Research Article

Principles of Effective USA Federal Fire Management Plans

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ABSTRACT

Federal fire management plans are essential implementation guides for the management of wildland fire on federal lands. Recent changes in federal fire policy implementation guidance and fire science information suggest the need for substantial changes in federal fire management plans of the United States. Federal land management agencies are also undergoing land management planning efforts that will initiate revision of fire management plans across the country. Using the southern Sierra Nevada as a case study, we briefly describe the underlying framework of fire management plans, assess their consistency with guiding principles based on current science information and federal policy guidance, and provide recommendations for the development of future fire management plans. Based on our review, we recommend that future fire management plans be: (1) consistent and compatible, (2) collaborative, (3)

RESUMEN

Los planes federales de manejo del fuego son guías esenciales de implementación para el manejo de incendios naturales en tierras federales. Cambios recientes en la orientación de políticas federales de implementación en incendios y la ciencia del fuego, sugieren la necesidad de cambios sustanciales en los planes federales de manejo del fuego de los Estados Unidos de América. Agencias federales se están esforzando en revisar el manejo del fuego en sus planes de manejo de tierras dentro de todo el país. Utilizando el sur de Sierra Nevada como un estudio de caso, describimos brevemente el marco subyacente de los planes de manejo del fuego, determinamos su consistencia guiándonos bajo principios basados en la información de la ciencia actual y políticas federales de referencia, y brindamos recomendaciones para el desarrollo de los planes de manejo del fuego en el futuro. Basados en nuestra revisión, recomendamos que los planes de manejo del fuego deberán ser: (1) consistentes y compatibles, (2) colaborativos, (3) claros y comprensibles, (4) contar clear and comprehensive, (4) spatially and temporally scalable, (5) informed by the best available science, and (6) flexible and adaptive. In addition, we identify and describe several strategic guides or "tools" that can enhance these core principles and benefit future fire management plans in the following areas: planning and prioritization, science integration, climate change adaptation, partnerships, monitoring, education and communication, and applied fire management. These principles and tools are essential to successfully realize fire management goals and objectives in a rapidly changing world.

con escala temporal y espacial, (5) estar basados en la mejor información científica disponible, y (6) ser flexibles y adaptables. Adicionalmente, identificamos y describimos algunas guías estratégicas o "herramientas" que puedan resaltar los principios esenciales y beneficiar en el futuro los planes de manejo del fuego en las siguientes áreas: en la planificación y la priorización, en la integración con la ciencia, en la adaptación a los cambios climáticos, en asociaciones, monitoreos, educación y comunicación, y en la aplicación del manejo del fuego. Estos principios y herramientas son esenciales para alcanzar en forma satisfactoria las metas y los objetivos en un mundo rápidamente cambiante.

Keywords: fire management plan, fire policy, Sierra Nevada, wildland fire

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INTRODUCTION

Federal land management agencies in the United States manage wildland fires to meet an array of resource goals and objectives, including the protection of human life and high-valued resources and assets (USDA and USDI 1995, 2001). A federal fire management plan (FMP) summarizes these goals (i.e., broad statements of intent) and objectives (i.e., specific statement of progress toward desired conditions) and provides an overarching decision framework for the coordinated management of wildland fire within a management unit (USDA and USDI 2014*a*). A FMP may also define the appropriate conditions under which fire managers may use wildland fire, both prescribed fire (planned ignitions) and wildfire (unplanned ignitions), to meet natural resource objectives. Accordingly, FMPs serve as essential guidance documents for federal land management agencies, especially in fire-adapted landscapes. Despite their critical importance, there is no clear direction on how to produce cohesive and effective FMPs or systematically review their consistency with rapidly emerging fire science information and federal policy implementation guidance.

Successful fire management planning and operations are highly dependent on interagency cooperation, from regional to international scales. However, divergent agency goals and lack of continuity among agency planning efforts often limit management options for fires crossing jurisdictional boundaries. For example, major differences in fire management goals between neighboring agencies can heavily constrain the application of wildfires to meet resource objectives in cross-jurisdictional landscapes (USDA and USDI 2014*b*). Conversely, alignment of fire management zones between neighboring agencies may facilitate greater large-scale fire benefits and interagency collaboration, even within large and complex landscapes (e.g., Meyer 2015). An essential first step in addressing this challenge is to identify a set of core principles and approaches that facilitate successful management of wildland fire (i.e., prescribed fire and wildfire) within and across jurisdictional boundaries.

Our immediate goal was to review FMPs from several federal land management agencies in the southern Sierra Nevada, a region noted for its fire-adapted ecosystems, topographically and biologically diverse biota, extensive use of wildland fire to meet resource objectives, and rich fire science information. However, our ultimate goal was to use this regional case study to illustrate broader FMP concepts and principles that are applicable across many regions of the United States, even those not dominated by federal lands with complex topographies. The primary land management agencies in the southern Sierra Nevada include the Forest Service (FS), National Park Service (NPS), and Bureau of Land Management (BLM). These three federal agencies are either currently in or about to enter the process of updating their FMPs under new policy direction (e.g., USDA and USDI 2009), fire science information, and planning rules that directly influence the associated land management plans. This update of federal FMPs encourages consideration of landscape-scale fire management approaches (e.g., cross-jurisdictional operations), greater use of wildland fire for resource objectives, and the potential effects of climate change. Although our case study review excludes state, local, private, and tribal lands, and lands administered by other federal agencies (e.g., Department of Defense) that operate under different planning procedures and constraints (e.g., more wildland-urban interface), our review and general recommendations are broadly applicable to these more administratively complex landscapes.

MANAGING FIRE IN THE SOUTHERN SIERRA NEVADA

The southern Sierra Nevada comprises approximately 35 620 km^2, with roughly 70 % in federal land ownership (Davis and Stoms 1996), including three national parks, five national forests, and one BLM field office. It is generally defined by the boundaries of the Stanislaus National Forest and Humboldt-Toiyabe National Forest (Bridgeport Ranger District) to the north, the Tehachapi watershed to the south, the western foothills of the Sierra Nevada to the west, the eastside slopes of the Sierra Nevada to the east, and the neighboring Glass and Sweetwater mountains and Mono Lake Basin in the northeastern portion of the study area (Figure 1). We used a modified version of the protected area-centered ecosystems boundary generated by Hansen *et al.* (2011) to delineate our study area based on ongoing collaborative efforts centered on this ecoregion (e.g., Nydick and Sydoriak 2011). This ecoregion captures six broad vegetation types with differing fire regimes that transition over extensive elevation gradients, including foothill woodlands and shrublands (e.g., chaparral), lower-montane forest, upper-montane forest, subalpine forests, alpine meadows and shrublands, and east-side arid woodlands and shrublands (van Wagtendonk and Fites-Kaufman 2006). Fire regimes generally transition from frequent, primarily low- to moderate-severity, fuels-limited, surface fires in the lower elevation woodlands and forests, to relatively infrequent, mixed severity (i.e., roughly equal proportions of all fire severity classes), climate-limited, surface fires with some localized torching and crown fires. Chaparral and arid woodlands and shrublands are largely characterized by moderately to highly infrequent, replacement severity (i.e., stand-replacing) crown fires (van Wagtendonk and Fites-Kaufman 2006).

The southern Sierra Nevada contains large contiguous areas of federal land ownership where federal agencies may manage wildland fire for resource objectives across diverse landscapes. However, modern rates of burning in the Sierra Nevada still remains relatively low compared to the total area requiring

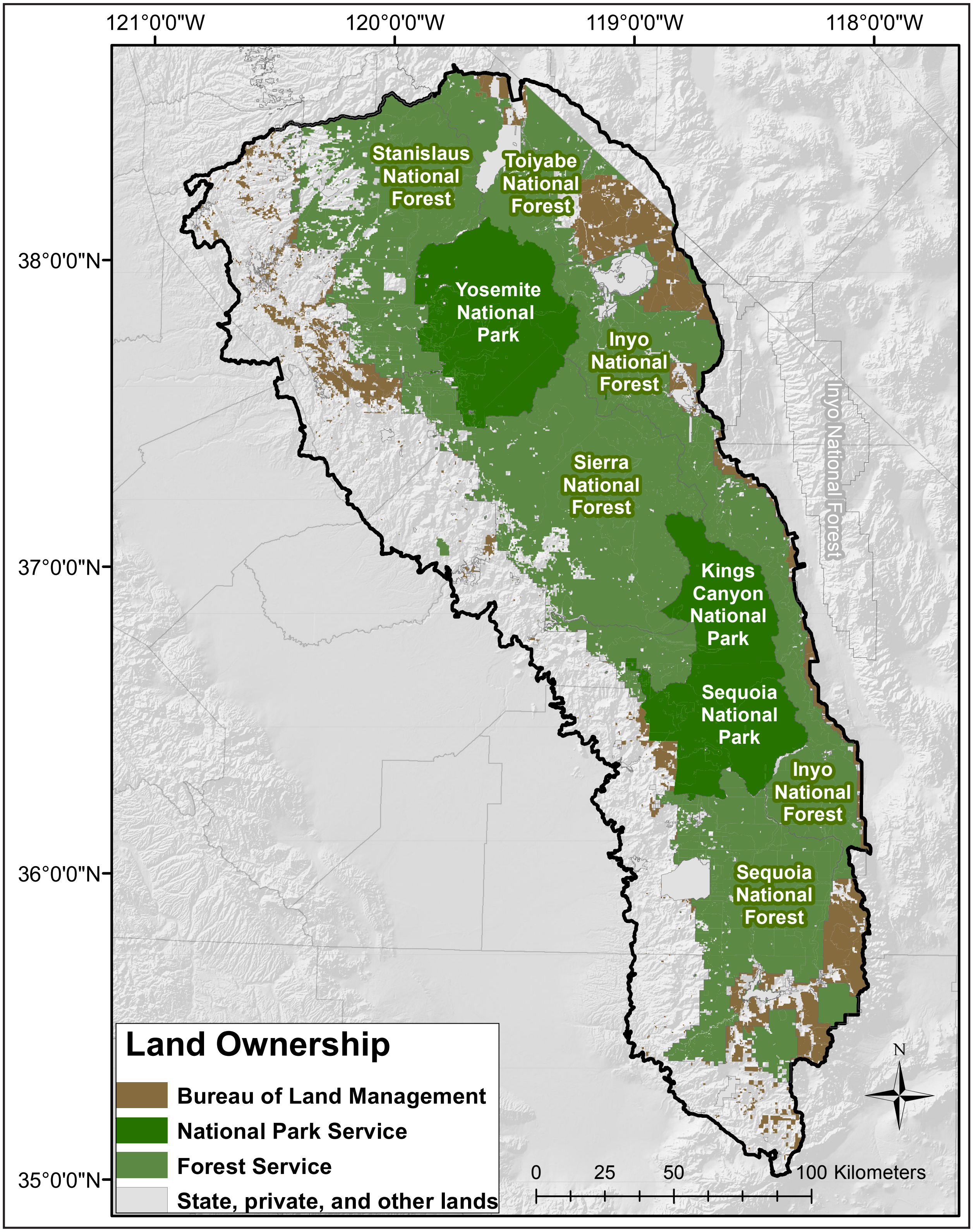

Figure 1. Geographic extent of the southern Sierra Nevada ecoregion and study area, based on the southern Sierra Nevada protected area-centered ecosystems boundary (black line). Source is the Protected Areas Database of the United States (PADUS version 1.2).

some form of fuels treatment based on presettlement (i.e., before Euro-American settlement) fire regimes, especially in lower montane forests (North *et al*. 2012, Mallek *et al*. 2013). Constraining factors that have contributed to this limitation include air quality concerns, increased risk in the wildland-urban interface, agency support and capacity changes (e.g., loss of "fire use" modules and management teams), public perception, potential impacts to natural and cultural resources, invasive species, personal liability and agency litigation concerns, and a pervasive culture of risk aversion in fire management (Stephens and Ruth 2005, van Wagtendonk 2007, Calkin *et al*. 2012).

Although there are significant barriers in the use of wildland fire, federal land management agencies have the opportunity to address these impediments during the land management plan and associated FMP revision processes. During this process, land management planners incorporate new federal policy direction and science information in the land management plan and revise corresponding FMP goals and objectives according to this information. Given the extent of current plan revision efforts (i.e., land management plan and FMP revisions) throughout the United States and in the southern Sierra Nevada in particular, a review of the planning process is timely. The purpose of this review is to: (1) define and explain the essential elements of FMPs, (2) briefly outline core FMP principles derived from federal policy implementation guidance, (3) evaluate FMPs in the southern Sierra Nevada for consistency with these core principles, and (4) provide recommended strategic approaches (i.e., tools) for integrating core principles and promoting effective fire management in fire adapted landscapes throughout the United States.

WHAT ARE FIRE MANAGEMENT PLANS?

A US federal fire management plan (FMP) "identifies and integrates all wildland fire management (both planned and unplanned ignitions) and associated activities within the context of an approved land or resource management plan" (USDA and USDI 2014*a*). A FMP also identifies values at risk (e.g., human life, property, and natural and cultural resources) to wildfire (potential fire-related losses and benefits) and outlines the appropriate response to wildland fire to protect, maintain, or enhance those values. Operational plans may supplement FMPs to address specific topics such as preparedness, fuels treatments, fire prevention, and communications. Although the fire management planning process and requirements may differ among federal agencies, a major function of all FMPs is to assure that wildland fire management goals and objectives are thoroughly coordinated both within and among agencies (USDA and USDI 2014*a*).

Federal fire policy has changed over time since the initial reintroduction of wildland fire as a management tool in the early 1970s. For example, following the summer of 1988 when more than 4850 km^2 burned in and around Yellowstone National Park, fire policy reaffirmed the basic objectives of federal fire management program but emphasized greater training, research, and interagency planning (USDA and USDI 1988). Similarly, following severe fires and multiple fatalities in the 1994 fire season, a joint commission of federal agencies created a revised policy for federal agencies with burnable acreage and reviewed and reaffirmed this policy in 1995 and 2001, respectively (USDA and USDI 1995, 2001). In 2009, this joint commission issued implementation guidance, which included nine guiding principles and 17 policy areas that cover issues from firefighter safety and communication to the use of wildland fire as a management tool (USDA and USDI 2009). The most recent guidance provides managers with the additional flexibility to manage wildfires for multiple objectives using a wide array of strategic and tactical options. This may include the concurrent use of protection and resource objectives on different parts of a fire perimeter to simultaneously prevent fire damage and promote resource benefits, respectively, if conditions are conducive to achieving these objectives. This updated policy guidance encourages cross-jurisdictional objectives at a landscape scale and greater interagency collaboration (USDA and USDI 2009).

Plan Hierarchy

Fire management plans are implementation documents firmly linked to land management plans. In many parts of the United States, federal land management agencies may consider fire as a resource management activity with targeted objectives tiered from broader land management plans, including general management plans (GMPs) in the NPS, resource management plans (RMPs) in the BLM, and land and resource management plans (LRMPs) in the FS. In all cases, managers balance fire protection and resource benefit objectives that minimize the potential negative impacts and maximize the positive outcomes of wildfire events.

The structure of planning efforts differs somewhat among federal agencies (Figure 2). Currently, FMPs in most NPS administrative units link to general management plans (GMPs) through resource stewardship strategies that provide specific measurable and integrated resource objectives. National Environmental Policy Act (NEPA) documents also support NPS FMPs to ensure consistency with federal laws and policies. In contrast, FMPs of BLM administrative units do not make resource management decisions, and the NEPA documents do not support these FMPs aside from supporting the RMPs. Consequently, BLM FMPs consolidate fire and fuels management goals and objectives from the RMPs and applicable federal laws, regulations, and policies including NEPA.

Forest Service FMPs are not supported by NEPA documents but instead provide general guidance for fire management under an ap-

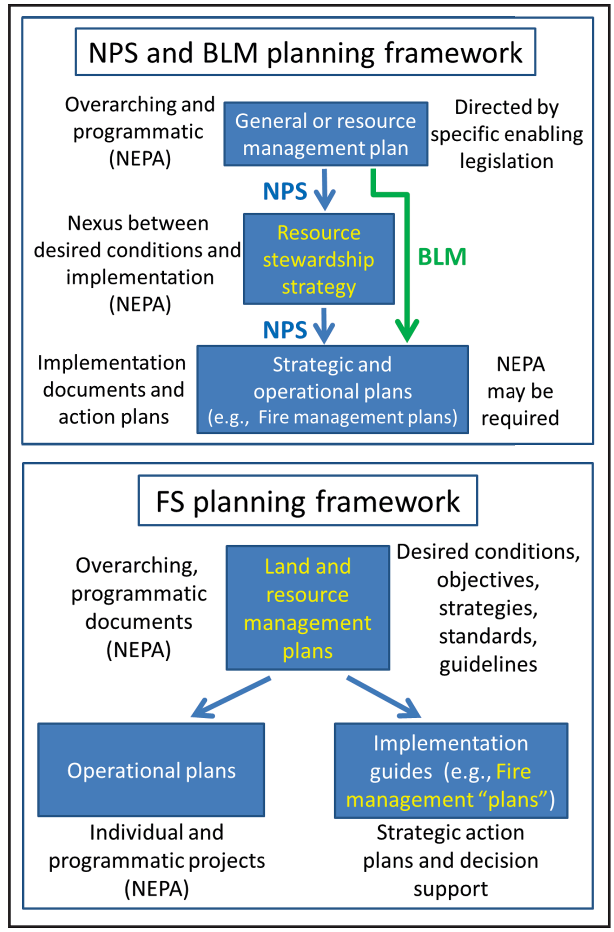

Figure 2. Current planning framework for federal land management agencies in the southern Sierra Nevada, including the National Park Service (NPS; top), Bureau of Land Management (BLM; top), and Forest Service (FS; bottom). Fire Management Plan compliance with federal laws and regulations (e.g., National Environmental Policy Act; NEPA) occurs at different levels within each planning framework. Planning elements in yellow font are recently revised based on changes in federal policy and direction. FS fire management "plans" are currently represented by two interrelated components (i.e., fire management reference system, spatial fire planning products) that provide guidance in meeting LRMP goals and objectives.

proved LRMP, often referred to as a "forest plan" (Figure 2). The current administrative direction further refines FS FMPs into two essential parts that guide implementation of the LRMP goals and objectives: (1) a "fire management reference system" that describes the required fire management program, and (2) spatial fire planning products that visually portray LRMP components (USDA-FS 2014*a*). Under a revised planning framework, also known as the "new forest planning rule," the FS has initiated a round of forest plan revisions in several national forests across the United States, including the Inyo, Sequoia, and Sierra national forests of the southern Sierra Nevada. This planning rule outlines a cyclic, adaptive planning process that emphasizes public involvement and collaboration, application of the best available science information, responsiveness to climate change, ecological restoration and monitoring of national forest lands, and the importance of wildland fire in the restoration and maintenance of fire-adapted ecosystems (USDA-FS 2015).

Clearly, the synchronization of these varied planning efforts is critical to developing an effective fire management strategy across administrative boundaries in the southern Sierra Nevada and other regions of the United States. Linking these efforts, such as the development of unified ecoregional management goals, can facilitate collaborative fire management approaches even within geographically or administratively complex landscapes. Such a coordinated approach would enhance the effectiveness of FMPs to advance the goals and objectives laid out in associated GMPs, LRMPs, and RMPs. However, a shared set of core principles is needed to help guide successful FMPs across federal agencies.

KEY PRINCIPLES OF EFFECTIVE FIRE MANAGEMENT PLANS

We reviewed interagency federal fire policy guidance and the extensive fire science literature for general recommendations relevant to the revision of federal FMPs and associated LRMPs GMPs, and RMPs. We also solicited and recorded feedback for FMP recommendations at recent fire management symposia and workshops hosted within the southern Sierra Nevada ecoregion (e.g., 2014 Southern Sierra Fire and Hydroclimate Workshop, 2013 Southern Sierra Change Adaptation Symposium, 2013 Southern Sierra Prescribed Fire Council, 2012 Southern Sierra Prescribed Fire and Smoke Symposium), although these events were not focused on FMP evaluation or revision. We reviewed these combined information sources and chose six essential principles for future fire management based on their consistent and repeated recommendation in federal fire policy implementation guidance and fire science literature; regional fire management symposia and workshops reinforced but did not singularly identify these principles. We primarily used recent federal fire policy implementation guidance (e.g., USDA and USDI 2009, 2014*b*) to identify the six core principles, whereas both relevant science literature and federal policy implementation guidance provided the basis for the main tenets, examples, and specific characteristics of each principle (Table 1). These six principles provide general recommendations that enhance the effectiveness of FMP goals, objectives, and tools (i.e., approaches that support achievement of goals or objectives through planning or implementation). We consider these principles and their central tenets to be instrumental in the development of effective federal FMPs in the United States. We evaluated the degree to which FMPs incorporated these principles based on their defining characteristics and related assessment criteria:

1. *Consistent and compatible*. Consistent and compatible FMPs have similar essential elements (e.g., goals, objectives), structure, and terminology within and across agencies that facilitate effective communication and understanding among agency partners, federal cooperators, and the public. FMPs that incorporate this principle are readily transferable across administrative units and disciplines (especially units within the same agency)

Table 1. Core principles for the development of federal fire management plans (FMP) based on current federal policy implementation guidance and relevant science information.

Principle	Main tenets and examples

Consistent and compatible	• Maximize consistency in format and terminology across agencies
	• Use consistent language and structure with land management plans
	• Ensure compatibility among agencies to maximize interagency cooperation in the ecoregion
	  o Synchronize FMP objectives across agency units
	  o Unify public messaging and outreach

Collaborative	• Recognize valued collaborative efforts, including:
	  o Coordination and cooperation between fire management and other disciplines
	  o Partnerships among agencies
	  o Fire science and management cooperatives
	  o Regional fire coalitions and collaborations
	• Develop an interagency FMP for the ecoregion or key firesheds

Clear and comprehensive	• Establish goals, objectives, tools that are clear and hierarchically integrated • Strike a reasonable balance between conciseness and depth
Spatially and temporally scalable	• Distinguish short- vs. long-term goals and objectives • Provide spatially explicit information for fire management zones and valued resources in FMP • Apply strategies and tools at different spatial scales within an administrative unit and across agency boundaries

Informed by best available science	• Use appropriate and reliable science information to inform key plan elements
	• Emphasize that science and monitoring are vital program tools
	• Create formal mechanisms for the integration of new science information
	  o Use FMP review schedule to incorporate new science
	  o Integrate and clearly define science information sources

Flexible and adaptive	• Build FMP flexibility to meet future challenges and constraints • Explain the process by which fire managers incorporate agency guidance and monitoring information in decision making and planning • Reconsider goals, objectives, and tools over time to ensure effectiveness in a rapidly changing world • Develop climate adaptation strategies in future operations based on decision-support tools

and based on simple and clearly defined terminology (e.g., use of a glossary) with limited use of agency-specific jargon and acronyms.

2. *Collaborative*. Collaborative FMPs contain clear reference to active partnerships and cooperative teams that facilitate improved coordination in fire management planning, implementation, and monitoring efforts. FMPs demonstrate collaborations by reference to multiple, active partnerships that focus on resolving the challenges and information gaps in the ecoregion (e.g., air quality, climate change).

3. *Clear and comprehensive*. Clear and comprehensive FMPs provide well-articulated and concise goals, objectives, and tools from higher-order policy documents (e.g., GMP, LRMP). For example, FMPs could include a table or flowchart that summarizes the plan

goals and objectives. A comprehensive FMP stands alone and includes essential information from a GMP, LRMP, or other higher level planning document. Adherence to this principle ensures that agency staff, federal cooperators, and the public clearly understand the main intent and direction of the plan.

4. *Scalable and spatial*. Scalable and spatial FMPs explicitly define the spatial and temporal scope of plan goals and objectives within and across administrative boundaries. Temporally scalable FMPs identify short- and long-term goals, objectives, and tools. Spatial FMPs provide a spatial fire planning format (e.g., biological and cultural resources are spatially mapped) to assist fire management planning and operations.
5. *Informed by best available science*. Science-based FMPs demonstrate that the primary plan components are rooted in science information that is relevant, accurate, and reliable. FMPs that support this principle integrate and reference peer-reviewed science information and identify assumptions, uncertainties, and gaps in this information. Science-based FMPs also explicitly demonstrate how fire managers will evaluate and incorporate new science information in future planning efforts (e.g., internal or external science panel review of FMP revisions).
6. *Flexible and adaptive*. Flexible and adaptive FMPs provide adaptive management mechanisms, such as the process of incorporating recommendations from progress reports in future operations or program implementation. Plans demonstrate this key principle through regular FMP updates that incorporate new technical information and policy direction (e.g., USDA and USDI 2014*b*). It is also demonstrated in the application of technical assessments and decision-support tools (e.g., climate vulnerability assessments, scenario planning) that assist federal agencies in planning for future uncertainty.

ASSESSMENT OF CURRENT FIRE MANAGEMENT PLANS

We examined seven federal FMPs within the southern Sierra Nevada to determine their consistency with the six key principles outlined in the previous section. Although nearly all federal agencies in our study area have annually reviewed or revised their FMPs since the latest federal fire policy implementation guidance was issued (i.e., USDA and USDI 2009), none have revised their FMPs since the most recent NPS and FS land management planning processes were initiated (e.g., new FS planning rule).

Our assessment focused on key words, phrases, or sections within individual FMPs that contained evidence of one or more key principles. We categorized a FMP as fully consistent, partially consistent, or inconsistent with each key principle (Table 1) based on the following definitions: (1) FMP is fully consistent if the key principle or central tenets are explicitly demonstrated in one or more focal sections or are readily apparent in the goals, objectives, and tools; (2) FMP is partially consistent if the key principle or central tenets are mentioned in passing emphasis (e.g., few words or brief phrases) or are somewhat apparent in the goals, objectives, and tools (i.e., mentioned in some but not all of these FMP elements); and (3) FMP is inconsistent if it lacks detectable evidence of the key principle and central tenets (including keywords) in the goals, objectives, and tools.

Based on these definitions, the majority of FMPs in the southern Sierra Nevada were either partially consistent or inconsistent with each of the six key principles (Figure 3).

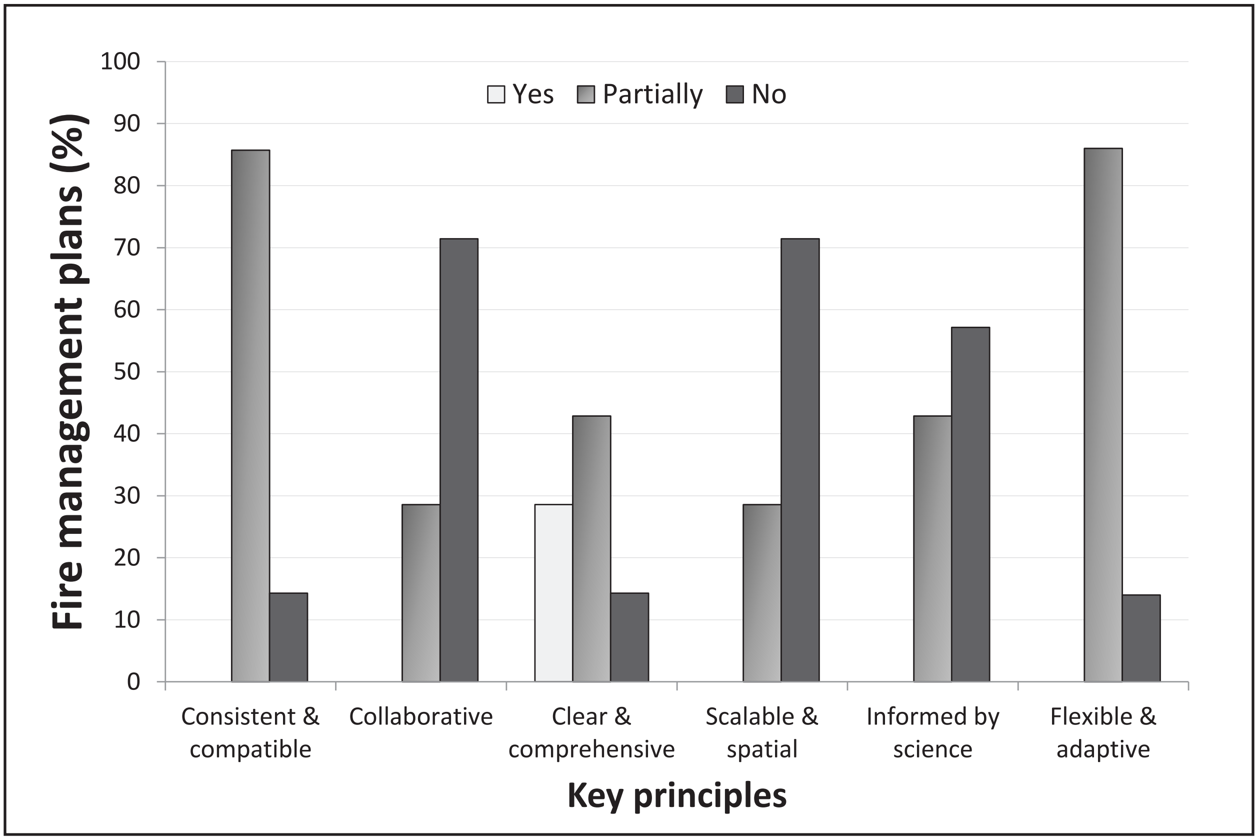

Figure 3. Percentage of federal fire management plans in the southern Sierra Nevada that is consistent, either completely or partially, with key principles for effectiveness. Figure is based on the analysis of seven fire management plans in the study area.

Overall, the key principles that ranked lowest were collaboration, spatial and temporal scalability, and best available science application. The low ratings in collaboration and application of best available science information are particularly concerning, because current federal policy implementation guidance and the science literature emphasize these essential principles in federal FMPs (e.g., USDA and USDI 2009, 2014*a*, 2014*b;* Stephens *et al.* 2010; Stein *et al.* 2013). Although the key principle related to consistency and compatibility was present in nearly all FMPs, no FMP in the ecoregion demonstrated full application of this essential principle. Likewise, nearly all FMPs were to some degree clear or comprehensive, but few FMPs demonstrated sufficient application of this principal element. Nearly all FMPs were flexible in terms of regular updates, but only one FMP demonstrated some degree of the adaptive management cycle, and no FMPs explicitly addressed adaptability, especially as it relates to climate change and other stressors not directly tied to wildfire risk and hazardous fuels.

FIRE MANAGEMENT TOOLBOX: APPROACHES AND RECOMMENDATIONS

The lack of consistency between southern Sierra Nevada FMPs and the six key principles underscores the need for guides or "tools" that facilitate principle integration. In this section, we present seven tools that integrate key principles for FMPs in our study area and other regions (Table 2). We based these tools on our extensive review of the science literature and

Table 2. Seven essential guides or "tools" that support the integration of one or more core fire management plan principles. Only those principles that are best supported by an individual tool or guide are listed (e.g., planning and prioritization may also support the application of best available science or flexible and adaptive approaches).

Tool or guide	Supports essential principle(s)
Planning and prioritization	Scalable, collaborative
Science integration	Informed by science
Climate change adaptation	Flexible and adaptive, informed by science
Partnerships	Collaborative, consistent and compatible
Monitoring	Flexible and adaptive, informed by science
Communication and education	Consistent and compatible, clear and comprehensive
Applied fire management	Collaborative, scalable

our knowledge of recent and ongoing planning and collaborative efforts inside and outside the ecoregion.

Planning and Prioritization

Background. Despite the many benefits of fuels management (Stephens *et al.* 2012), the strategic placement of fuel treatments is necessary to maximize their effectiveness at landscape scales (Finney *et al.* 2007, Schmidt *et al.* 2008). Planning and prioritization of fuel treatments and consideration of fire risk management across landscapes can effectively limit the spread of large and severe wildfires, especially in forested areas with relatively few management constraints (Hof *et al.* 2000, Finney 2001). However, many fire-prone landscapes are topographically complex and contain an array of values at risk (e.g., residential structures, sensitive wildlife habitat), which confound analytical approaches designed to augment fuel treatment effectiveness in these landscapes (Collins *et al.* 2010). The projected impacts of climate change further complicate this prioritization effort (Nydick and Sydoriak 2011). In the absence of practical decision-support tools that facilitate fuel treatment prioritization, many federal land managers in the southern Sierra Nevada and elsewhere focus on areas of past wildfire activity, greatest accessibility, and fewest operational constraints, which may limit effectiveness at a landscape scale (Finney *et al.* 2007). However, analytical approaches can significantly improve risk and hazard evaluation and fuel treatment prioritization both within and across administrative boundaries (Syphard *et al.* 2011, Rideout and Wei 2013, Scott *et al.* 2013).

Ideally, prioritization and risk evaluation approaches should identify strategic areas within larger landscapes based on a variety of scale-dependent considerations, including management constraints, opportunities, and uncertainties (Table 3). For example, the spatial distribution of the wildland-urban interface may constrain opportunities in the use of wildland fire, especially when potential treatment areas contain many values at risk to wildfire. In the following sections, we briefly describe two analytical approaches currently in use in the southern Sierra Nevada and elsewhere in the United States for fire and fuels management planning and prioritization.

Risk and hazard evaluation. Spatial evaluation of wildland fire risk and hazard can assist in the prioritization of fuels management and development of an effective fire management response framework (Ager *et al.* 2011). Factors that determine fire risk typically include wildfire probability, intensity, and potential impacts on valued resources and assets (i.e.,

Table 3. Eight important considerations for the development of spatial wildland fire risk assessments and the prioritization of fuel treatments within managed landscapes.

Primary considerations:
1. Areas of special ecological, cultural, or social significance (i.e., values at risk)
2. Core fire maintenance and restoration zones, where wildland fire may be managed for resource objectives appropriate with the values at risk
3. Protection zones, where fires are managed with the fewest negative consequences especially in areas characterized by frequent natural or human ignitions, multiple sensitive values at risk, and high probability of success for the prevention of undesirable fire effects
4. Areas of special significance that are moving to a more departed (i.e., adverse) condition category in the near future, as indicated by Fire Return Interval Departure (FRID), LANDFIRE Vegetation Condition Class (VCC), or a similar index
5. Zones that constrain the types of fuel treatment activities that are available for implementation (e.g., mechanical thinning in sensitive wildlife habitats)
6. Areas that potentially benefit from interagency coordination and planning (e.g., adjacent to administrative boundaries)
7. Climate change, population growth, and their influence on future fire hazard and risk
8. Degree of uncertainty associated with fire hazard and risk evaluations

expected losses; Hardy 2005, Scott *et al*. 2013). Valued resources may include natural (e.g., vegetation, wildlife habitat, water and air quality), cultural (e.g., historic sites, tribal cultural sites), or social (e.g., infrastructure, neighboring communities, wilderness) assets. In comparison, fire hazard characterizes the fuel loading conditions and is typically related to the physical properties of a wildfire (e.g., fireline intensity, flame length), and its resistance to control (Hardy 2005, Calkin *et al.* 2010). More recently, Scott *et al*. (2013) expanded the concepts of fire risk and hazard to include the potential benefits of wildland fire. This more comprehensive approach quantifies wildfire effects as the net change in value, considering both the relative benefits and losses with changes in fire intensity (Finney 2005). The spatial representation of fire risk, hazard, and management objectives and options, especially at the ecoregional scale, provides a valuable tool for identifying strategic responses to wildfire, including the use of wildland fire to achieve FMP objectives (Calkin *et al.* 2010, Scott *et al.* 2013). For example, the FS Southern Sierra Wildfire Risk Assessment is currently evaluating fire hazard and risk to high-value resources and assets (e.g., vegetation, watersheds) in the ecoregion. Estimation of risk includes an evaluation of the positive and negative responses of valued resources to fire of varying intensity (P. Bowden, Forest Service, Vallejo, California, USA; unpublished data). This assessment is currently supporting forest planning efforts for the national forests in the southern Sierra Nevada. However, the temporal scope of this risk assessment approach is generally short, such that the temporal dynamics of succession and fire are not simulated (Scott *et al.* 2013), although periodic wildfire risk assessment updates can partially address this issue. Additionally, this approach depends on reliable and spatially integrated vegetation data for the region of interest, which may be difficult to obtain and validate for a large and complex ecoregion.

Fire Return Interval Departure. Fire Return Interval Departure (FRID) is another analytical approach to fuels treatment prioritization in the southern Sierra Nevada. Caprio and Graber (2000) initially developed this approach to prioritize fuel treatment location and facilitate wildfire management decisions in Sequoia and Kings Canyon national parks. Safford and Van de Water (2014) expanded the use of the FRID approach to the national forests in California. The NPS FRID analysis calculates the time since the last recorded fire event relative to the maximum average presettlement fire return interval (i.e., the length of time between fires in a particular area prior to Euro-American settlement). This approach provides insights into fuel loading, potential fire behavior, and fire effects. In comparison, the FS FRID analysis calculates the difference between current and presettlement fire frequencies and is an indication of the number of fires an area has "missed" since the beginning of consistent fire recordkeeping (1899 to 1910). Both NPS and FS FRID calculations are available for the entire Sierra Nevada (Safford and Van de Water 2014), lending feasibility of this approach to ecoregional analyses that span agency boundaries, especially in forests characterized by fuel-limited fire regimes (Steel *et al.* 2015). In the southern Sierra Nevada, FRID analysis has assisted in the prioritization of forest landscapes with the greatest need for treatment (e.g., Caprio and Lineback 2002) and in interagency fire management planning efforts that combine several analytical approaches (e.g., Nydick and Sydoriak 2011). Moreover, these FRID calculations are simple, complementary, and useful methods to compare fire management achievements against historic benchmarks and target areas at high risk of threshold-type responses (Safford and Van de Water 2014). Limitations of the FRID approach include its reliance on accurate historical fire records, reliable spatial vegetation data, and robust fire return interval information. FRID uses fire frequency and history, but it does not explicitly consider fire intensity, severity, or seasonality patterns; however, Steel *et al.* (2015) found a positive relationship between FRID and the proportion of high severity fire in many low- to mid-elevation forests of California.

Science Integration

The integration of science information is critical to the development of robust, comprehensive, and responsive FMPs and fire policies (Stephens and Ruth 2005, USDA and USDI 2009). The best available science information is relevant, accurate, and reliable, and managers are required to consider the consistency and uncertainty of scientific studies (USDA-FS 2015). For example, some scientific information has converged on a set of core doctrines that are supported by the weight of scientific evidence (e.g., fire is an essential ecological process in forests of western North America), but other areas of inquiry are characterized by higher degrees of scientific uncertainty (e.g., fuel treatment effects on sensitive wildlife populations; Stephens *et al.* 2014). Consequently, fire managers rely on a diverse set of information sources for the delivery, interpretation, and application of best available science information (Youngblood *et al.* 2007).

Information relevant to FMPs includes the ecological, physical, and socioeconomic sciences and generally encompasses a wide array of sources, including peer-reviewed literature and technical documents (e.g., agency reports), fire consortia and working groups, traditional ecological knowledge, and inventory and monitoring data. Fire science information sources relevant to the ecoregion include the Association for Fire Ecology (AFE; national and international), California Fire Science Consortium (CFSC; state) currently supported by the Joint Fire Science Program (JFSP, national), Southern Sierra Nevada Fire Science Working Group (SSFSWG; ecoregional), Southern Sierra Prescribed Fire Council (SSPFC; ecoregional), and Southern Sierra Strategic Framework (SSSF; ecoregional). All of these organizations or groups focus primarily on the dissemination of fire science or technical information to land managers and fire practitioners, with a particular emphasis on federal land management agencies. This science delivery is accomplished through a combination of technical meetings and symposia (all groups), science briefs and syntheses (CFSC, JFSP), webinars (CFSC), technical reports and assessments (JFSP, AFE, SSSF), field trips and workshops specific to the ecoregion (CFSC, SSFSWG, SSSF), and other approaches (e.g., newsletters, blogs, social media). Collectively, these "boundary spanning" organizations serve as a significant and ready source of science information in support of fire management planning efforts (e.g., Kocher *et al.* 2012). In addition, these and other interagency partnerships are supportive of federal fire policy implementation guidance calling for greater interagency cooperation, especially as it relates to science integration (USDA and USDI 2009).

Other sources of relevant science information for FMPs derive from direct science-management partnerships and stakeholder collaborations that facilitate collective learning. Science-management partnerships have been invaluable to the development of effective fire and land management decision making in the southern Sierra Nevada for several decades. These include ongoing and emerging research collaborations between the southern Sierra Nevada national forests and the FS Pacific Southwest Research Station (PSW), including such collaborative projects as the Teakettle Experimental Project and Experimental Demonstration Landscapes concept currently proposed for studying fire-related treatments across large landscapes (North 2002, North *et al.* 2014). The National Park Service and US Geological Survey Yosemite Field Station and Sequoia and Kings Canyon Field Station have maintained an equally beneficial relationship in the ecoregion, supporting a nationally recognized fire science and management partnership for over two decades (van Wagtendonk 2007). In addition, agency partnerships with academia and agency scientists have also resulted in a wealth of fire science and natural resource information (e.g., Sierra Nevada Adaptive Management Project, a joint effort by the University of California, state and federal agencies, and the public to study forest management in the Sierra Nevada).

Although these diverse fire science information sources are readily available within the southern Sierra Nevada, timely integration of this information into fire management planning remains limited. This limitation results, in part, from the lack of a formal and regular review process that integrates fire science and monitoring information into FMPs (e.g., a 5-year review that ensures FMP goals are consistent with new science findings). Notably, fire and resource managers in the ecoregion often do not collect, analyze, or report monitoring data for the purpose of evaluating FMP objectives and tools. One potential solution to this issue is to clearly define an adaptive management cycle and identify the process of collecting, evaluating, and integrating science and monitoring information with each FMP revision phase.

Finally, the identification of key science information gaps is an important but often missing component of FMPs. Ideally, fire and resource managers regularly identify new fire science information needs and communicate this information to agency and academic research partners during regional workshops or symposia. Managers could also communicate this information by providing a list of essential information needs in the FMP during an annual review process.

Climate Change Adaptation in Fire Management Plans

Background. Climate adaptation planning is an approach to prepare for, cope with, and respond to the impacts of current and future climate change (Stein *et al.* 2013). The process of adaptation planning creates a framework for assessing and mitigating vulnerability and managing for change (Joyce *et al.* 2009, Peterson *et al.* 2011). Adaptation planning is a cycle (Figure 4) in which participants (e.g., land managers, scientists, stakeholders) define goals and objectives, assess resource vulnerability, reevaluate goals and objectives in light of resource vulnerability, craft and implement adaptation actions, monitor effectiveness, and adjust adaptation actions and goals as new information becomes available (Stein *et al.* 2013). We focused on two methods in assessing resource vulnerability (i.e., climate vulnerability assessment, scenario planning) and provide examples of climate adaptation strategies that are developed from these assessment methods. Both the assessment of climate vulnerability and development of climate adaptation strategies are relatively new in natural resource and fire management planning, but these steps are supported by current agency guidance (e.g., USDA-FS 2011, USDI Secretarial Order No. 3289) and overarching federal policy (e.g., US Executive Order No. 13653: Preparing the United States for the Impacts of Climate Change). In the southern Sierra Nevada, land managers have recently used two complementary approaches to assess projected impacts of climate change and altered fire regimes: (1) climate vulnerability assessments, and (2) climate change scenario planning. Both of these approaches have an inherent degree of uncertainty (e.g., projected changes in precipitation) and rely on a diverse array of information sources, from climate models to expert knowledge.

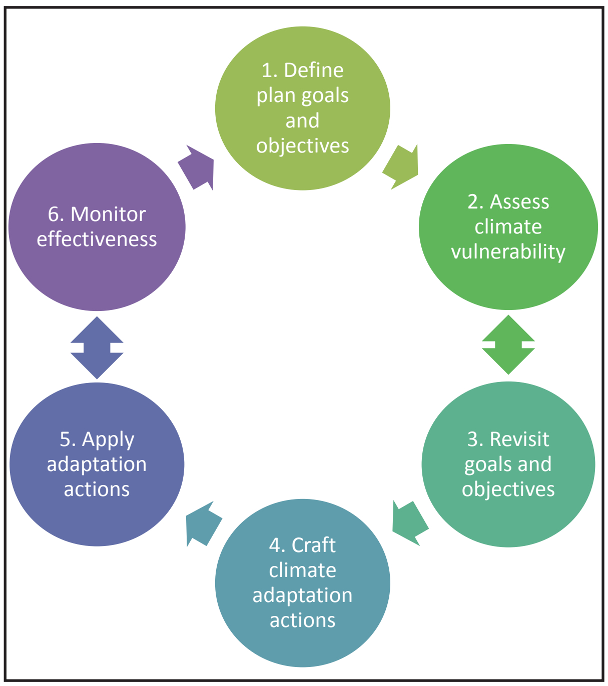

Figure 4. Climate adaptation planning is an iterative cycle comprised of several stages. Bi-directional arrows represent transitory steps in the process that may require reassessment of vulnerability with revision of goals and objectives (stages 2 to 3) or adjustment of adaptation actions following monitoring evaluation (stages 5 to 6). Figure is based on Stein *et al.* (2013).

Climate vulnerability assessments. Climate vulnerability assessments evaluate the effects of climate change and related stressors on key resources of interest (Peterson *et al.* 2011, Stein *et al.* 2013). The climate vulnerability approach attempts to identify the vulnerability of key resources based on three component parts: exposure, sensitivity, and adaptive capacity (Glick *et al.* 2011). Exposure is a measure of how much change a resource will experience; sensitivity refers to how that change will affect the resource; and adaptive capacity is the resource's ability to cope with anticipated change. Thus far in the southern Sierra Nevada, federal land managers have used the climate vulnerability assessment approach in two instances, including the FS-sponsored Sierra Nevada vulnerability assessment (addresses climate change; Kershner 2014), and interagency, NPS-sponsored southern Sierra fire and climate vulnerability assessment project (addresses both climate change and altered fire regimes; Nydick and Sydoriak 2011). The latter effort has been especially supportive of fire management and resource planning efforts in the region, including the NPS resource stewardship strategy and FS LRMP revision.

Scenario planning. Another method for evaluating the potential impacts of climate change on focal resources is scenario planning (USDI-NPS 2013). This approach involves the creation of scenarios to explore several potential futures (often informed by climate vulnerability assessments), such as the vulnerability of natural resources under divergent future conditions. For example, one scenario may describe a hot and dry future with more frequent fires, while another could involve a warm and wet future with less frequent but higher intensity fires. Managers could devise a suite of alternative fire management actions that could be implemented across these divergent futures, thereby "hedging one's bets" in the face of uncertainty (Stein *et al.* 2013). The multiagency southern Sierra alternative fire futures project is an example of the use of scenario planning in assessing the projected impacts of climate change and future fire regimes on focal resources (Nydick and Sydoriak 2011).

Climate adaptation strategies. The next step in climate adaptation is the development and selection of applied adaptation strategies. These adaptation strategies reduce the vulnerability of key resources by minimizing exposure, decreasing sensitivity, or increasing adaptive capacity. In the southern Sierra Nevada, fire and resource managers developed an array of adaptation strategies, including the restoration of resilient forest conditions, reintroduction of fire as a key ecological process, and promotion of spatial heterogeneity (Stephens *et al.* 2010, Peterson *et al.* 2011, Stephens *et al.* 2013; Table 4). Adaptation strategies from regions with rapidly expanding populations may also emphasize local community

Table 4. Proposed climate adaptation strategies for fire management in the southern Sierra Nevada. Strategies are primarily based on regional workshops, published literature, and technical assessments specific to the ecoregion.

Climate adaptation approach	Example(s)
1. Development of ecoregional Fire Management Plan	Proposed federal FMP for southern Sierra Nevada ecoregion (NPS, FS, BLM)
2. Use of cross-jurisdictional demonstration landscapes to facilitate shared learning	Kings River watershed with extensive science and monitoring infrastructure to test climate adaptation strategies implemented across administrative boundaries (NPS, FS)
3. Adaptive seasonality in fire management operations	Greater use of wildland fire for resource objectives during winter months and following wetter winters
4. Fuel treatment prioritization and restoration informed by climate vulnerability assessment	Prioritize climate refugia for fuel treatment and restoration efforts; facilitate or accept transitions in high vulnerability areas (e.g., projected loss of coniferous forests)
5. Fewer operational constraints for the use of wildland fire	Greater flexibility in GMP, RMP, or LRMP standards and guidelines, such as more flexible Limited Operating Periods (LOPs) related to prescribed fire
6. Development of post-fire "climate-smart" restoration strategies	Focus post-fire reforestation efforts (e.g., tree planting) in areas that will support forests of the future with climate change; consider more drought-tolerant species in seedling mixes (e.g., oaks) with wider and more variable spacing to facilitate future heterogeneity and resilience (FS)
7. Adjust fire operations during large and severe wildfires	Avoid the creation of larger high-severity fire patches resulting from burnout and mop-up operations to protect partially unburned refugia that aid post-fire recovery

planning, protection of connectivity between climate refugia, and development of diverse partnerships with state and private entities (Nydick and Sydoriak 2011, Stephens *et al*. 2013). These varied approaches represent alternative strategies, each associated with a set of risks, constraints, and potential benefits. The formulation of regional climate adaptation strategies is vital to the development of flexible and adaptive FMPs.

Partnerships

Stakeholder and agency collaborations in the southern Sierra Nevada are diverse, including partnerships among federal agencies, state and local agencies, non-governmental organizations, academia, industry, and public interest groups. These partnerships contribute to the process of shared learning and trust building, build consistency in overarching goals and objectives, and provide a unique source of information for consideration in FMPs (Sturtevant and Jakes 2008, Lachapelle and McCool 2011). In the southern Sierra Nevada, these partnerships include technical discussions with regulatory agencies (e.g., San Joaquin Air Pollution Control District), information sharing with fire practitioners, traditional ecological knowledge, public perceptions regarding wildland fire, and stakeholder perceptions of valued resources and assets (Charnley *et al*. 2014). Two examples of relevant stakeholder collaborations in the ecoregion include the Southern Sierra Prescribed Fire Council and Dinkey Collaborative Forest Landscape Restoration Project (Bartlett 2012, Charnley *et al*. 2014). Additionally, the southern Sierra Nevada corresponds with the regional extent of the Southern Sierra Federal Managers Group, a federal interagency partnership that facilitates cross-boundary communication in support of regional land management planning. Nearly all of these collaborations have emerged in the ecoregion within the past five years, underscoring the recent emphasis of collaboration in land management and fire management planning (Charnley *et al*. 2014). Collaborative information may prove to be particularly valuable for FMPs when such information is not available from research, monitoring, and other science-based information sources. Collaborations also provide much needed support for public outreach and communication efforts during planned fire management operations, including consistent messaging to local communities (Sturtevant and Jakes 2008). For example, partnerships within the Southern Sierra Prescribed Fire Council have supported public outreach efforts during the first phase (2014) of the Boulder Burn, a multiyear 2400 ha to 3600 ha prescribed burn project on the Sequoia National Forest. These joint efforts resulted in an improved communication plan that notified nearby residents and the medical community of potential smoke impacts well before and immediately prior to planned ignition dates, minimizing air quality impacts to smoke-sensitive groups (e.g., elderly, asthmatics).

Monitoring

Monitoring is a fundamental part of the adaptive management process (Lovett *et al.* 2007). Fire managers rely on monitoring information to evaluate the effectiveness of FMP elements, including tools, objectives, and measureable goals (Stephens and Ruth 2005). Moreover, monitoring is considered critical for evaluating and improving FMP performance based on current federal fire policy implementation guidance (USDA and USDI 2009, 2014*b*). Essential elements of a monitoring strategy include: (1) clear articulation of monitoring objectives and indicators based on compelling questions; (2) specification of thresholds of concern based on desired conditions (e.g., derived from concepts such as the natural range of variation; Romme *et al.* 2013); (3) identification of potential management actions when thresholds of concern are reached; (4) selection of appropriate monitoring protocol;

(5) maintenance of data quality and consistency, including long-term data accessibility; and (6) development of mechanisms for learning and adaptive management, such as evaluation phases devoted to internal review, feedback, and adaptation (Lovett *et al.* 2007, Lindenmayer *et al.* 2013).

Federal agencies monitor fire effects and fuels using standardized, field-based protocols, such as the interagency FIREMON-FEAT Integrated (FFI) (Lutes *et al.* 2009), NPS fire monitoring handbook (USDI-NPS 2003), FS Common Stand Exam (CSE; USDA-FS 2014*b*), natural fuel photo series (e.g., Maxwell and Ward 1979), and specialized regional (e.g., Safford *et al*. 2012) protocols. While these field-based, standardized monitoring protocols are instrumental in post-fire monitoring efforts throughout the region, in many cases they are limited to relatively smaller spatial scales (e.g., project- and stand-level scales). In comparison, there are several recent and emerging remote-sensing technologies that are expanding the scope of fire effects and fuels monitoring to large landscape and regional scales. These recent and new technologies include fire severity monitoring (e.g., Monitoring Trends in Burn Severity project; Eidenshink *et al.* 2007), LANDFIRE data (especially for regional- to national-scale monitoring; Nelson *et al.* 2013), Light Detection and Ranging (LiDAR), and hyperspectral imagery (Lentile *et al.* 2006). Researchers and managers alike have used these newer technologies to conduct fire-related research and monitoring assessments across large spatial scales in many parts of the southern Sierra Nevada (e.g., Miller and Safford 2012, Kane *et al.* 2013), including across jurisdictional boundaries to facilitate interagency comparisons and cooperative learning (e.g., Miller *et al.* 2012). These emerging remote-sensing technologies, when combined with field-based approaches for validation, are crucial for monitoring the effects of fire across large spatial and temporal scales. Federal agencies may use similar technologies and approaches to monitor and evaluate FMP objectives related to vegetation, smoke emissions, watershed function, wildlife habitat, and other resources.

Communication and Education

Communication and education ensure that federal agencies and their partners effectively implement and convey FMP goals, objectives, and strategies (Sturtevant and Jakes 2008). This is consistent with federal fire policy implementation guidance calling for better interagency communication and education of the public and personnel (USDA and USDI 2009). A primary element of effective communication and education in FMPs is to identify goals, key messages, target audiences, and learning approaches (USDA and USDI 2009, 2014). It is particularly important to develop clear and consistent messages within and among cooperating agencies (including the federal, state, and local levels) to maximize communication effectiveness for staff, partner agencies, and the public. The following are examples of key messages from the Sequoia and Kings Canyon national parks' FMP (SEKI 2009): (1) fire is an essential ecological process; (2) society's influence has altered historic fire regimes, leading to a dangerous build-up of vegetation in our wildlands; (3) land management agencies are committed to a balanced fire program that will reduce risks and realize benefits of fire; (4) fire managers respect the force of fire and take their responsibilities very seriously; (5) improving the health of the land and reducing risks to communities requires partnerships among federal and state agencies, tribal governments, fire departments, communities, and landowners; and (6) public education needs to be part of fire management programs. These and similar key messages communicated across agencies would greatly enhance the capability of education and communication efforts (especially interactive communication) designed to inform the public of FMP goals, objectives, and strategies (Toman and Shindler 2006, Toman *et al.* 2006).

Public and agency education programs are most influential if they target stakeholders and personnel affected by wildland fire management, including the effects of smoke. Public education programs focused on fire management can increase effectiveness with the use of online resources, interactive public workshops, field demonstration tours, and media networks (Toman *et al.* 2006, Sturtevant and Jakes 2008). Stakeholder collaborations (e.g., Southern Sierra Prescribed Fire Council) and boundary organizations (e.g., California Fire Science Consortium) can also facilitate public and agency education programs through increased capacity and communication systems (Kocher *et al*. 2012, Charnley *et al*. 2014). Personal, interactive communication between fire managers and public members (e.g., in-person, two-way discussions with stakeholder groups) can also build public support for fire management activities, such as prescribed fire programs near the wildland-urban interface (McCaffrey 2004, Toman *et al.* 2006). Lastly, fire training and education programs may significantly enhance capacity in the application of prescribed fire (e.g., Fire Learning Networks; Goldstein *et al.* 2010). Adequate training and education of the next generation of wildland fire professionals are absolutely essential to achieve the goals and objectives of FMPs, especially those pertaining to the use of wildland fire to meet diverse resource objectives (Kobziar *et al.* 2009).

Applied Fire Management

There are three general fire and fuels management approaches for achieving resource objectives in the southern Sierra Nevada: mechanical treatments, prescribed fire, and wildfires managed to meet resource management objectives. These fire management tools have specific advantages and constraints when applied exclusively or in combination at different spatial scales (Collins *et al.* 2010, Quinn-Davidson and Varner 2011, Ryan *et al.* 2013). The extent to which land managers implement each of these approaches varies among the federal agencies in the ecoregion, with relatively greater use of wildland fire by the NPS, and mechanical treatments by the FS and BLM. The BLM currently does not manage wildfires for resource objectives in the ecoregion.

In 1969, Sequoia and Kings Canyon national parks implemented the first prescribed natural fire program that permitted lightning fires to burn under prescribed conditions (Kilgore and Briggs 1972). Since that time, both the NPS and FS have managed numerous wildfires to meet resource management objectives in the southern Sierra Nevada (Figure 1), including many cooperatively managed wildfires (van Wagtendonk 2007, Meyer 2015). Despite this progress, current fuel treatment rates in Sierra Nevada forest ecosystems are insufficient to mitigate increasing fire severity trends in the region (North *et al.* 2012). This current "backlog" of untreated forests in the Sierra Nevada will not significantly decline with the use of prescribed fire and mechanical treatments alone, except at highly localized spatial scales. For example, less than approximately 20 percent of the land base is accessible to mechanized equipment in the national forests of the southern Sierra Nevada due to administrative, legal, ecological, or operational constraints (North *et al.* 2015). Several constraints limit the widespread application of prescribed fire in the ecoregion (e.g., air quality, agency capacity), especially in remote landscapes lacking suitable access points. Rather, the use of wildfires managed for resource objectives is the primary management tool with the potential to address this backlog (North *et al.* 2012). This tool can substantially increase the scale and geographic scope of fuel management and ecological restoration objectives in fire-adapted ecosystems of the Sierra Nevada (North *et al.* 2014). Large, self-contained "firesheds" that are predominantly outside the wildland-urban interface (but potentially spanning administrative boundaries) are particularly suitable landscapes for the use of wildfires managed for resource objectives (Meyer 2015). Even in more challenging landscapes (e.g., with mixed public and private land ownership), the use of wildland fire may be a feasible option but will require cross-jurisdictional coordination, regular communication with air quality regulators and other partners, adequately trained and educated fire management staff (e.g., Kobziar *et al.* 2009), public education programs, sustained and adequate agency funding, use of a diverse array of applied management tools at appropriate spatial scales, strong advocates for the use of wildland fire (especially decision makers), and land management plans that encourage greater management flexibility (e.g., less stringent limited operating periods).

CONCLUSIONS

Current science information and federal fire policy guidance underscores several key principles in the effective management of wildland fire on federal lands in the United States. However, a considerable proportion of federal fire management plans in the southern Sierra Nevada do not fully incorporate these key principles, especially in the areas of collaboration, spatial and temporal scalability, and integration of new science information. Incorporation of an array of planning, communication, science integration, climate adaptation, and other fire management tools can substantially improve the effectiveness of current fire management plans both inside and outside the region. Integration of these key principles and tools is necessary if federal fire management plans are to remain successful in today's increasingly complex world.

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