	Our simulations indicate that fuel reduction treatments in these ecosystems consistently reduced fire severity. However, reducing the fraction by which carbon (C) is lost in a wildfire requires the removal of a much greater amount of C, since most of the C stored in forest biomass (stem wood, branches, coarse woody debris) remains unconsumed even by high-severity wildfires. For this reason, all of the fuel reduction treatments simulated for west Cascades and Coast Range ecosystems as well as most of the treatments simulated for east Cascades resulted in a reduced mean stand C storage. One suggested method of compensating for such losses in C storage is to utilize C harvested in fuel reduction treatments as biofuels. Our analysis indicates that this will not be an effective strategy in the west Cascades and Coast Range over the next 100 years. We suggest that forest management plans aimed solely at ameliorating increases in atmospheric CO2 should forgo fuel reduction treatments in these ecosystems, with the possible exception of some east Cascades ponderosa pine stands with uncharacteristic levels of understory fuel accumulation. Balancing a demand for maximal landscape C storage with the demand for reduced wildfire severity will likely require treatments to be applied strategically throughout the landscape rather than indiscriminately treating all stands.

High-severity wildfire effects on carbon stocks and emissions in fuels treated and untreated forest

North, Malcolm P.; Hurteau, Matthew D.
2011
Forest Ecology and Management 261(6): 1115-1120

Source	Web of Science, 05/01/2015 (Steve Van Tuyl)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")
Type of reference	Peer-reviewed journal article
Study type	
Location	Sierra Nevada Mountains (mostly central and northern) California, USA
Ecosystem type	
Stated aim of study	Examined tradeoffs in carbon stock reduction and wildfire emissions in 19 fuels-treated and -untreated forests burned in twelve wildfires. The fuels treatment was a commonly- used thinning from below and removal of activity fuels (slash created by the thinning) either by whole tree removal, or piling and burning.
Broad outcomes	The fuels treatment removed an average of 50.3Mg C ha−1 or 34% of live tree carbon stocks. Total carbon (fuels treatment plus wildfire emission) removed from treated sites was 119% of the carbon emitted from the untreated/burned sites. However, with only 3% tree survival following wildfire, untreated forests averaged only 7.8Mg C ha−1 in live trees with an average quadratic mean tree diameter of 21cm. In contrast, treated forest averaged 100.5Mg C ha−1 with a live tree quadratic mean diameter of 44cm. In untreated forests 70% of remaining total ecosystem carbon shifted to decomposing stocks after the wildfire, compared to 19% in the fuels-treated forest. In wildfire burned forest, fuels treatments have a higher immediate carbon 'cost', but in the long-term may benefit from lower decomposition emissions and higher carbon storage.

Fire suppression and fuels treatment effects on mixed-conifer carbon stocks and emissions

North, Malcolm; Innes, James; Hurteau, Matthew
2009
Ecological applications: a publication of the Ecological Society of America 19(6): 1385-1396

Source	Agricola, 05/14/2015 (Rob Fiegener)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article

Study type

Location Teakettle Experimental Forest, southern Sierra Nevada Mountains, California, USA

Ecosystem type Sierra Nevada mixed-conifer forest

Stated aim of study Depending on management, forests can be an important sink or source of carbon that if released as CO2 could contribute to global warming. Many forests in the western US are being treated to reduce fuels, yet the effects of these treatments on forest carbon are not well understood. We compared immediate effects of fuels treatments on carbon stocks and releases in replicated plots before and after treatment, and against a reconstruction of active-fire stand conditions for the same forest in 1865.

Broad outcomes Total live-tree carbon (C) was substantially lower in modern fire-suppressed conditions (and all treatments) than same forest under an active-fire regime. Fire suppression has increased stem density, but current forests have fewer very large trees, reducing total live- tree C stocks and shifting a higher proportion into small-diameter, fire sensitive trees.

Prescribed burning released 14.8 Mg C/ha, with pre-burn thinning increasing the average release by 70% and contributing 21.9–37.5 Mg C/ha in milling waste. Fire suppression may have incurred a double C penalty by reducing stocks and contributing to emissions with fuels-treatment activities or inevitable wildfire combustion. All treatments reduced fuels and increased fire resistance, but most gains were achieved with understory thinning, with only modest increases in much heavier overstory thinning. Modifying current treatments to focus on reducing surface fuels, actively thinning most small trees, and removing only fire-sensitive species in merchantable, intermediate sizes would retain most of the current C-pool levels, reduce prescribed burn and potential future wildfire emissions, and favor stand development of large, fire-resistant trees that can better stabilize C stocks.

Theory and practice of wildland fuels management

Omi, Philip N.
2015
Current Forestry Reports 1(2): 100-117

Source Suggested by David W. Peterson, 05/29/2015

Search terms Not found via keyword search.

Type of reference Peer reviewed journal article

Study type review, discussion of research needs

Location western, southwestern, and southeastern USA.

Ecosystem type long-needled pine and dry, mixed conifer forests

Stated aim of study	Objectives for this paper include: 1) provide historical perspective [on fuels treatment], including previous practitioners and policy precedents, 2) summarize current fuel treatment practices in managed forests, focusing on western and southeastern USA, 3) summarize theoretical understanding that informs practices, and 4) suggest areas of needed future emphasis. A central postulate is that theory and practice of fuel management are restricted by shortcomings in fuel and treatment quantification. As an immature science, fuel treatment metrics and measurement standards need refinement or are yet to be developed.
Broad outcomes	

A case for developing place-based fire management strategies from traditional ecological knowledge

Ray, Lily A.; Kolden, Crystal A.; Chapin, F. Stuart
2012
Ecology and Society 17(3): 37

Source	Web of Science, 05/14/2015 (Rob Fiegener)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article
Study type	social science, policy
Location	
Ecosystem type	
Stated aim of study	Sustainability science promotes place-based resource management because natural processes vary among ecosystems. When local science is limited, land managers may have to generalize from other ecosystems that function differently. One proposed solution is to draw upon traditional ecological knowledge (TEK) accumulated by indigenous groups through resource use. Integrating TEK with conventional resource management is difficult, especially when the two offer competing explanations of local environments. Managers may discount TEK that contradicts conventional resource management. This study investigated whether such disagreements arise when nonlocal resource management generalizations displace place-based science. It compared claims about wildfires made by Athabascan forest users residing at Koyukuk National Wildlife Refuge with those in the USFWS fire management plan for that refuge, focusing on two aspects of fire ecology & management: 1) drivers of landscape flammability, including climate change, and 2) the feasibility of using wildfires and prescribed burns to achieve resource management objectives.

Broad outcomes Results indicated that some disagreements came from reliance of the federal fire management plan on generalized national narratives at the expense of place-based science. In some cases, conflicts between traditional ecological knowledge and conventional resource management, rather than indicating a dead end, can identify topics requiring in-depth, place-based research.

Objectives and considerations for wildland fuel treatment in forested ecosystems of the interior western United States

Reinhardt, Elizabeth D.; Keane, Robert E.; Calkin, David E.; Cohen, Jack D.
2008
Forest Ecology and Management 256(12): 1997-2006

Source Web of Science, 05/01/2015 (Steve Van Tuyl)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")

Type of reference Peer-reviewed journal article

Study type synthesis

Location Interior western USA

Ecosystem type Interior western USA forests

Stated aim of study 1) summarizes objectives, methods, and expected outcomes of fuel treatments in forests of the Interior West, 2) highlights common misunderstandings and areas of disagreement, and 3) synthesizes relevant literature to establish a common ground for future discussion and planning. Includes explicit discussion of fuels treatments, including prescribed fire, in the context of climate change.

Broad outcomes Of special concern is that [climate-driven] changes in fire regime may be quite abrupt rather than gradual and these changes will occur in ecosystems where fire has been excluded for several decades. Thus, fuel treatment analyses should not be driven by specific assumptions about weather and climate. Expected severity of burns and extensive area burned may spell dire consequences for many western US flora that are not adapted to this rapid change. One way to mitigate adverse fire severity is to implement fuel treatments across landscapes so when unplanned fires occur they will tend to be less severe, especially in short fire return interval forests that historically burned in low- severity fires. There is some debate on whether fuel treatments are needed in the wildland if climate and fire regimes change. The reasoning is that climate is inherently variable and dynamic and because of this, fire regimes will change and render fuel treatments ineffective; it may be difficult to craft restoration treatments when the fire regime, and therefore desired stand conditions, are a moving target. However, fuel treatments could become increasingly important to protect people and property from fire in WUI and urban areas as fire seasons lengthen and become drier. Wildland ecosystems also require treatment to buffer effects of the rapidly changing environment. Active fuel management will be needed to minimize adverse effects of high severities and ensure post-fire landscapes contain ecologically viable patterns and composition. The best way to buffer ecosystems against adverse effects of future climates is to increase their resilience. Fire was a major process on the historical landscape. Therefore, in anticipation of more extensive and uncontrollable fires in the future, we must prepare the landscape to accept these changes with minor effects to the biota. The fact that we have had several decades of fire exclusion along with predicted climate change may foster future fires that severely alter landscapes in structure, composition, and function. Ecosystem restoration treatments that reduce fuels may protect ecosystem elements during the climate change transition period. [From conclusions.]

Wildfire and fuel treatment effects on forest carbon dynamics in the western United States

Restaino, Joseph C.; Peterson, David L.
2013

Forest Ecology and Management 303: 46-60

Source	Web of Science, 05/14/2015 (Rob Fiegener)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article
Study type	review and synthesis
Location	western USA
Ecosystem type	western USA forests, dry temperate
Stated aim of study	Climate-driven increases in wildfire extent and severity are expected to increase the risks of reversal to C stores in western US forests and affect the potential of dry forests to sequester C. Fuel treatments that successfully reduce surface fuels can mitigate wildfire spread and severity, while reducing tree mortality and emissions from wildfire. But heterogeneous burn environments, site-specific variability in post-fire ecosystem response, and uncertainty in future fire frequency and extent complicate assessments of long-term (decades to centuries) C dynamics across large landscapes. This study reviews evidence for treatment and wildfire effects on C dynamics, summarizes elements of C release associated with fuel treatments, explores the influence of temporal and

	spatial scales on C dynamics and examines trade-offs between C release from fuel treatments and mitigated wildfire severity.
Broad outcomes	Results of studies on effects of fuel treatments and wildfires on long-term C retention across large landscapes are limited and equivocal. Stand-scale studies, empirical and modeled, describe a wide range of total treatment costs (12–116 Mg C ha[1]1) and reductions in wildfire emissions between treated and untreated stands (1–40 Mg C ha[1]1). Conclusions suggest the direction (source, sink) and magnitude of net C effects from fuel treatments are similarly variable ([1]33 Mg C ha[1]1 to +3 Mg C ha[1]1). Studies at large spatial and temporal scales suggest there is a low likelihood of high-severity wildfire events interacting with treated forests, negating any expected C benefit from fuels reduction. The frequency, extent, and severity of wildfire are expected to increase as a result of changing climate, and additional information on C response to management and disturbance scenarios is needed improve the accuracy and usefulness of assessments of fuel treatment and wildfire effects on C dynamics.

Climate change impacts on fire regimes and key ecosystem services in Rocky Mountain forests

Rocca, M. E.; Brown, P. M.; MacDonald, L. H.; Carrico, C. M.
2014
Special Section: Fire, forests and climate change: an assessment of the continental US. 327: 290-305

Source	CAB Abstracts, 05/14/2015 (Rob Fiegener)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article
Study type	review
Location	Central Rocky Mountains
Ecosystem type	Central Rocky Mountain forests and woodlands
Stated aim of study	Central Rocky Mountain forests span broad gradients in climate, elevation, and other environmental conditions, encompassing great diversity in species, ecosystem productivities, and fire regimes. Objectives of this review 1) characterize likely short-and long-term effects of projected climate changes on fuel dynamics and fire regimes for four Rocky Mountain forest types; 2) review how these changes are likely to affect carbon sequestration, water resources, air quality, biodiversity; and 3) assess suitability of 4 management alternatives to mitigate these effects and maintain forest ecosystem services.

Broad outcomes Fire frequency is likely to increase in the short term in all areas because of warmer, longer, drier fire seasons, but this change is likely to lead to longer-term reduction in vegetation productivity in some moisture-limited forest types, e.g. piñon-juniper and lower montane. This will decrease fuel accumulation rates and consequently reduce fire risk and result in longer fire return intervals. Restoration treatments that use PF or mechanical thinning to restore historical forest structure and landscape heterogeneity have the potential to reduce chances of uncharacteristically severe and damaging wildfires in lower montane forests. Use of PF and mechanical treatments in upper montane forests are projected to be moderately effective in mitigating potential climate change impacts by reducing fire extent and severity. PF and mechanical treatments could effectively prepare upper montane forests for coming changes in fire regimes and help maintain the ecosystem over the longer-term. Use of PF in the subalpine is more difficult given high fuel loadings, uncertain public acceptance of initiating stand-replacing fires that are characteristic of this forest type, and associated effects on air and water quality. Even if subalpine forests were indeed vulnerable to type conversion in coming decades, PF and mechanical thinning would be unlikely to mitigate this conversion because fire regimes in these forests are climate limited, not fuel limited. In lower and upper montane forests, both PF and mechanical treatments have the potential to restore and maintain historical forest structure, promote native diversity, and lower risk of severe air quality events. Treated forests will store less C than untreated forests but, in montane ecosystems, should be more resistant to type conversion and associated long-term loss of C. Where feasible, PF in these forests may be the better choice for mimicking a natural process and promoting biodiversity.

Fire regimes, forest change, and self-organization in an old-growth mixed- conifer forest, Yosemite National Park, USA

Scholl, Andrew E.; Taylor, Alan H.
2010
Ecological Applications 20(2): 362-380

Source Web of Science, 05/01/2015 (Steve Van Tuyl)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")

Type of reference Peer-reviewed journal article

Study type historical reconstruction

Location Western part of Yosemite National Park, California, USA

Ecosystem type Mixed conifer forest, Yosemite National Park, CA

Stated aim of study Restoration of fire to dry mixed-conifer forests altered by decades of fire suppression is a guiding principle of NPS resource management. To better understand conditions before fire exclusion, characteristics of forest changes since excluding fire, and influence of topographic or self-organizing controls on forest structure, this study reconstructed spatial and temporal characteristics of fire regimes and forest structure in a 2125-ha mixed- conifer forest in Yosemite NP. Discusses use of prescribed fire to reduce risk of stand- replacing fire in these highly altered forests by coupling explicit reference conditions with consideration of current conditions and projected climate change.

Broad outcomes	Climate change heightens the risk of stand-replacing fire in these highly altered forests. Restoration of the self-limiting fuel–fire–forest structure mosaic that characterized these forests before fire suppression with PF would reduce the risk of unusual high-severity fire. Managers need to apply multiple burns at short intervals for a sustained period to reduce surface fuels and create small canopy openings characteristic of the reference forest. By coupling explicit reference conditions with consideration of current conditions and projected climate change, management activities can balance restoration and risk management. Use of PF as the restoration agent in boundary forests will connect them to interior forests where the fire regime is a mixture of WFU and wildfires. Increasing connectivity among ecosystems with a process that has influenced forest adaptation for millennia should promote the capacity for species persistence and migration under a changing climate.

Managing burned landscapes: Evaluating future management strategies for resilient forests under a warming climate

Shive, K. L.; Fulé, P. Z.; Sieg, C. H.; Strom, B. A.; Hunter, M. E.
2014
International Journal of Wildland Fire 23(7): 915-928

Source	Web of Science, 05/01/2015 (Steve Van Tuyl)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")
Type of reference	Peer-reviewed journal article
Study type	modeling
Location	Arizona, within boundaries of 2002 Rodeo-Chedeski Fire
Ecosystem type	Ponderosa pine
Stated aim of study	Modeled forest growth in ponderosa pine forests that burned in Arizona's 2002 Rodeo–Chediski Fire using the Forest Vegetation Simulator Climate Extension. Initial stand structures were defined by pre-fire treatment (treated or untreated)

and low or high fire severity. Also compared 'No Management' with 4 future management strategies: prescribed fire at 10- and 20-year intervals, an uneven-aged harvest applying Individual Tree Selection (ITS) prescriptions with cutting every 20 years that favored harvest of ponderosa pine and Douglas-fir, and a second ITS strategy with prescribed fire immediately after harvest.

Broad outcomes Under extreme climate change, existing forests persisted for several decades, but shifted towards pinyon–juniper woodlands by 2104. Under milder scenarios, pine persisted with reduced growth. Prescribed burning at 10- and 20-year intervals resulted in basal areas within the HRV in low-severity sites that were initially dominated by smaller diameter trees; but in sites initially dominated by larger trees, the range was consistently exceeded. For high-severity sites, prescribed fire was too frequent to reach the HRV's minimum basal area. Alternatively, for all stands under milder scenarios, uneven-aged management resulted in basal areas within the HRV because of its inherent flexibility to manipulate forest structures. These results emphasize the importance of flexible approaches to management in a changing climate. [From abstract.]

Wild land fire emissions, carbon, and climate: Science overview and knowledge needs

Sommers, William T.; Loehman, Rachel A.; Hardy, Colin C.
2014
Forest Ecology and Management 317: 1-8

Source Suggested by Jeff Behan (Web of Science), 05/30/2015

Search terms Not found via keyword search. Found on Web of Science while accessing a different paper. Added because it explicitly discusses Hurteau, North & others' included studies on PF use and forest carbon.

Type of reference Peer reviewed journal article

Study type synthesis

Location

Ecosystem type

Stated aim of study Wildfires are an important component of the terrestrial carbon (C) cycle and one of the main pathways for movement of C from the land surface to the atmosphere. Fires have received much attention in recently as potential catalysts for shifting landscapes from C sinks to C sources. This synthesis paper provides a description of ecological drivers of wildfires and C in forested ecosystems across the spatial and temporal scales at which system drivers (climate, weather), behaviors (wildfire occurrence, spread, intensity), and resulting patterns (vegetation composition and structure, C emissions) occur and interact. Improved understanding of these relationships is critical if we are to anticipate and respond to major changes in the global earth system expected in coming decades and centuries.

Broad outcomes Unless structural or functional ecosystem shifts occur, net C balance in fire-adapted systems at steady state is zero when assessed over the entire post-fire successional sequence and at landscape scales. When evaluated at fine spatial scales and over short periods of time, however, wildfires may seem to release more C to the atmosphere than remains on site. Measurements of wildfire C emissions are thus highly biased by the spatial and temporal scales that bound them, and may over- or under-estimate C source- sink dynamics that provide critical feedbacks to the climate system.

Short- and long-term effects of thinning and prescribed fire on carbon stocks in ponderosa pine stands in northern Arizona

Sorensen, C D; Finkral, A J; Kolb, TE; Huang, CH
2011
Forest Ecology and Management 261(3): 460-472

Source Env. Science & Pollution Management, 05/14/2015 (Rob Fiegener)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")

Type of reference Peer-reviewed journal article

Study type

Location Northern Arizona, USA

Ecosystem type Ponderosa pine

Stated aim of study Euro–American logging practices, intensive grazing and fire suppression have increased the amount of carbon (C) stored in southwestern US ponderosa pine forests. Current stand conditions leave these forests prone to high-intensity wildfire, which releases a pulse of C emissions and shifts C storage from live trees to standing dead trees and woody debris. Thinning and prescribed burning are commonly used to reduce risk of intense wildfire, but also reduce on-site C stocks and release C to the atmosphere. This study quantified impacts of thinning on C budgets of 5 p. pine stands in northern Arizona, including fossil fuels consumed during logging operations. Used pre- and post-treatment data on C stocks and the Fire and Fuels Extension to the Forest Vegetation Simulator to simulate long-term effects of intense wildfire, thinning, and repeated prescribed burning on stand C storage.

Broad outcomes FEE–FVS simulations showed that thinning increased mean canopy base height, decreased mean crown bulk density, and increased mean crowning index, and thus reduced risk of high-intensity wildfire at all sites. Untreated stands that incurred wildfire once within the next 100 years or once within the next 50 years had greater mean net C storage after 100 years compared to treated stands that experienced PF every 10 years or every 20 years. Treated stands released greater amounts of C overall due to repeated prescribed fires, slash burning, and 100% of harvested logs being counted as C emissions because they were used for short-lived products. However, after 100 years treated stands stored more C in live trees and less C in dead trees and surface fuels than untreated stands burned by intense wildfire. Long-term net C storage of treated stands was similar or greater than untreated wildfire-burned stands only when a distinction was made between C stored in live and dead trees, C in logs was stored in long-lived products, and energy in logging slash substituted for fossil fuels. Mean total pre-treatment carbon (C) stock, including above- ground live and dead trees, below-ground live and dead trees, and surface fuels across five sites was 74.58Mg C ha−1 and the post-treatment mean was 50.65Mg C ha−1 in the first post-treatment year. Mean total C release from slash burning, fossil fuels, and logs removed was 21.92Mg C ha−1.

Modern fire regime resembles historical fire regime in a ponderosa pine forest on Native American lands

Stan, A. B.; Fulé, P. Z.; Ireland, K. B.; Sanderlin, J. S.
2014
International Journal of Wildland Fire 23(5): 686-697

Source	CAB Abstracts, 05/01/2015 (Steve Van Tuyl)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")
Type of reference	Peer-reviewed journal article
Study type	historical reconstruction
Location	Hualapai Tribal Lands, Arizona, USA
Ecosystem type	Ponderosa pine-dominated forest
Stated aim of study	Forests on tribal lands in the western USA have seen the return of low-intensity surface fires for decades longer than forests on non-tribal lands. This study examined the surface fire regime in a ponderosa pine dominated forest on Hualapai tribal lands in Arizona where prescribed fire has been used since the 1960s. Temporal (frequency and seasonality) and spatial (synchrony) attributes and regulators of the fire regime over three land-use periods (historical, suppression, modern) were inferred between 1702-2007 using fire-scarred

trees. Results are discussed in the context of managing this type of forest as climate and fire regimes change, including use of prescribed fire.

Broad outcomes Findings suggest that the current prescribed burning program in the ponderosa pine forest on the Hualapai tribal lands is effectively mimicking some temporal and spatial attributes of the past surface fire regime. Fire frequency and asynchrony patterns are qualitatively similar between the modern and historical periods. Owing to the early use of prescribed burning and thinning, forests on tribal lands may be in an advantageous position relative to others in the western US, potentially having characteristics that support greater resistance to severe burning and thus, increased resilience to the effects of climate change.

Fuel treatment impacts on estimated wildfire carbon loss from forests in Montana, Oregon, California, and Arizona

Stephens, S. L.; Boerner, R. E. J.; Moghaddas, J. J.; Moghaddas, E. E. Y.; Collins, B. M.; Dow, C. B.; Edminster, C.; Fiedler, C. E.; Fry, D. L.; Hartsough, B. R.; Keeley, J. E.; Knapp, E. E.; McIver, J. D.; Skinner, C. N.; Youngblood, A.
2012
Ecosphere 3(5) art38

Source CAB Abstracts, 05/14/2015 (Rob Fiegener)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")

Type of reference Peer-reviewed journal article

Study type experiment

Location Montana, Oregon, California, and Arizona, USA

Ecosystem type common dry coniferous forest types in the western US.

Stated aim of study Using forests to sequester carbon in response to climate change is being considered across the globe. This study reports effects of common forest fuel reduction treatments on carbon pools of live and dead biomass as well as potential wildfire emissions from six different sites in four western US states representative of the most common dry coniferous forest types in the western US. Also predicts median forest product life spans and uses of materials removed during mechanical treatments. Uses Fire and Fire Surrogate study data. Treatments and data collection methods varied somewhat among sites. But sufficient similarity in how experiments were conducted facilitated comparison of results across sites.

Broad outcomes Carbon (C) loss from modeled wildfire-induced tree mortality was lowest in mechanical plus PF treatments, followed by PF-only treatments. Wildfire emissions varied from 10–80 Mg/ha and were lowest in PF and mechanical followed by PF treatments at most sites.

Mean biomass removals per site ranged from ~30–60 dry Mg/ha; median lives of products in first use varied considerably (10-50 years). Research suggests most benefits of increased fire resistance can be achieved with relatively small reductions in current C stocks.

Retaining or growing larger trees also reduced vulnerability of C loss from wildfire. In addition, modeled vulnerabilities to C losses and median forest product life spans varied considerably across study sites, which could be used to help prioritize treatment implementation.

Snowpack, fire, and forest disturbance: Interactions affect montane invasions by non-native shrubs

Stevens, Jens T; Latimer, Andrew M
2015
Global Change Biology 21(6): 2379-2393

Source	Academic Search Premier, 05/14/2015 (Rob Fiegener)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article
Study type	experiment
Location	Sierra Nevada Mountains, California, USA
Ecosystem type	rain-snow transition zone, Sierra Nevada Mountains, CA
Stated aim of study	Montane regions worldwide have had relatively low plant invasion rates, a trend attributed to increased climatic severity, low rates of disturbance and reduced propagule pressure relative to lowlands. Experiments at elevations above the invasive range of non- native species can clarify the relative contributions of these mechanisms to montane invasion resistance, yet such experiments are rare. Furthermore, global climate change and land use changes are expected to cause decreases in snowpack and increases in disturbance by fire and forest thinning in montane forests. We examined the importance of these factors in limiting montane invasions using a field transplant experiment above the invasive range of two non-native lowland shrubs, Scotch broom and Spanish broom, in the rain-snow transition zone of the Sierra Nevada of California. We tested the effects of canopy closure, prescribed fire, and winter snow depth on demographic transitions of each species.
Broad outcomes	Establishment of both Scotch broom and Spanish broom was most likely at intermediate levels of canopy disturbance, but at this intermediate canopy level, snow depth had negative effects on winter survival of seedlings. We used matrix population models to show that an 86% reduction in winter snowfall would

cause a 2.8-fold increase in population growth rates in Scotch broom and a 3.5-fold increase in Spanish broom. Fall prescribed fire increased germination rates, but decreased overall population growth rates by reducing plant survival. However, at longer fire return intervals, population recovery between fires is likely to keep growth rates high, especially under low snowpack conditions. Many treatment combinations had positive growth rates despite being above the current invasive range, indicating that propagule pressure, disturbance, and climate can all strongly affect plant invasions in montane regions. We conclude that projected reductions in winter snowpack and increases in forest disturbance are likely to increase the risk of invasion from lower elevations.

Simulating landscape-scale effects of fuels treatments in the Sierra Nevada, California, USA

Syphard, A. D.; Scheller, R. M.; Ward, B. C.; Spencer, W. D.; Strittholt, J. R.
2011
International Journal of Wildland Fire 20(3): 364-383

Source	CAB Abstracts, 05/14/2015 (Rob Fiegener)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article
Study type	
Location	Sierra Nevada Mountains, California, USA
Ecosystem type	Sierra Nevada mixed-conifer forest
Stated aim of study	In many coniferous forests of the western US, wildland fuel accumulation and projected climate conditions increase the likelihood that fires will become larger and more intense. Fuels treatments and prescribed fire are widely recommended, but there is uncertainty regarding their ability to reduce the severity of subsequent fires at a landscape scale. This study investigated interactions among landscape-scale fire regimes, fuels treatments and fire weather in the southern Sierra Nevada, California. A spatially dynamic model of wildfire, succession and fuels management was used to simulate long-term, broad-scale effects of thin-from-below fuels treatments followed by prescribed fire under current weather conditions and under more severe weather.
Broad outcomes	Simulated fuels management minimized mortality of large, old trees, maintained total landscape plant biomass and extended fire rotation, but effects varied based on elevation, type of treatment and fire regime. The simulated area treated had a greater effect than treatment intensity, and effects were strongest where more fires intersected treatments and when simulated weather

conditions were more severe. In conclusion, fuels treatments in conifer forests potentially minimize the ecological effects of high-severity fire at a landscape scale provided that 8% of the landscape is treated every 5 years, especially if future fire weather conditions are more severe than in recent years.

Simulating post-wildfire forest trajectories under alternative climate and management scenarios

Tarancón, Alicia Azpeleta; Fulé, Peter Z.; Shive, Kristen L.; Sieg, Carolyn H.; Meador, Andrew Sánchez; Strom, Barbara

2014

Ecological Applications 24 (7):1626-1637

Source	Suggested by Carl Seilstad, 05/26/2015
Search terms	Not found via keyword search.
Type of reference	Peer-reviewed journal article
Study type	modeling
Location	Northern Arizona, USA
Ecosystem type	multi-species forest, northern Arizona, USA
Stated aim of study	Post-fire predictions of forest recovery under future climate change and management actions are necessary for forest managers to make decisions about treatments. This study applied the Climate-Forest Vegetation Simulator (Climate-FVS) to compare alternative climate and management scenarios in a severely burned multispecies forest of Arizona, USA.
Broad outcomes	Severe climate change led to deforestation under all management regimes, but important differences emerged under moderate scenarios: treatments that included regular prescribed burning fostered low density, wildfire-resistant forests composed of naturally dominant ponderosa pine. Non-fire treatments under moderate climate change were forecast to become dense and susceptible to severe wildfire, with a shift to dominance by sprouting species. Current US forest management requires modeling of future scenarios but does not mandate consideration of climate change effects. However, this study showed substantial differences in model outputs depending on climate and management actions. Managers should incorporate climate change into the process of analyzing environmental effects of alternative actions.

Climatic stress increases forest fire severity across the western United States

van Mantgem, Phillip J.; Nesmith, Jonathan C. B.; Keifer, MaryBeth; Knapp, Eric E.; Flint, Alan; Flint, Lorriane
2013
Ecology Letters 16 (9) 1151-1156

Source	Academic Search Premier, 05/14/2015 (Jeff Behan)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming")
Type of reference	Peer-reviewed journal article
Study type	
Location	Western USA
Ecosystem type	coniferous forests
Stated aim of study	Using prescribed fire data, tested how climate relates to fire severity (individual tree mortality probabilities) across coniferous forests of western USA. Examined if climate influences post-fire tree mortality across a range of locations and species. Assembled prescribed fire effects monitoring data from FEAT/FIREMON Integrated, merging forest plot data across NPS units in western USA into a single relational database. Also included relevant plot data from Fire and Fire Surrogate project. Prescribed fire data are particularly well suited to exploring the relationship between climate and fire severity because prescribed fires are conducted over a relatively narrow range of fire weather but over a potentially wide range of interannual climatic conditions.
Broad outcomes	[All data came from PFs.] Findings show post-fire tree mortality of coniferous trees was influenced by climate across the western US, describing what appears to be a general, but overlooked, climate–fire relationship. This relationship appeared to be consistent across broad geographical regions, major genera and tree sizes. Climate was predictive of tree mortality after accounting for fire damage and defenses, supporting conceptual models of tree mortality that account for combined effects of multiple long- and short-term stressors. In this case, longer term climatic stress (5 years prior to fire) predisposed trees to be killed from short-term fire damage. Pervasive warming can be expected to increase the incidence of high severity fire by creating conditions where lower fuel moisture results in fires of higher intensity. An important implication of our results is that chronic stresses on western forests, including continued warming, may also lead to de facto increases in fire severity independent of changes in fire intensity.

Prescribed fire as a means of reducing forest carbon emissions in the Western United States.

Wiedinmyer, C.; Hurteau, M. D.
2010
Environmental Science & Technology 44 (6) 1926-1932

Source Web of Science, 05/01/2015 (Steve Van Tuyl)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")

Type of reference Peer-reviewed journal article

Study type modeling

Location Western US

Ecosystem type Dry temperate forested ecosystems

Stated aim of study Used a regional fire emissions model to estimate the potential reduction in fire emissions when prescribed burning is applied in dry, temperate forested systems of the western US Daily CO_2 fire emissions for 2001−2008 were calculated for the western US for two cases: a default wildfire case and one in which prescribed burning was applied.

Broad outcomes Wide-scale PF application can reduce CO_2 fire emissions for the western U.S. by 18-25% in the western U.S., and by as much as 60% in specific forest systems. Although this work does not address important considerations such as the feasibility of implementing wide- scale PF management or the cumulative emissions from repeated prescribed burning, it does provide constraints on potential carbon emission reductions when prescribed burning is used. [From abstract.]

Exploring the onset of high-impact mega-fires through a forest land management prism.

Williams, J.
2013
Forest Ecology and Management 294: 4-10

Source CAB Abstracts, 05/01/2015 (Steve Van Tuyl)

Search terms ("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")

Type of reference Peer-reviewed journal article

Study type	synthesis and policy
Location	Reviews 4 wildfires outside USA, 2 in eastern USA; 6 in western USA
Ecosystem type	Mixed conifer, also Australian forests
Stated aim of study	Explores the mega-fire phenomenon through a forest land management prism in an attempt to focus on the contributory factors that may set the stage for high-impact mega- fires. Draws on results from two overviews of such fires from around the world and firsthand experiences dealing with others in the USA. Areas where land management decisions have led to extensive fuel buildups and wildfires that increasingly exceed suppression capabilities are contrasted with areas where management has been better aligned with fire regimes through use of prescribed fire at intensities, intervals, and scales to effectively reduce fuels to protect people, maintain forest resilience, ensure biodiversity, and increase suppression effectiveness.
Broad outcomes	Drought and fire exclusion policies have been implicated in the large fire problem. However, several high impact mega-fires can be further traced to land management decisions that resulted in dense forest conditions with high biomass and fuel build-ups over extensive areas. As droughts have intensified, more of these accumulated fuels have become available to burn at intensities that exceed suppression capabilities. In contrast, some places have managed to largely avoid high-impact mega-fires. Lands in Florida and Western Australia have better aligned policies and practices with disturbance regimes that define the forested landscapes that they protect. They use PF at appropriate intensities, intervals, and scales to reduce fuels as the means to protect people, maintain forest resilience, ensure biodiversity, and increase margins of suppression effectiveness. Forest land management policies and practices that, by design or by default, result in greater volumes of fuel and rely on suppression capabilities to maintain these conditions may no longer be sustainable as droughts deepen and become more widespread. Suggests that adapting wildland fire management programs, forest land management policies, and the current regulatory framework to the reality of warmer, drier climate patterns will be essential in reducing mega-fire risks. Protecting fire-prone landscapes can no longer rely on suppression alone; protection will become more dependent on the management of forests where high-impact mega-fires incubate.

Interactions of climate, fire, and management in future forests of the Pacific Northwest.

Wimberly, M. C.; Liu, Z. H.
2014
Special Section: Fire, forests and climate change: an assessment of the continental US. 327 () 270-279

Source	CAB Abstracts, 05/01/2015 (Steve Van Tuyl)
Search terms	("prescribed fire" OR "prescribed burn" OR "controlled burn" OR "planned ignition" OR "broadcast burn") AND ("climate change" OR "global warming" OR "global change" OR "climate warming") AND ("adaptation" OR "mitigation" OR "resilience" OR "change management" OR "adapt" OR "climate adaptation")
Type of reference	Peer-reviewed
Study type	synthesis
Location	Pacific northwestern USA
Ecosystem type	
Stated aim of study	Longer, hotter, drier fire seasons are projected for the PNW under future climate scenarios. Area burned by wildfires also projected to increase. Fuel treatments are an important management tool in drier PNW forests where they have been shown to modify fire behavior and fire effects. But we know relatively little about how treatments will interact with changing climate and expanding human populations to influence fire regimes and ecosystem services over larger areas and longer time periods. To address this knowledge gap, this paper synthesizes recent literature on climate, fire, and forest management in the PNW to summarize projected changes and assess how forest management, including prescribed fire, can aid in adapting to future fire regimes and reducing their negative impacts.
Broad outcomes	Multiple studies project that wildfires will occur more frequently and burn larger areas under projected future, warmer climates in the PNW, potentially impacting multiple ecosystem services. Fuel treatments that modify both canopy fuels (thinning) and surface fuels (prescribed burning) can reduce fire severity within treated areas and can also reduce burn probability and severity across larger landscapes by modifying fire behavior and fire effects in untreated areas. PF is a critical component of these treatments, and thinning without accompanying treatment of surface fuels is less effective than thinning and burning at reducing the severity of large fires. But there is also considerable uncertainty about the degree to which changing climate and increasing human encroachment into the WUI may increase the cost and complexity of fire suppression and constrain use of PF in the future. Increasing both funding and public support for PF will be critical for sustaining critical ecosystem processes and reducing fire risk in PNW dry forests. Increased future fire risk will be likely concentrated in specific “hot spots” where physiographic settings and

vegetation types that are more conducive to burning intersect the expanding WUI where low-density development puts property at risk and potentially constrains PF use. The next generation of integrated assessments will need to incorporate novel data sources and models to more effectively integrate future climate projections with a variety of processes and constraints operating at the stand and landscape levels, including vegetation succession, fire spread, treatment effects, and expansion of human populations into wildland areas.

Appendix F

Scientists-Managers Workshop Participants

Name	Affiliation
RJ Hannah	US Forest Service, Central Oregon Fire Management Service
Kirk Will	Colorado Division of Fire Prevention and Control
Dan Thompson	Canadian Forest Service
Jeff Ennenga	Clackamas Community College
Cyndi Sidles	U.S. Fish and Wildlife Service
Richy Harrod	Okanogan-Wenatchee National Forest
Sharon Hood	Rocky Mountain Research Station, Fire, Fuel, and Smoke Program
Carrie Berger	Northwest Fire Science Consortium
Ben Curtis	Colville National Forest
Tonya Neider	North Cascades National Park
Doug Shinneman	USGS Forest and Rangeland Ecosystem Science Center
Becky Kerns	Pacific Northwest Research Station
Lisa Ellsworth	Oregon State University
Ernesto Alvarado	University of Washington
Morris Johnson	Pacific Northwest Research Station/Pacific Wildland Fire Sciences Lab
Amanda Stamper	The Nature Conservancy
Deana Wall	Central Oregon Fire Management Service
Don Motanic	Fire Subcommittee of the Intertribal Timber Council
Cindy Kolomechuk	Oregon Department of Forestry
Missy Matty	U.S. Geological Survey
Corey Gucker	Northern Rockies Fire Science Network
Megan Creutzburg	Institute for Natural Resources
Mark Fitch	National Park Service
Liz Ernst	Michigan Technological University
Jeremy Jiron	Pueblo of Isleta Department of Natural Resources
Paul Lujon	Pueblo of Isleta Department of Natural Resources
Matthew Landis	U.S. Environmental Protection Agency
Armando Gonzalez-Caban	Pacific Southwest Research Station
Erin Law	Montana/Idaho Airshed Group
Christopher O'Connor	Rocky Mountain Research Station
Alex Robertson	Deschutes National Forest/Ochoco National Forest
Gustavo Bisbal	Northwest Climate Science Center

Appendix G

Scientists-Managers Workshop Agenda

The Future of Fire and Fuels Management: Adapting Fuels Treatments in a Changing Climate

Monday, April 11, 2016

9:00 AM – 5:00 PM

Location:

Oregon Convention Center; 777 NE Martin Luther King Jr Blvd; Portland, Oregon

EcoAdapt™ Institute for Natural Resources NW CSC Northwest Climate Science Center

Hosted by:

In collaboration with:

Northwest Fire Science Consortium Northern Rockies Fire Science Network

This workshop culminates the Available Science Assessment Project (ASAP), sponsored by the Northwest Climate Science Center (NW CSC), through which EcoAdapt and the Institute for Natural Resources are evaluating the science behind fire and fuels management climate adaptation actions in Northwest national forests, with a focus on prescribed fire. This project focused on Washington, Oregon, Idaho, and western Montana forests, but findings may be more broadly applicable. The workshop builds on interviews with national forest managers who manage resources under shifting fire regimes, a systematic mapping of relevant literature, and an earlier science review panel discussion of the state of the science behind prescribed fire use under changing climate conditions. We are now bringing managers and scientists together for broader discussions regarding fuels management in the context of climate change.

Workshop Objectives:

- Document knowledge of how fuels management is changing in response to shifts in climate and fire regimes;
- Explore opportunities for further integration of scientific research and climate-informed management;
- Discuss agency plans and priorities for managing fire (with specific reference to the role of prescribed fire) under changing climate conditions;
- Describe the intended management application of desired future research and products on fire and fuels management;
- Develop partnerships between fire experts and forest/fire managers to ensure future research is addressing specific management needs;
- Explore and develop new methods for managing fire and fuels in a changing climate; and
- Help identify and refine funding priorities in the area of fire regimes and climate change.

AGENDA	
8:45	Coffee and sign in *Please register at the conference check-in booth if you have not already done so.*
9:00	Welcome and Meeting Objectives
9:10	Introductions & Energizer
9:30	Presentation: ASAP Project Background & Process Review
9:45	Presentation: Reviewing the ASAP findings – what does the literature say?
10:00	Group Discussion: Prescribed fire scientific consensus
10:45	Break
11:00	Group Discussion: Incorporating climate change into prescribed fire application
12:30	Lunch
1:30	Solutions Room discussion
3:30	Break
3:45	Group Discussion: Incorporating climate change into fire and fuels management, reflecting on Solutions Room discussions
4:30	Group Discussion: Identifying critical research and management questions
4:50	Next steps and adjourn

More information on the Available Science Assessment Project may be found at: http://ecoadapt.org/programs/state-of-adaptation/asap.