Available Science Assessment Project
Overview of Literature Search and Results

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Review question and literature search strategy

As part of the Available Science Assessment Project (ASAP), we conducted a search to find peer-reviewed and gray literature that addressed prescribed fire use under climate change, employing systematic review techniques adapted from the medical field. Systematic reviews differ from traditional literature reviews by documenting explicitly focused review questions, search terms and sources, and criteria for including relevant literature. We addressed the following question:

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?

To focus the review, we assumed: 1) that prescribed fire can be effective in mitigating fuel loads and fire effects, and helping promote open forest structure at the stand level, and 2) that large areas of western US forests are likely to be hotter and drier in coming decades, with associated increases in wildfire intensity, severity, and extent. For the purposes of our review, these issues were assumed to be settled. *Only literature that explicitly linked prescribed fire use with climate change was included.*

Search strings: "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".

Databases searched: AGRICOLA, Academic Search Premier, CAB Abstracts, Environmental Sciences and Pollution Management, Web of Science, Google Scholar. Around 200 unique hits; about 60 deemed relevant, i.e. explicitly linked prescribed fire use with climate change in some fashion.

Systematic knowledge synthesis for climate change adaptation can benefit from supplemental efforts to document institutional knowledge and stimulate participatory learning. Toward this goal, we held a workshop in June 2015 to discuss literature search results with wildfire and fuels management experts to enrich our knowledge base. Attending scientists helped us understand the scope and context of the issues and available information. They also suggested additional relevant literature. The next section summarizes these combined findings.

Results and lessons learned from literature review and 2015 expert workshop

General findings from and about the literature

- Prescribed fire was in widespread use well before climate change emerged as a major issue. There appears to be little evidence regarding a need to alter the fundamental mechanics of prescribed fire use in response to climate change. Instead, most evidence we found supports the notion that **the *rationales* and *conditions* for use of prescribed fire are evolving in response to climate-related shifts in wildfire regimes**, rather than the tool itself.

- Climate change effects on forests continue to unfold, intertwined with other ecological changes related to Euro-American land management over the past century. Despite intense interest in the subject, **major knowledge gaps remain regarding the effectiveness of prescribed fire (and broader fuels reduction efforts) in reducing the number or extent of large wildfires at the *landscape* level,** regardless of whether or not these fires were "climate related".

- Most included studies addressed prescribed fire use in the context of broader fuel treatment prescriptions - usually including thinning - and the effectiveness of these prescriptions toward forest ecosystem maintenance and restoration goals under a changing climate. Robust findings that prescribed fire and fuels management can reduce the intensity and severity of wildfire at the forest *stand* level should continue to apply, at least in the near term. **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.**

- One expert summed up the current state of science regarding our review question by describing two "spheres of thought": 1) climate change effects on forest ecosystems and, 2) wildfire fuels management. He noted that these areas of research are connected but that the literature often does not make these connections. He suggested that **making linkages between climate change effects and fuels management more explicit would be very useful.**

Key themes from the literature and 2015 expert workshop

- **The potential for forest biome shifts or type conversions, fundamental ecosystem or species changes or migrations in response to climate changes.** This theme includes ecosystem "tipping points", the potential for climate-driven vegetation or forest structure change, or for forests to be replaced by non-forest ecosystems after stand-replacing fire, and how these trends could affect decisions about where to apply fuels treatments. Related management considerations include the potential need to triage, i.e. shift focus away from the most vulnerable, "at risk" areas, better understand leading edges and trailing edges of tree species migrations, invasive species potential after prescribed fire, use of prescribed fire as a stalling mechanism, or to protect pockets of habitat, e.g. old-growth stands. An over-arching question is: how can prescribed fire and fuels reduction help keep forested lands from converting to non-forest?

- **How to preserve forest carbon stocks or "carbon carrying capacity" via fuels treatments, including prescribed fire**. Western forests currently sequester ~100 million tons of carbon (C) each year, but this strong sink is threatened by predicted increases in wildfire area burned and severity. Many studies looked at how fuels treatments- usually thinning and prescribed fire- affect forest C stocks. We found debate and little apparent consensus regarding the potential for fuels treatments to significantly affect this C sink. Findings vary widely depending on forest type, spatial and temporal scope of analysis, and assumptions regarding future wildfire probabilities, severity and extent. One author suggested that the potential for future stand replacing fires to result in vegetation type conversions is often underestimated and that such considerations could, at least in some cases, shift the balance of C stock accounting to favor more proactive fuels management to reduce the chances of forests being converted into non-forest ecosystems with much less capacity for C storage.

- **Where and when to use prescribed fire under climate change.** In essence, this theme is simply the addition of climate-related considerations to what have always been overarching questions when planning fuels treatments. Changes in temperature and precipitation regimes are already affecting burn windows when prescribed fire can be safely used. One highly relevant study using prescribed fire data found that across a broad range of ecosystem types, tree genera and tree sizes, longer term climatic stress (5 years prior to fire) predisposed trees to be killed from short-term fire damage. This has obvious implications for understanding expected tree mortality rates resulting from prescribed fire use under climate change. Increasing focus on forest carbon stocks and potential for forest vegetation changes will be additional factors to consider.

- **The likelihood that managed wildfire will play a larger role in fuels reduction as climate change effects continue to unfold.** Managers will have limited control over the expected rise in unplanned ignitions resulting from climate effects on forests and wildfire regimes, but they will have some options for managing the resulting wildfires to try and achieve objectives they might otherwise address via prescribed fires. This will increase incentives to have prescriptions in place to address fuels reduction goals to the extent possible once fires start. 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. 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. The definition of "prescribed fire" is already evolving to encompass this.

Three particularly relevant papers

Mantgem, Phillip; Nesmith, Jonathan C.; Keifer, MaryBeth; Knapp, Eric E.; Flint, Alan; Flint, Lorriane. 2013. *Climatic stress increases forest fire severity across the western United States*. Ecology Letters 16, 9, pp. 1151-1156.
PDF available (free download) at: http://climate.calcommons.org/sites/default/files/ele12151.pdf

REVIEW NOTE: This paper is perhaps the most relevant to our review question that we found. Findings are discussed in terms of aiding understanding of climate change effects on wildfire severity – which they do - but the interesting thing for our purposes is that the study used prescribed fire data to get at this. So the findings have even more direct implications for understanding how climatic stresses on individual trees effects mortality rates after prescribed fires, i.e. increases in fire intensity due to lower fuel moisture and increases in fire severity that are independent of fire intensity due to climatic stresses on trees. This study directly shows that going forward, across much of the west, we can expect that fire prescriptions will likely result in higher tree mortality rates than they might have in the past.

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.

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.

Joshua S. Halofsky, Jessica E. Halofsky, Theresa Burcsu, Miles A. Hemstrom. 2014. *Dry forest resilience varies under simulated climate-management scenarios in a central Oregon, USA landscape*. Ecological Applications 24: 1908–1925.
PDF available (free download) at:
https://www.researchgate.net/publication/271196856_Dry_forest_resilience_varies_under_simulated_climate-management_scenarios_in_a_central_Oregon_USA_landscape

REVIEW NOTE: Over a period spanning many decades, literally hundreds of studies have examined the ecological effects of silvicultural and restoration prescriptions on forest vegetation. Studies that explicitly incorporate climate change into these investigations are much less common, but increasing. This study looked at the effects of an active management scenario that included prescribed fire on forest vegetation composition and structure through the lens of a range of future climate scenarios, including continued warming. The region studied was central Oregon.

[Paraphrased from abstract and discussion.] Determining appropriate actions to create or maintain landscapes resilient to climate change is challenging because of uncertainty associated with potential effects of climate change and their interactions with land management. We 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.

Without climate change, area in dry province forest types remained constant. With climate change, dry mixed-conifer forests increased in area (by an average of 21–26% by 2100), and moist mixed-conifer forests decreased in area (by an average of 36–60% by 2100), under both management scenarios. Average area in dry mixed-conifer forests varied little by management scenario, but potential decreases in the moist mixed conifer forest were lower with active management. 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. Increased application of prescribed fire 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.

With changing climate in the dry province of central Oregon, our results suggest the likelihood of sustaining current levels of dense, moist mixed-conifer forests with large-diameter, old trees is low (less than a 10% chance) irrespective of management scenario; an opposite trend was observed under no climate change simulations. However, results also suggest active management within the dry and moist mixed-conifer forests that creates less dense forest conditions can increase the persistence of larger-diameter, older trees across the landscape. Owing to projected increases in wildfire, our results also suggest future distributions of tree structures will differ from the present. Overall, our projections indicate proactive management can increase forest resilience and sustain some societal values, particularly in drier forest types. However, opportunities to create more disturbance-adapted systems are finite, all values likely cannot be sustained at current levels, and levels of resilience success will likely vary by dry province forest type. Land managers planning for a future without climate change may be assuming a future that is unlikely to exist.

Engel, Kirsten H. 2014. Perverse Incentives: *The Case of Wildfire Smoke Regulation*. Ecology Law Quarterly 623; Arizona Legal Studies Discussion Paper No. 12-26.
PDF available (free download) at:
https://www.snre.arizona.edu/sites/snre.arizona.edu/files/Engel_Wildfire_Policy_ELQ-1.pdf

REVIEW NOTE: The vast majority of literature we found was from the natural science and policy fields. This interesting and apparently fairly unique paper is an analysis of how air pollution law and policies contribute to "underprovision of prescribed fire". Natural resource managers are likely all too familiar with the social challenges of implementing prescribed fires, but may not be as familiar with the legal and policy disconnects that contribute to these challenges. Understanding how what the author describes as "an anachronistic and inaccurate distinction between 'natural' and 'anthropogenic' fire" contributes to policy disconnects and exacerbates implementation of prescribed fires could give managers a stronger foundation to discuss these issues. This may be especially helpful as the expected rise in number of wildfires across the west increases instances of smoke in communities adjacent to forestlands and brings smoke and forest management issues into public awareness more often.

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 underprovision 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 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 and benefits of prescribed fire.