U.S. federal fire and forest policy: emphasizing resilience in dry forests

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Abstract. Current U.S. forest fire policy emphasizes short-term outcomes versus long-term goals. This perspective drives managers to focus on the protection of high-valued resources, whether ecosystem-based or developed infrastructure, at the expense of forest resilience. Given these current and future challenges posed by wildland fire and because the U.S. Forest Service spent >50% of its budget on fire suppression in 2015, a review and reexamination of existing policy is warranted. One of the most difficult challenges to revising forest fire policy is that agency organizations and decision making processes are not structured in ways to ensure that fire management is thoroughly considered in management decisions. Current resource-specific policies are so focused on individual concerns that they may be missing the fact that there are "endangered landscapes" that are threatened by changing climate and fire. We propose that forest restoration should be at least equal to other land management priorities because large-scale restoration is necessary for the sake of forest ecosystem integrity now and into the future. Another proposal is to switch the "default" rule in federal planning documents that currently have to "justify" managed wildland fire; instead, U.S. federal agencies should be required to disclose the long-term ecological impacts of continued fire suppression. Proposed legislation that identifies the most expensive 2% of wildfires annually to be funded from emergency funding instead of by the federal land management agencies. If increases in forest restoration fail to accompany the change in how large wildfires are funded, then U.S. fire suppression costs will remain high while resilience will continue to decline. Expansion of the wildland–urban interface will continue to drive suppression costs higher; new federal partnerships with States and local governments are needed to address this problem. Given the legacy of fire suppression and a future of climate change, management for other values in forests will be, in the long run, futile without also managing for long-term forest resilience.

Key words: fire management; fire suppression; forest policy; forest restoration; prescribed fire; wildfire.

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INTRODUCTION

In 1995, wildfire-related expenses represented 16 percent of the U.S. Forest Service (USFS) appropriated funds; by 2015, 52 percent of the appropriated funds were related to wildfire management (USDA 2015). This substantial shift toward greater wildfire-related expenditures directly impacts the USFS ability to manage its lands because less resources are available for other programs (e.g., vegetation management, habitat restoration, research, and

recreation; USDA 2015). The U.S. National Park Service (NPS) has also reduced funding for fire restoration by shifting funds in the last decade to reduce fire hazards primarily near the wildland–urban interface (T. Nichols, *personal communication*, 2015). These changes are particularly problematic as U.S. federal agencies are facing declining ecosystem integrity in many dry forest types, brought about by the interacting effects of past management practices and increased drought stress associated with climate change (Allen 2007, Williams et al. 2010, 2014, Hessburg et al. 2015). Ecological restoration of forest composition, structure, and processes based on reference conditions prior to fire regime interruption and excessive resource exploitation is linked to greater resilience to wildfire and other contemporary stressors including climate change (Larson et al. 2013, Kalies and Yocom Kent 2016).

Current forest and fire policy in the western United Sates emphasizes short-term outcomes versus long-term goals (Calkin et al. 2015). This emphasis precludes the western United States from creating a strategy to produce a sustainable fire program. In contrast, the southeast United States has been successful in implementing a program of prescribed fire in federal, state, and private lands beginning early in the 20th century (Brenner and Wade 1992, Ryan et al. 2013). There are many reasons for the continued challenges in western U.S. fire management, some legal and bureaucratic, perhaps more of them political and even basic human nature/psychology (Thompson 2014, Fischer et al. 2016). Irrespective of the specific causes, this short-term perspective drives land management to focus on protection of certain high-valued resources, whether ecosystem-based (wildlife habitat) or developed infrastructure (homes in the urban–wildland interface), at the expense of forest resilience. This protection focus attempts to preserve many of these resources in their current state. Protecting infrastructure in the urban–wildland interface, which largely drives the costs of fire suppression (Gude et al. 2013, Thompson et al. 2013), is a justifiable preservation goal. However, the goals are more complex for ecological resources given our understanding of the dynamism that characterizes "intact" functioning landscapes (Bonnicksen and Stone 1982, Hessburg et al. 2005, 2015, Spies et al. 2006). In "intact" landscapes dominated by dry forest types, fire can both maintain existing vegetation conditions by limiting the extent (Collins et al. 2009) and severity (Parks et al. 2014, Rivera-Huerta et al. 2016) of subsequent fires and can create new, early seral vegetation patches (Collins and Stephens 2010).

Past and current policies focused on fire suppression and resource protection have contributed to significant ecological change in many dry, mid- to low-elevation forests in the western United States. Changes at the scale of individual forest stands include increased tree densities, smaller average tree diameters, increased proportions of shade-tolerant tree species, and elevated surface fuel loads relative to historical or pre-Euro-American settlement conditions (Parsons and Debenedetti 1979, Stephens 2004, Scholl and Taylor 2010, Collins et al. 2011). At the landscape scale, dry forests have shifted from highly variable arrangements of different vegetation structure/composition patches (e.g., Collins et al. 2015) to more homogenous forested conditions (Hessburg et al. 2005, 2016). These changes have substantially increased the vulnerability of many dry forests to uncharacteristically extensive and severe perturbations, particularly from fire and insects/disease (Allen 2007). There is uncertainty in both tree regeneration (e.g., Collins and Roller 2013) and susceptibility to reburning (e.g., Coppoletta et al. 2016) following such events in these forests.

The concept of ecological resilience has undergone numerous interpretations (Newton and Cantarello 2015) since being initially popularized by Holling (1973). We consider resilience to be the ability of a system to absorb impacts before a threshold is reached where the system changes into a different state (Gunderson 2000). In the context of wildland fires, resilience is illustrated by the recovery of Rocky Mountain lodgepole pine (*Pinus contorta* var. *latifolia*) forests following the severe 1988 fires in Yellowstone National Park (Turner et al. 2003). In contrast, due to fuel accumulation after a century of fire exclusion, some ponderosa pine (*P. ponderosa*) and dry mixed conifer forests have been converted to alternative stable states such as shrublands and grasslands by severe fires, displaying a lack of resilience by not returning to the original forest condition (Savage and Mast 2005, Odion et al. 2010, Collins and Roller 2013,

Cocking et al. 2014). Under historical regimes of frequent surface fires, these forests were once relatively open and dominated by large trees (Collins et al. 2015, Stephens et al. 2015); logging and fire exclusion led to dense stands of smaller trees with high horizontal and vertical fuel continuity, increasing the probability of crown fire (Fulé et al. 2012, Hagmann et al. 2014). Resilience is implied in the concept of ecological restoration, "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (Society for Ecological Restoration 2004). Ecological restoration involves recapturing the range of natural variability in ecosystem functions and processes, such as fire regimes (Falk 2006). Millions of hectares of dry western U.S. forests are in need of restoration to increase their resilience to fire, insect attack, and climate change-induced drought.

Given the current and future challenges posed by wildland fire, a review and reexamination of existing policy is warranted. This article builds upon previous studies (Stephens and Ruth 2005, Calkin et al. 2015, North et al. 2015*a*) by describing additional barriers to policy modification and presenting strategies for responding to an increasingly difficult forest resilience problem with implications for communities, federal land management agencies, States, counties, firefighters, and the public. We begin by identifying important impediments to achieving large-scale forest resilience and propose ways to restructure agencies to prioritize long-term goals for fire management. We recognize that the mixed public and governmental context, as well the context of the land management agencies themselves with their own histories and traditions, may naturally resist policy changes (Stephens and Ruth 2005).

Our analysis proceeds from a perspective that long-term forest resilience is an essential goal for ecologically sustainable forest management. We recognize the importance of values in making socially important natural resource management decisions in the context of scientific uncertainty, and that there are important values in forests besides long-term forest resilience (Biber 2012). However, given the legacy of fire suppression, management for other forest values long-term will be futile without managing for forest resilience in dry forests.

Current Impediments to Forest Resilience

Procedural and legal challenges

Although relatively large-scale forest restoration has been advocated by the Forest Landscape Restoration Act of 2009 (Schultz et al. 2012) and the National Cohesive Wildland Fire Management Strategy (WFLC 2014, Pyne 2015), a key challenge is the current process of planning and environmental review. Stakeholders dissatisfied with agency decisions can resort to lawsuits to challenge the management plans they disagree with. Courts have generally deferred to agency expertise, but the risk of a courtroom loss (often on procedural grounds) means that the agency does have an incentive to invest in more thorough analyses (USDA 2002, Keiter 2006). While planning and environmental review are necessary components of effective management decision making, at some point increased investment in planning decreases the availability of resources for on-the-ground restoration activities.

Beyond the environmental review process, U.S. federal agency organizational structure and decision making processes may also be limiting meaningful progress toward forest restoration. Specifically, there is an apparent lack of sufficient incentives for agencies to prioritize long-term goals over shorter-term impacts. Managing wildfire for resource benefit is a glaring example of this. The literature indicates that increased use of fire (prescribed and managed wildfire) under appropriate weather and fuel conditions should be a central part of restoring forest resilience because it is a dominant ecosystem process (Franklin and Agee 2003, Dombeck et al. 2004, Aplet 2006, van Wagtendonk 2007, North et al. 2009, 2015*a*). This has also been recognized in high-level agency fire management documentation (e.g., USDA-USDI 2009, WFLC 2014). Despite this apparent consensus, there is little evidence to suggest there has actually been increased implementation of managed wildfire in the western United States (North et al. 2015*a*). In 2009, the category "wildland fire use" was eliminated from fire statistics reporting, moving all unplanned ignitions to a single "wildland fire" category that is further divided into planned and unplanned ignitions. The current system does not allow for separating out wildfire area burned for resource benefit but does give

more flexibility to fire managers to manage active events. There are a few isolated areas with notable documented achievements regarding managed wildfire (the southwest United States and portions of the Northern Rocky Mountains), but as a whole, there has been little change in the amount of wildfire managed for ecological goals. The most likely reason is the external constraints on agency decision making, namely public and political pressure to minimize short-term risk by suppressing fires at all costs. A key challenge for policy making is finding leverage points to ameliorate those constraints.

Another important challenge facing forest restoration is that considerations of particular resources or species can dominate forest planning. The Endangered Species Act (ESA), Clean Air Act, Clean Water Act, and special species considerations under National Forest Management Act (NFMA) all require a focus on particular resource issues or species (Stephens and Ruth 2005). While there are benefits from a focus on protecting individual resources or species, this focus can also be implemented in a dysfunctional way, leading to a tunnel vision that concentrates only on how management decisions might have negative impacts on specific resources. This is particularly true for fire management, which does not receive particularized attention under any federal statute, but which is an overarching concern for forest management. A failure to recognize and plan for direct (short-term) and indirect (long-term) effects will lead to unsustainable forests, both for the biotic communities they support and the ecosystem services they provide to society (Table 1). Focusing too much on individual resource concerns may lead managers to overlook the "endangered landscapes" these resources are within. We use this term "endangered landscapes" to convey the vulnerability of many dry forests to significant, long-term state changes due to their currently departed conditions (Fig. 1). An example of this vulnerability is the widespread tree mortality observed in ponderosa pine and mixed conifer forests throughout California (Asner et al. 2016).

Resilience is outranked by other goals

Agencies such as the USFS pursue "multiple-use" goals because Congress has directed them to manage public lands for a wide range of objectives, from mining to cultural landscapes, from

Table 1. Summary of policy recommendations (ranked most important (1) to least important (5)) that could improves U.S. federal forest and fire management.

Priority	Recommendation
Procedural and legal	
1	Make forest resilience a stand-alone, top land management priority and connect it to managing long-term for endangered species
2	Ensure fire suppression funding does not impede restoration efforts
3	Switch default environmental review rules for managed wildfire
4	Provide for equal balance in decision making between long- and short-term impacts
Planning and implementation	
1	Mandate evaluation of opportunities for ecologically beneficial fire in land management planning
2	Expand capacity and utilization of interagency modules dedicated to increasing beneficial fire
3	Develop specific performance measures for forest resilience
4	Increase educational requirements for wildfire and forest management personnel to included fire ecology and ecosystem dynamics
5	Analyze long-term impacts of continued suppression
Outreach and collaboration	
1	Engage in collaborative planning to ensure firewise development in the WUI, including appropriate fire suppression cost sharing
2	Increased public–private collaborations for landscape-level fuel management (including expanding ecologically beneficial fire)
3	Increase education and outreach to non-federal resource agencies on inevitability of fire

timber to habitat, from wilderness to recreation (Biber 2009, Calkin et al. 2011). Of course, agencies always must choose among these goals when they make decisions. Choices might include whether to reserve a particular piece of land for oil and gas leasing or for habitat protection, or whether to spend agency staff time on enforcing off-road vehicle closures or conducting wildlife surveys. Even in managing fire, agencies face multiple trade-offs between these different goals (Wilson et al. 2011, Spies et al. 2014). Because resources are limited, there are inherent conflicts
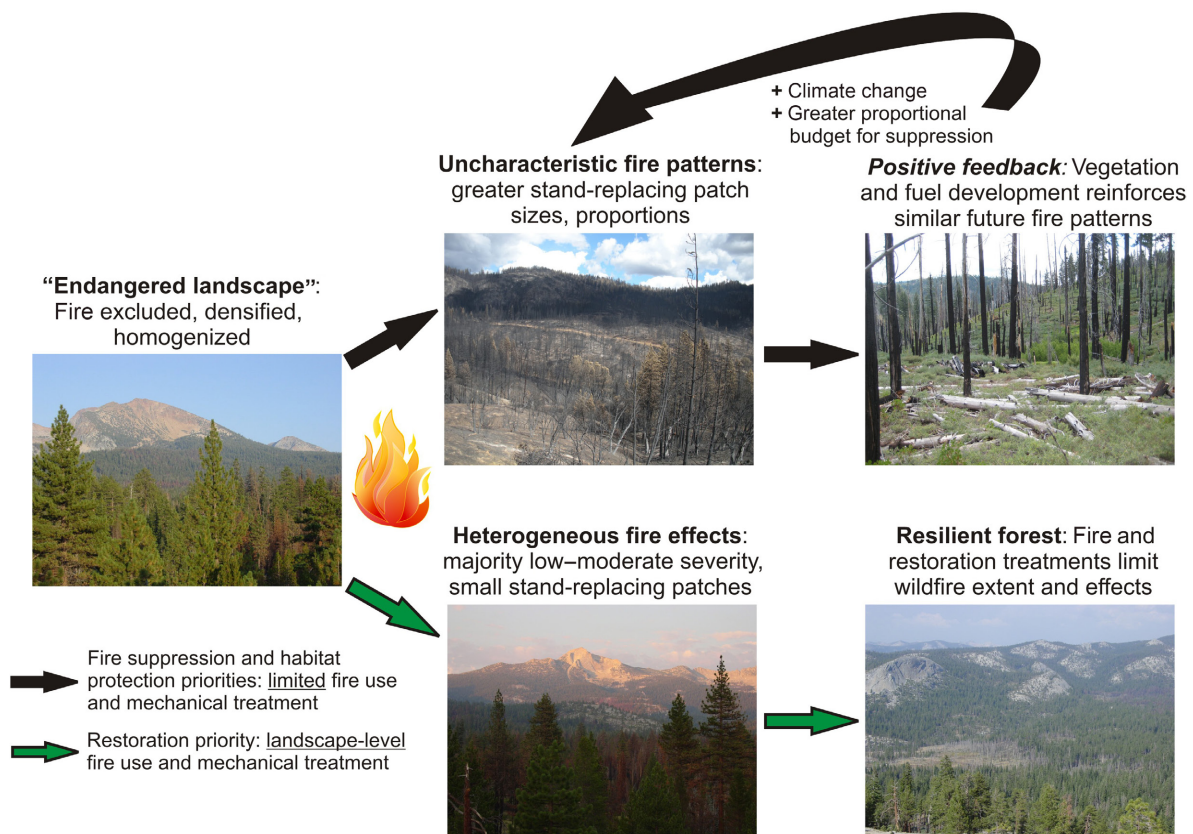
+ Climate change
+ Greater proportional
budget for suppression

Uncharacteristic fire patterns:
greater stand-replacing patch
sizes, proportions

Positive feedback: Vegetation
and fuel development reinforces
similar future fire patterns

"Endangered landscape":
Fire excluded, densified,
homogenized

Heterogeneous fire effects:
majority low–moderate severity,
small stand-replacing patches

Resilient forest: Fire and
restoration treatments limit
wildfire extent and effects

Fire suppression and habitat
protection priorities: limited fire use
and mechanical treatment

Restoration priority: landscape-level
fire use and mechanical treatment

Fig. 1. Conceptual model depicting two divergent land management approaches for dry forests that historically experienced frequent, low–moderate intensity fire regimes. The approaches are indicated by the different arrow colors. The starting point is a common condition for many landscapes dominated by these forests today in the western United States. The "+" indicates external pressures that may further reinforce the feedback loop.

between the different goals agencies pursue. In choosing which goals to pursue, agency leaders will generally emphasize goals (1) for which the incentives or stakes are higher, and (2) for which success or failure is easier to measure (Biber 2009). Both of these factors cut against agencies managing for forest resilience as opposed to other goals they are tasked with, especially fire suppression.

Forest resilience is only provided for in a limited way in the federal statutes that guide USFS decision making. It is barely mentioned in two of the major statutes guiding USFS decision making (the Forest Service Organic Act and the NFMA) nor is it covered in the more generic laws that are most important for agency decision making (the National Environmental Policy Act (NEPA), or the ESA). The only statute that does

refer to the concept to some extent, and imposes some mandates on the agency to consider forest resilience, is the Healthy Forests Restoration Act (HFRA). However, the HFRA focuses on streamlining administrative and legal procedures for particular restoration projects, rather than setting an overall mandate for the agency as a whole (Keiter 2006). Thus, compared to many of the other goals that the USFS is tasked to accomplish, forest resilience has lower legal salience. Outside groups can challenge agency decisions for failure to consider the impacts on endangered species, for instance, and often win (Miner et al. 2014). But a legal claim against the USFS for failing to manage for forest resilience would be difficult to win. Thus, the legal stakes for forest resilience are lower than they are for many other agency goals.

Measurement is also easier for many other goals than forest resilience. It is easy to quantify how much timber has been cut on a National Forest or how much oil and gas has been produced on leases. Even visitation numbers often can be estimated reasonably well. But measuring forest resilience is more challenging (Das et al. 2007, Collins et al. 2014). We can measure how many hectares of land has received treatments (such as thinning or prescribed fire) or estimate the number of fires that an area has theoretically missed during fire suppression (Safford and Van de Water 2014), but these methods fail to directly assess progress toward improved resilience. Despite a growing capacity to conduct assessments of fire risk based on fuel treatments (Ager et al. 2010*a*, *b*, 2014) and research that has documented the effectiveness of fuel treatments in modifying wildfire behavior (Agee and Skinner 2005, Fulé et al. 2012), estimating how successful treatments will be over the long-run is still difficult. Uncertainties exist in fire management, including how future fires will burn in particular places and times, how those fires will affect specific resources, and how dynamic changes in ecosystems and climate will affect future fire behavior (Finney 2005, Thompson and Calkin 2011, Hyde et al. 2013, Franklin et al. 2014). Given these measurement challenges and uncertainties, it is perhaps no surprise that land management agencies often emphasize oversimplified metrics for accomplishments (e.g., area treated) rather than actual improvements in forest resilience (Stephens and Ruth 2005, Aplet 2006).

Risk aversion and disincentives

The political and legal stakes of fire suppression are sky-high, especially with the expansion of the urban–wildland interface. There is tremendous public, media, and political pressure on U.S. federal agencies to ensure that fires do not harm private property, endanger lives, or threaten socially valued resources (Busenberg 2004, Aplet 2006, Canton-Thompson et al. 2008, Liang et al. 2008, Donovan et al. 2010, Quinn-Davidson and Varner 2012, Calkin et al. 2013, Moritz et al. 2014). The public generally perceives fire as both bad and preventable and expects quick results in controlling fires (Dombeck et al. 2004, Kauffman 2004, Hardy 2005, Moritz and Stephens 2008). Failure by the agency to control fires might result

in legal liability for harm to private property, primarily in the urban–wildland interface (Yoder et al. 2004, Aplet 2006, Keiter 2006, Canton-Thompson et al. 2008). Although managers may aim toward the goals of resilience and suppression simultaneously as presented in the National Cohesive Wildland Fire Management Strategy (WFLC 2014), the pressures related to suppression far exceed those calling for improved forest resilience (Maguire and Albright 2005, Aplet 2006, Wilson et al. 2011). Thus, it is no surprise that the USFS operates in a risk-averse manner and emphasizes fire suppression, such that the vast majority of fires are suppressed, even in wilderness where the potential harm to private property or lives are minimal, and even where managed wildfire may be approved under relevant agency planning documents (Aplet 2006, Doane et al. 2006, Thompson 2013).

The long-term nature of forest resilience adds incentives to focus on fire suppression. People tend to discount long-term risks compared to short-term risks, and emphasize the small risks of short-term losses of important resources (Sunstein 1993, Maguire and Albright 2005, O'Laughlin 2005, Wilson et al. 2011, Calkin et al. 2013). Preventing a fire from severely burning a community or endangered species habitat avoids a short-term risk, one that is weighed heavily by the public and land managers even if it is a relatively small one (Donovan et al. 2010, Wibbenmeyer et al. 2013, Calkin et al. 2015). Treating a forest landscape to make it more resilient to fire, insects, and climate change can incur short-term impacts, but overall will reduce long-term risk (e.g., Tempel et al. 2015, Jones et al. 2016).

Accordingly, fire suppression response continues to prevail due to a set of decisions and disincentives that heavily favor short-term outcomes. First, it is often most cost-effective in the short-term to contain fire at the smallest reasonable extent but the collective impact of this response over the long-term is to ensure continued fuel accumulation and greater future fire hazard, especially in forests adapted to low–moderate intensity fire regimes (Stephens et al. 2013; Fig. 1). Second, line officer (people with general decision authority) and fire manager decisions are influenced by the potential to incur personal and career liability (Stephens and Ruth 2005, Calkin et al. 2011, Donovan et al. 2011), which

often results in more risk adverse responses (i.e., aggressive suppression). These decisions are often more legally or politically defensible than those that attempt to use fire to achieve resource benefit because all fires pose some risk to life and property (O'Toole 2007, Ager et al. 2014). Third, at the level of wildland fire agencies themselves, the emergency-like nature of aggressive suppression may be one way to counteract declining or flat budgets, especially given the lack of resource extraction-derived revenue in some land management agencies (Lueck and Yoder 2015).

Incentives are therefore not in place to promote long-term forest or community resilience (Donovan and Brown 2005, 2007). Fire suppression outcomes are praised by the public and politicians: Fire fighters are always heroes because it is dangerous work. People and fire suppression businesses continue to get paid; in fact, the "fire–industrial complex" is growing (see O'Toole 2007). Additionally, long-duration fires with large numbers of personnel can be a major boost to rural economies in the short-term, in some cases exceeding that from recreation and tourism (Davis et al. 2014). However, what has been accomplished at the end of the day? Have ecosystems been improved? Safety increased? The urban–wildland interface improved? From a perspective of long-term resilience, success needs to be defined differently.

Restructuring Agencies to Prioritize Forest Resilience

Forest restoration as an "umbrella" goal

Given the momentum and rationale behind continued fire suppression, substantive change that appropriately balances short-term outcomes with long-term consequences may be difficult. However, changing the structure of agency decision making and analysis to provide greater incentives for emphasizing forest resilience could begin to shift the current paradigm (Maguire and Albright 2005). Making forest restoration a top land management priority would begin this transition (Table 1). It could be argued from the existence of high-profile restoration initiatives that this is already a high priority for U.S. federal agencies (USDA 2012, 2013, WFLC 2014). However, it appears commitment of resources and the incentives to choose restoration outcomes over

other more immediate goals (e.g., wildlife habitat conservation, fire suppression) may not yet be in place to meaningfully advance implementation of restoration activities (North et al. 2012, 2015a, Calkin et al. 2015, Hessburg et al. 2015). To make a substantive change in ecological resilience, forest restoration should at least be equal to other land management priorities because large-scale restoration in frequent fire-adapted forests is necessary for the sake of forest ecosystem integrity now and into the future.

While numerous co-benefits can result from a wide range of restoration activities such as fire hazard reduction (Agee and Skinner 2005), habitat improvement for endangered species (Tempel et al. 2015, Stephens et al. 2016), wood production (Hartsough et al. 2008), job creation, and possible increased water yield (Boisrame et al. 2016), each on its own often cannot justify the expense and potential impacts of the scale of restoration needed. For example, fire hazard reduction is often used as a key justification for implementing restoration treatments. However, current fire frequencies are so diminished in many areas that the probability of a severe wildfire actually impacting a treated area during its expected lifespan of effectiveness is relatively low (Ager et al. 2010a, b, Campbell et al. 2011). If treatment costs are evaluated solely against the chance that a wildfire burns a treated area, it may be difficult to justify the investment, although Snider et al. (2006) argued that treatments were cost-effective. However, if forest restoration was a high priority, stand-alone objective, linked with incentives and targets, decisions could be made that do not rely on other outcomes (e.g., treated areas burned by wildfire, wood and biomass production). This prioritization might be accomplished through agency regulations or planning documents, or through changes to the agency's statutory authority.

Another benefit of focusing on forest restoration as a primary justification for management is that it can build trust with stakeholders about management decisions (Table 1). For instance, some environmental groups may be suspicious that restoration projects are simply cover for increasing commercial logging on public lands (Stephens and Ruth 2005). Demonstrating that projects are justified solely on forest resilience grounds can alleviate those concerns. Recent

research has improved the structural underpinnings that could be used during mechanical restoration treatments (Larson and Churchill 2008, 2012, North et al. 2009, Fry et al. 2014). Building trust with public groups is a central component of improving public acceptance of fire and forest restoration (McCaffrey et al. 2012).

Promoting ecologically beneficial fire

A switch in the "default" rule in federal planning documents is another option (Table 1; Thompson 2013). For instance, instead of having to justify managing a wildland fire for resource benefit, the USFS and NPS might instead be required to disclose the long-term ecological impacts (thorough NEPA analysis) of continued fire suppression and exclusion. This would send a message about the importance of forest resilience relative to fire suppression as well as increase the incentives to allow managed wildland fire, prescribed fire, and mechanical restoration treatments. Indeed, the paperwork burdens of developing planning documents for the use of fire have been cited as a major impediment to greater managed wildland fire (Aplet 2006, Thompson 2013, Calkin et al. 2015). As a first step, recent changes in USFS planning guidance require spatial fire plans to identify zones in which managed wildland fire would be optional or promoted for resource benefit (WFDSS 2015). Going further, a programmatic NEPA analysis in these areas could provide some streamlining benefits in facilitating later environmental review for prescribed and managed fire.

While the current USFS planning rules do include fire as one issue to be considered in the mandatory sustainability analysis for the plan (36 C.F.R. § 219.8(a)(1)(v)), and as one of the uses to be provided for on National Forest lands (36 C.F.R. § 219.10(a)(8)), providing more specific and concrete planning requirements for managers to allow for wildland and prescribed fire would be beneficial. Likewise, while agency guidance calls for plans (Fire Management Reference System and Spatial Fire Plans) for all areas with burnable timber, the document fails to set the baseline for analysis based on a presumption of allowing fire to occur (USDA-USDI 2009, USDA n.d.). Similarly, while the USFS Manual and Handbook include fire as one of the resources to be considered in management decisions and land-use

planning, again the particular long-term nature and challenge of fire is not addressed. And while the uncertainty in forest resilience will limit the ability of agencies to make precise predictions, even the process of doing the analysis should help reduce legal and institutional barriers to increasing long-term forest resilience. National forests in California (Inyo, Sequoia, Sierra) are pioneering some of these efforts, but system-wide guidance and requirements would provide stronger incentives for all units to take these steps (Thompson et al. 2016; USDA-FS 2014).

Shifting toward a broad view of restoration

Resource managers will benefit from thinking in terms of connecting resilience and adaption strategies to managing long-term for endangered species protection, beginning with an acceptance of a broader perspective on habitat conservation (Stephenson 2013), even re-assessing what habitats are feasible for conservation under new environmental constraints (Fill et al. 2015). Traditional decision making for management of endangered species will rely less upon place-based habitat goals (Gregory et al. 2013) and more on facilitating the movement of plants and animals to historic or newly suitable habitats (Millar et al. 2007, Minteer and Collins 2010, Stephens et al. 2010, 2016). Fire management is integral to these decisions. Managers could explicitly design prescribed fire and mechanical treatments to produce more varied forest conditions to meet both habitat and resilience needs (Larson and Churchill 2008, 2012, North et al. 2009, Fry et al. 2014). By accepting short-term movement or loss of individuals in response to restoration treatments, local populations may benefit long-term from the improving survivability of key habitat features (e.g., large trees) in future wildfires (Franklin et al. 2014, Stephens et al. 2014*a*, Hessburg et al. 2015). Increased heterogeneity in forest structure will complement resilience objectives in forests adapted to frequent fire (Stephens and Fulé 2005, Larson and Churchill 2012, Collins et al. 2016). We note that there are challenges in this approach that will need to be addressed. For instance, how should late-seral species be managed as climate warms? How can diverse, relatively young habitats that occupy sites currently managed for the preservation of old-growth wildlife be restored and maintained? More

broadly, we will need to weigh or reduce the uncertainty inherent in trading the loss of current individuals of an endangered species for the potential for more and better quality habitat in the future.

MANAGEMENT IMPLEMENTATION THAT FACILITATES FOREST RESILIENCE

Fire suppression continues to be the dominant theme of fire management in the United States and worldwide (Stephens et al. 2014b). Although wildfire suppression success in the United States appears to be relatively stable (between 97 and 99 percent of ignitions are contained at less than 120 ha), the amount of area burned from large fires has been increasing over the last several decades further prompting increased wildfire suppression effort (Westerling and Swetnam 2003, Westerling et al. 2006, Calkin et al. 2015). These large fires are in the small percentage that "escape" initial suppression efforts, primarily because they burn under extreme weather and fuel conditions (North et al. 2015a). The patterns that these large fires create on the landscape are quite different from those created by wildfires managed for resource benefit (Miller et al. 2012, Meyer 2015). Despite this, drivers of fire suppression response, both within the current season and future responses, are forcing an increasing suppression response with negative consequences to future wildfire risk and associated loss (Calkin et al. 2015).

To break away from a continued focus on fire suppression, more emphasis could be placed on developing and utilizing managed fire interagency teams (Table 1; North et al. 2015a). Currently there are over 40 "Wildland Fire Modules" throughout the United States (http://www.wildlandfiremodules.info/index.html). Increasing the number and use of these modules would require allocating more personnel to take advantage of favorable burning conditions (with both prescribed and managed wildfire). This would include keeping some of these modules intact and available year-round and focused on using fire in restoration. Climate change is forecasted to produce more dry winters (Seager et al. 2007) that could be used to increase beneficial fire area. Currently the majority of U.S. federal firefighters are hired seasonally, so reform in job descriptions and hiring policies

would be needed to allow some of them to work throughout the year with consideration for not placing excessive stress on firefighters. Burning during seasons when fire did not occur historically would require careful monitoring as ecological effects may be different (Knapp et al. 2009), but the advantage is these fires could occur when weather and smoke dispersal could be more favorable.

Broader use of fire under appropriate weather and fuel conditions and greater social acceptance can also come from increasing public–private collaboration. Non-governmental organizations, notably The Nature Conservancy (TNC), are fostering cooperation through the Fire Learning Network (Schultz et al. 2012). With a relatively small staff, TNC reaches out to fire professionals as well as landowners and people in the private sector to facilitate development of interagency fire qualifications for non-governmental employees. The network supports partnerships to maximize opportunities for integrating fire planning, increasing efficiency, and allowing more burning under appropriate conditions. Through the prescribed fire training exchange (TREX) program, TNC and agency partners host university students, private fire companies, tribes, and federal and state managers to combine education with practice. Partnerships do more than help the non-governmental people; they also spur innovation within governmental agencies through exposure to the differing goals and approaches of outside entities, whether they are environmental activists, for-profit enterprises or tribal nations. In the legal and administrative realm, Prescribed Fire Councils are being formed to develop standards of practice for using prescribed fire and reducing hazards in the wildland–urban interface (Ryan et al. 2013). Drawing on the long experience of other regions of the United States, such as the southeastern United States (Kobziar et al. 2015), newer prescribed fire councils in the west are working to create agreements that allow for substantial expansion of beneficial fire. These networks could be expanded to facilitate the use of fire in private, State, tribal, and federal land management (Table 1).

In addition to expanding ecologically beneficial fire, significant expansion of mechanical treatments will be needed to achieve long-term forest resilience objectives. Most available evidence suggests that mechanical restoration and fire hazard reduction treatments are accomplished with few

unintended resource impacts, as most ecosystem components (vegetation, soils, song birds, small mammals, bark beetles) exhibit very subtle changes or no measurable effects at all (Stephens et al. 2012). Longer-term treatment impacts to carbon sequestration and wildlife with large home ranges are not as clear and often hinge on two key variables: expected wildfire probability and vegetation recovery following wildfire (Law et al. 2004, Campbell et al. 2011, Stephens et al. 2014a, Tempel et al. 2015, Hurteau et al. 2016). Although mechanical treatments do not serve as complete surrogates for fire (Schwilk et al. 2009), their application often meets restoration objectives while mitigating fire hazards (Collins et al. 2014). Allowing local managers to select the most appropriate restoration treatments for their area is the best approach because of diverse land management objectives, infrastructure, and current conditions.

Workforce changes are another way to advance land management agencies focus on long-term resilience. Most federal wildland fire management programs rely primarily on a workforce of technician-level personnel, with little importance placed on college education (Kobziar et al. 2009). Efforts to standardize federal fire programs to include professional level management positions have mostly failed. Only Department of the Interior agencies have chosen to require college-level education for managerial positions within their fire programs. The USFS has opted instead for a system based only on managerial experience and fire management-specific qualifications for all but a few positions. This can result in a managerial fire staff with limited understanding of fire ecology and fuels management, which are of critical importance for understanding the short- and long-term implications of fire management decisions (Kobziar et al. 2009). Requiring university undergraduate education for more specialist and managerial-level federal fire jobs could enhance the ability of agencies to get appropriate treatments done.

Addressing Political and Other External Constraints on Fire Management

Developing analytic and training tools to manage the political risks of fire

Spatially explicit analyses of exposure to wildfire at large spatial scales can be used to estimate risk associated with managing wildfire for resource benefit. This has been carried out for project planning areas (Ager et al. 2010b, Scott et al. 2012) as well as for all National Forests in the western United States (Ager et al. 2014). These analyses provide robust quantification of fire risk to the wildland–urban interface, in particular, and can be used to identify areas where forest restoration efforts may be able to reduce housing exposure to wildfire. Often these targeted areas may be well outside of the urban–wildland interface (Ager et al. 2014). The critical component to this approach is that these treatments create more opportunity to use fire under appropriate conditions to advance forest resilience (North et al. 2012, 2015a), rather than simply creating anchor points to stop fire spread (Moghaddas and Craggs 2007, Reinhardt et al. 2008). These treatments can complement the use of flame-resistant construction materials and improved land-use planning, which are critical to reduce the risk of losses in the urban–wildland interface (Cohen 2000, Gill and Stephens 2009, Gibbons et al. 2012, Calkin et al. 2014, Moritz et al. 2014).

Risk-based decision support systems for strategic wildfire management could be further emphasized in fire management. These systems include new analytical methods to measure wildfire risk to human and ecological values and to inform fuel treatment investment strategies at national, regional, and local scales (Calkin et al. 2011). However, training on how to implement appropriate wildfire risk management concepts in land management planning is currently limited. The National Wildfire Coordinating Group (NWCG) training program could be modified to address this need with an intended audience of agency line officers and incident management teams that are responsible for implementing fire management strategies (Table 1; Calkin et al. 2011).

Better balancing fire with other goals

Identifying external political and legal constraints and asking for them to be removed may not be an effective way to improve fire management and forest resilience. Instead, there needs to be a better understanding of why those constraints exist and what their impacts are (Fischer et al. 2016). In the end, it may be determined
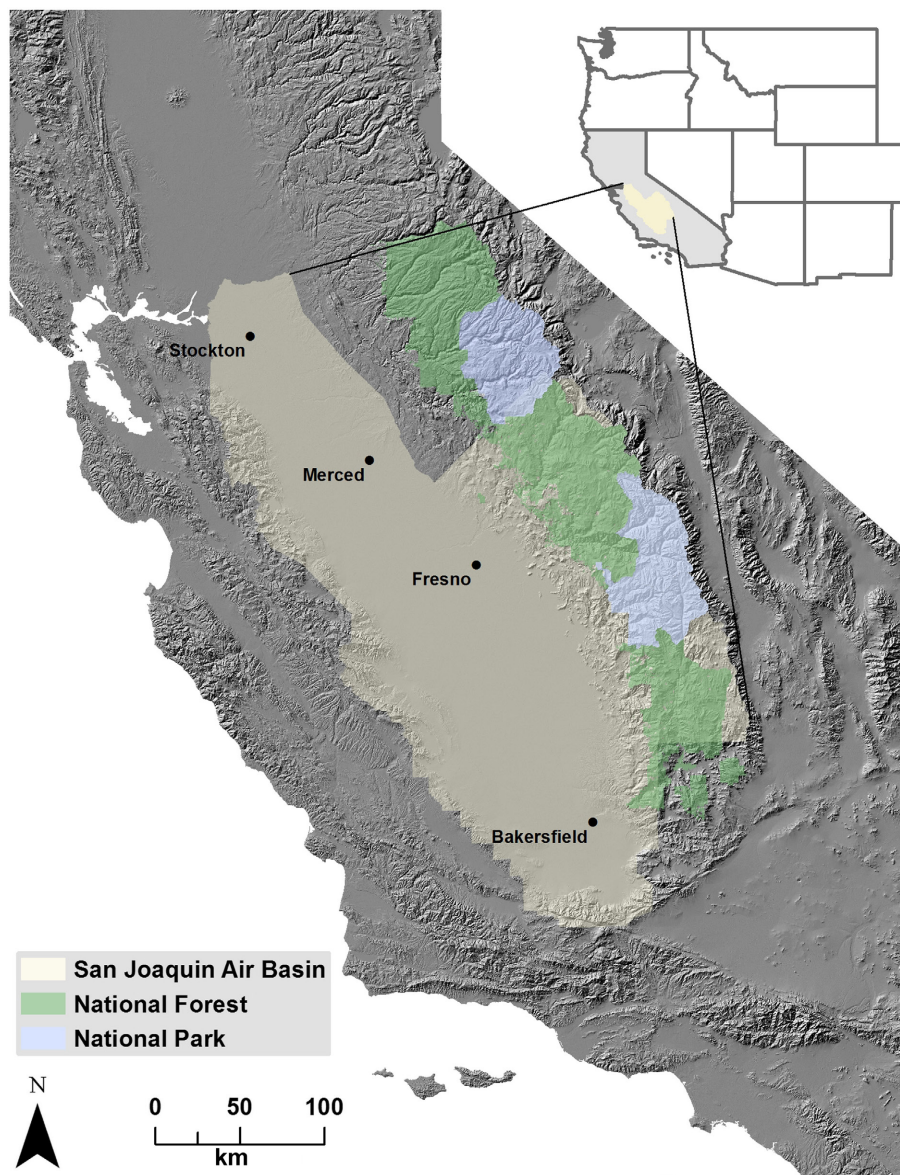
Fig. 2. The San Joaquin Air Basin in California, USA. This basin is largely defined by topography, which in combination with prevailing wind patterns tends to lead to poor air quality, particularly in the southern portion of the basin.

that forest resilience requires the superseding of those other goals. But it is more politically feasible, and may lead to better policy outcomes, if the primary focus is on identifying ways that most of those other goals can be achieved while still advancing forest resiliency.

The San Joaquin Valley in California (Fig. 2) has the worst air pollution in the country,

imposing significant and disproportionate health impacts on its communities (Cisneros and Perez 2007). Simply waiving air quality restrictions on all fire management techniques could significantly undermine air quality protection, especially given the large amount of federally managed land within and adjacent to this air basin (Fig. 2), although it should be noted that emissions from prescribed or managed fire are a

small component of this airshed (Cisneros et al. 2014, Schweizer and Cisneros 2014, Preisler et al. 2015). However, if prescribed fire were to receive different treatment from air quality regulations, agricultural interests may well ask whether their burning techniques should be less regulated as well; after all, both involve the use of fire to manage natural resources.

There is potential for a solution that could achieve both air quality and forest resilience goals. For instance, one justification for prescribed and managed wildfire is that it reduces the risk and scope of uncontrolled wildfires and improves forest resilience (Fig. 1; e.g., Parsons and Debenedetti 1979, Agee and Skinner 2005). Given the observed trends in large fire occurrence (Dennison et al. 2014) and predicted future fire activity (Westerling et al. 2011), restoration of forest landscapes is crucial. Uncontrolled wildfires will likely produce much worse air quality problems over the long run than any managed or prescribed fire program (Schweizer and Cisneros 2014). From a long-term perspective, prescribed fire and managed wildfire can improve air quality in the Valley. Thus, if the air quality constraint is rewritten to require a demonstration that the fire management tool will produce long-run air quality benefits, it may be able to both facilitate managed wildfire and prescribed fire and protect air quality (both by reducing uncontrolled wildfires in the future and by preventing increases in agricultural burning).

Another option might be to "level the playing field" by requiring similar air quality analyses for wildfires and prescribed and managed fires (Engel 2013). Wildfire smoke in the Clean Air Act is exempted from regulatory compliance standards, while smoke from prescribed and managed fire is regulated. This inconsistency is short-sighted and only adds to the list of disincentives for promoting proactive fuels and restoration work. Absent state and federal efforts to aggressively develop and implement an active prescribed and managed fire or mechanical programs to reduce uncharacteristic wildfire events and their emissions, state air regulatory agencies should count wildfire emissions when determining compliance with air quality standards. Including wildfires in the air quality accounting would become a driver for ecologically

appropriate fire management and other restoration (i.e., mechanical) treatments.

Addressing resistance to ecologically beneficial fire in state and local agencies

Non-federal fire agencies also play an important role in shifting the default "full suppression" response. Black et al. (2010) interviewed state and local cooperating fire agencies and county commissioners regarding the USFS's use of alternative (less than full suppression such as burning fuels between a natural fire break and the wildfire) fire management strategies. Most interviewees stated they did not support these actions. All the cooperators interviewed said that their mission included a full suppression mandate, and some were suspicious that anything less than full suppression was simply the federal agencies' way of trying to contain costs under declining budgets. Alternative fire suppression strategies have an advantage of enhancing restoration, especially under moderate weather in areas with limited roads and steep topography that does not allow machine access (Collins and Stephens 2007, van Wagtendonk 2007, van Wagtendonk and Lutz 2007, North et al. 2012, 2015b, Meyer 2015). It is in the long-term interest of the federal land managers seeking to undertake effective and ecologically sustainable forest management to increase the area burned by appropriate fire regimes on public and private lands, and this will probably require revised fire management agreements with non-federal partners (Table 1). One possible option to facilitate a change in perspective among state and local fire agencies is federal funding for training courses on resilience for local fire agency personnel. The National Cohesive Wildland Fire Management Strategy emphasizes collaboration across federal, state, and local entities to more effectively manage fire and is a promising starting point for these efforts (USDA-USDI 2014).

Change how fire management is funded

Budgets are a fundamental constraint on restoring forest resilience. This is particularly true given the combined effects of flat or declining budgets and greater proportions being allocated to suppression (USDA 2015). Increased fire suppression costs in the last decades can partially

be explained by the expanding urban–wildland interface (Gude et al. 2013, Thompson et al. 2013). Aggressive firefighting adjacent to populated areas deflects the true cost of development by placing the burden on the federal taxpayer instead of the developer or homeowner (Calkin et al. 2011), which further subsidizes continued development in the urban–wildland interface. Because the federal government has not historically regulated development policies in the privately owned wildland–urban interface, state and local jurisdictions could pay for fire suppression in the interface (Stephens et al. 2013). State and local jurisdictions might even charge landowners to cover some of the fire suppression costs that their development activities impose (Table 1), as California has recently carried out. This could enable a significant increase in critical federal forest restoration funding by eventually reducing construction in the urban–wildland interface.

Conclusion

In a democracy, laws are the product of a decision making process that (ideally) reflects public preferences. One of the reasons why fire management has not received the attention it deserves is because fire is a difficult problem for the public to fully understand. Fire is a long-term process, and managing fire involves risks to private property and natural resources (Table 1). Public and political discourse does not handle long-term risks such as fire well. Any changes in policies and management will need to take these political dynamics into account and, ideally, help shape future debates and public understanding (Collins et al. 2013). Indeed, having a motivated public endorse long-term forest resilience objectives could be one of the fundamental pathways to increased forest restoration at large spatial scales (North et al. 2015a).

There are limits to what alternate fire management strategies can accomplish. For instance, in contrast to forests adapted to frequent, low–moderate fire regimes, forests adapted to infrequent, high-severity fires (such as Rocky Mountain lodgepole pine) have different resilience concerns. There are no clear guidelines for increasing the resilience in these forests other than allowing natural fires to burn and minimizing additional

stresses from excessive grazing, recreation, and salvage logging (Stephens et al. 2013). As long as current fires are within the range of historical variation of past fire regimes, they will not reduce ecosystem resilience (Keane et al. 2008). However, should current fires diverge from historical fire regimes, ecological resilience will be degraded (Collins and Roller 2013, Hagmann et al. 2014, Hessburg et al. 2015, Stephens et al. 2015). The creation of novel ecosystems could be the product of changing fire regimes in crown fire-adapted ecosystems (Hobbs et al. 2009).

One of the most important and fundamental challenges to revising forest fire policy is the fact that agency organizations and decision making processes are not structured in ways to ensure that fire management is thoroughly considered in management decisions. There are insufficient bureaucratic or political incentives for agency leaders to manage for long-term forest resilience; thus, fire suppression continues to be the main management paradigm. Current resource-specific policies and procedures are so focused on individual concerns that they may be missing the fact that there are "endangered landscapes" that are threatened by changing climate and fire (Fig. 1). Without forest resilience, all other ecosystem components and values are not sustainable, at least over the long-term. It is therefore necessary to create incentives and agency structures that facilitate restoration of wildland fire and ecologically based fuel treatment to forest landscapes.

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