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Postfire Restoration Framework for National Forests in California

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Cover Photos: Upper (panoramic): Burned forest landscape one year following the 2015 Rough Fire showing a mixture of fire effects. Giant Sequoia National Monument, Sequoia National Forest. Photo by Marc Meyer. Lower Left: Resprouting manzanita (*Arctostaphylos glandulosa*) six months after the 2017 Thomas Fire. Dry Lakes Ridge Botanical Special Interest Areas, Los Padres National Forest. Photo by Nicole Molinari. Lower middle: Monarch giant sequoia (*Sequoiadendron giganteum*) that burned at low to moderate severity two years after the 2015 Rough Fire in Grant Grove, Kings Canyon National Park. Photo by Marc Meyer. Lower Right: Big sagebrush (*Artemisia tridentata*) and bitterbrush (*Purshia tridentata*) before (top, 2010) and after (bottom, 201) the 2016 Owens River Fire, Mono County, CA. Photo by Michele Slaton.

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Postfire Restoration Framework for National Forests in California

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Abstract

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Increasing frequency and extent of high-severity wildfires pose a significant threat to California's ecosystems. This is evident in both tree- and shrub-dominated landscapes, where novel, human-driven fire regimes may result in large-scale alteration of terrestrial ecosystems and decline in the services they provide. Based on these trends and a broader consideration of sustainability, there is a growing need for a well-supported, science-based approach to postfire management. This report presents a framework to guide the development of postfire restoration on national forests in California. The framework is founded on a set of guiding principles and a five-step process that leads to the development of a restoration portfolio that can inform project planning and monitoring. We discuss the application of this approach to California's forest, chaparral, and sagebrush-steppe ecosystems. The restoration framework can inform future postfire management, monitoring, and research in California's diverse ecosystems.

Keywords: Ecological restoration, ecosystem resilience, ecological integrity, fire regimes, fire management, natural range of variation, wildfire, climate change, California.

Executive Summary

We propose a science-based framework for ecological restoration interventions after major wildfires on USDA Forest Service lands in California. Changing fire regimes, interacting with other ecological disturbances and stressors, are threatening the ecological integrity and ecosystem services of California's forests, woodlands, and shrublands. The postfire restoration framework is guided by principles of ecological restoration and includes a landscape assessment process and tools, as well as a framework for decisionmaking to plan and implement restoration projects. Three case studies are included that focus on the following:

- Potential failure of conifer forests to regenerate following uncharacteristically large and severe wildfires
- Loss of key ecosystem services in chaparral ecosystems affected by repeated burning
- Invasion of sagebrush steppe landscapes by nonnative annual grasses following fire

Increased fuel loading and shifts in forest composition in forest or woodland landscapes following wildfires are other major concerns considered in the report. However, changes in fuel loads and shifts in species composition also arise from other causes of extensive mortality, including extended droughts, bark beetle outbreaks, and sudden oak death. As such, all these agents of change represent a growing concern.

The postfire restoration framework is rooted in six science-based guiding principles:

- Restore key ecological processes
- Consider landscape context
- Promote regional native biodiversity
- Sustain diverse ecosystem services
- Establish a prioritization approach for management interventions
- Incorporate adaptation to agents of change

The framework includes five steps that connect restoration goals, opportunities, and potential actions that serve as the foundation for future project planning, monitoring, and adaptive management:

- An interdisciplinary team of specialists identifies priority resources, desired conditions, and restoration goals.
- The team gathers and analyzes relevant spatial data and other information to evaluate current and potential future landscape conditions.
- The team uses a postfire flowchart to identify restoration opportunities.
- The team develops a list of potential management actions that are linked to these opportunities.
- The team builds a suite of potential restoration actions that support landscape restoration goals ("restoration portfolio") by prioritizing actions based on feasibility and constraints.

Numerous analytical tools, approaches, and datasets are available to assist in evaluating landscape condition and trends in the postfire flowchart and restoration portfolio. Some of these tools and data may be broadly applied, but many are specific to individual ecosystem types or landscapes. For example, the postfire regeneration tools in appendix 3 are appropriate only for certain conifer-dominated ecosystems.

This report proposes a framework for developing landscape-scale postfire (and related) restoration plans on Forest Service lands in California. Selected restoration approaches are described in this report for illustrative purposes. The effectiveness of specific tactics are addressed in other publications, but continued long-term research and monitoring efforts are needed to evaluate the extent to which they effectively restore ecological integrity and sustain ecosystem services.

Contents

Chapter 1: Principles of Postfire Restoration

Marc D. Meyer, Jonathan W. Long. Hugh D. Safford, Sarah C. Sawyer, Malcolm P. North, and Angela M. White[1]

Introduction

Over the past century, a variety of environmental stressors, combined with effects from past and current management activities (e.g., fire exclusion, past timber harvest practices, livestock grazing, water diversion), have substantially altered the status of most California ecosystems. These changes include major shifts in ecological disturbance regimes, such as flooding, insect and disease outbreaks, and fire (Barbour et al. 2007, Mooney and Zavaleta 2016). For terrestrial ecosystems, the most profound ecological disturbances are those that substantially increase plant mortality, and in California's Mediterranean climate, fire has long been viewed as the primary natural disturbance factor driving ecosystem composition, structure, function, and geographic distribution (Keeley and Safford 2016, van Wagtendonk and Fites-Kaufman 2006).

Objectives for Postfire Interventions

Forest managers are charged with meeting multiple objectives for national forest lands. Major disturbances such as wildfires may influence the long-term trajectory of ecosystems in ways that affect achievement of these objectives. Those objectives include ensuring public safety; providing a supply of timber and favorable waterflows; supporting rural economies; restoring degraded or damaged ecosystems; and maintaining habitat for threatened, endangered, and other species of conservation concern (see app. 1). An example of the latter is late-successional-associated wildlife such as the California spotted owl (*Strix occidentalis occidentalis*), whose reproductive capacity may fail to keep pace with habitat losses because of uncharacteristically severe wildfire (Stephens et al. 2016). In addition to those objectives, managers may be concerned with maintaining carbon storage by ensuring or accelerating the recruitment of large trees, especially in areas that may undergo a state shift to nonconifer forested vegetation following large, high-severity fires (Hurteau and Brooks 2011).

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Across national forest lands within California (fig. 1.1), restoring the integrity of ecosystems is an important goal (USDA FS 2015). This report focuses on interventions to achieve that goal, although it recognizes that land managers have many objectives and there is potential for conflicts among them. Furthermore, objectives may need to be shaped in response to limitations on the resources that managers can invest in postfire landscapes, as well as constraints on the scope of various programs that may limit interventions in scope and time after a wildfire. As discussed in the following chapter, economic feasibility of interventions may be a particularly relevant consideration when prioritizing potential interventions, although the contributors to this report thought it was more appropriate to focus on ecological conditions and objectives in the initial steps of the framework.

Shifts in Fire Regimes and Rationales for Restorative Interventions

Ecological restoration following uncharacteristic wildfires may address the direct effects of the wildfires or degradation that predated the fire. It is important to recognize that wildfires are natural, essential (or keystone) ecosystem processes in the California bioregion. Consequently, **individual wildfire events** can be restorative. On the other hand, substantial and persistent changes in **fire regimes** can exert major pressures on ecological and evolutionary processes and patterns (Dale et al. 2001, D'Antonio and Vitousek 1992, Noss et al. 2006). In California, as in most of the Western United States, fire regimes have experienced major changes in frequency, severity, size, seasonality, ignition sources, and other components since mid-19th century Euro-American colonization. The best documented changes have been in fire frequency, and the direction of change has varied in different ecosystems, as shown in maps of fire regime departure for the state. Some California ecosystems, especially chaparral in southern California, now experience generally much more frequent fire than before Euro-American colonization. There are also concerns that some areas of sagebrush steppe in eastern California (the Great Basin) may also be experiencing fires at rates more frequent than those to which they were adapted even though statewide maps show that fire return intervals are close to, or somewhat longer than, reference values (fig. 1.2). Interior chaparral ecosystems in southern California have been experiencing increased frequency of fires (fig. 1.2). Meanwhile, many other ecosystems, particularly semiarid forests and woodlands dominated by pines (*Pinus*) and oaks (*Quercus*) in the Sierra Nevada and northern California, experience far less fire than they did historically. Indeed, many of these forested systems have experienced a nearly complete absence of fire over the past century (Safford and Van de Water 2014, Steel et al. 2015). The

It is important to recognize that wildfires are natural, essential (or keystone) ecosystem processes in the California bioregion. Consequently, individual wildfire events can be restorative. On the other hand, substantial and persistent changes in fire regimes can exert major pressures on ecological and evolutionary processes and patterns.

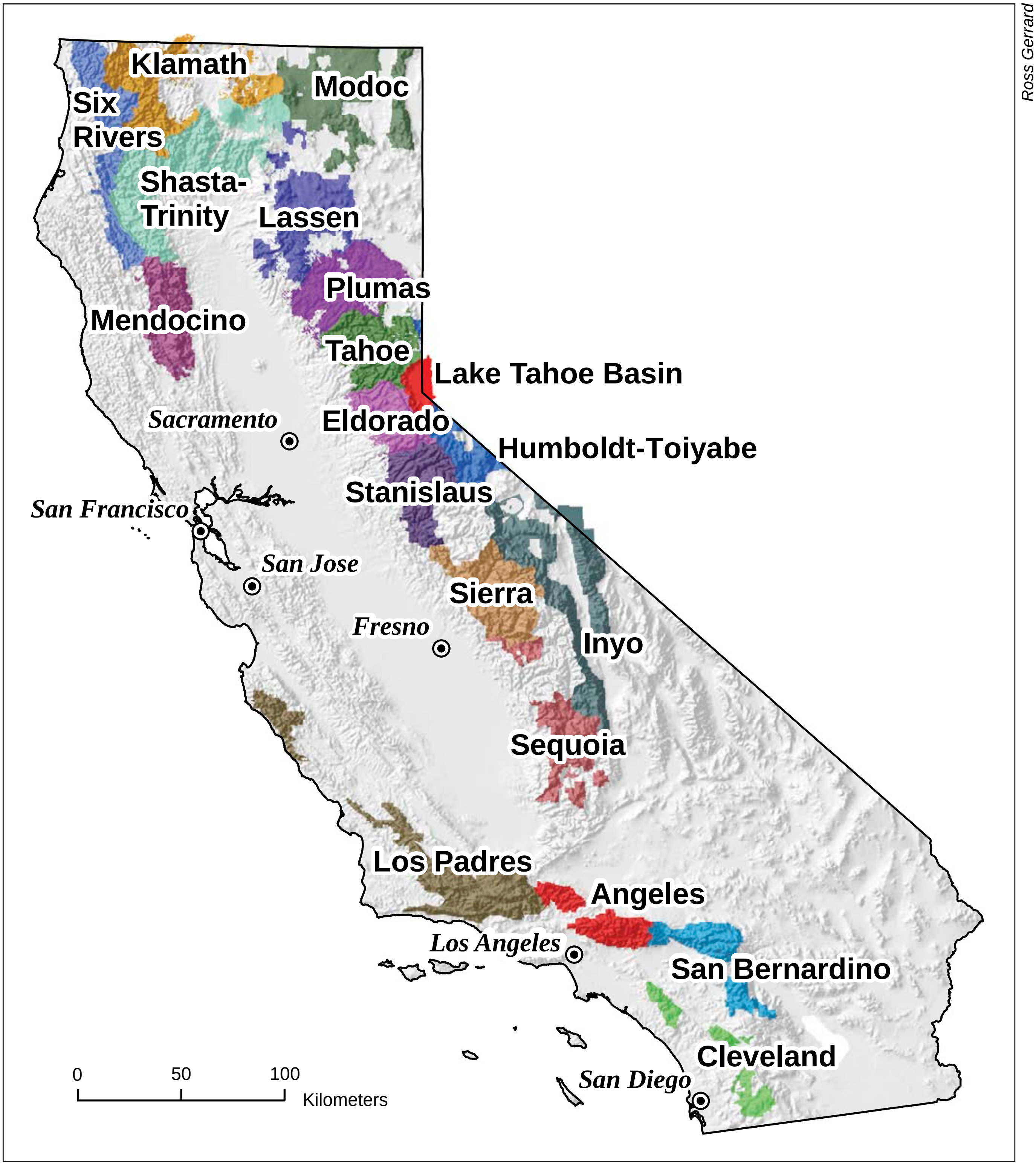

Figure 1.1—National forests in California.

Nicole Molinari

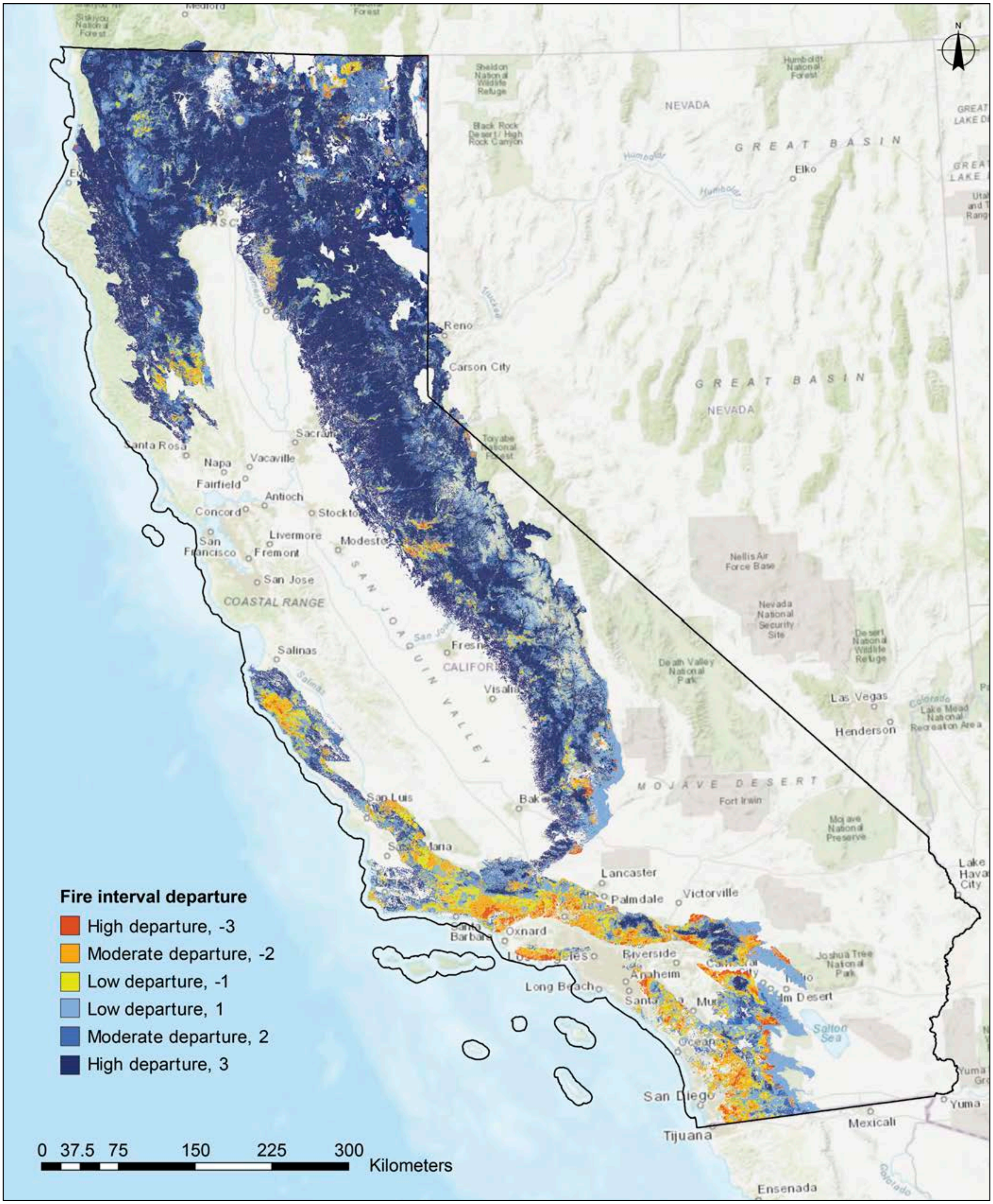

Figure 1.2—Fire regime interval departure condition classes for California. Negative departures indicate areas that are currently burning more frequently than before Euro-American colonization. Positive departures indicate areas that are burning less often than before Euro-American colonization. See Safford and Van de Water (2014) for more detail.

long-term lack of fire has resulted in a century of fuel buildup that, in combination with the warming climate, is producing uncharacteristically large and severe fires (Mallek et al. 2013, Miller et al. 2009, Moghaddas and Hubbert 2014, Safford and Stevens 2017). This report considers how these changes in fire regimes threaten important ecosystem functions and services.

We discuss these chaparral and semiarid forest systems in further detail below and in the case studies in subsequent chapters. We recognize that there are other ecosystems, including grasslands and woody vegetation types (including certain closed-cone conifer forests) that evolved with more intense replacement fires as the predominant disturbance. Those types are not a focus of this report, although many of the principles and approaches for assessing interventions could be applied to them as well. Throughout California, fires are increasingly the originators of altered landscapes that present new challenges to land managers, challenges that are further complicated by the growing influences of climate and demographic change, invasive species, and evolving social views (e.g., public attitudes toward fire and its role in terrestrial ecosystems) (Stephens et al. 2013, 2016).

Shrublands—

Many western shrubland landscapes are characterized today by ecosystem conditions that promote wildfire frequencies that are much higher than under pre-Euro-American conditions. In sagebrush steppe and desert shrubland systems, major causes of degradation have been poorly managed livestock grazing and the introduction of nonnative annual grasses (such as cheatgrass, *Bromus tectorum* L.). These grasses cure earlier than native species and provide a continuous, highly flammable fuelbed that links shrubs and trees across erstwhile open spaces of soil (Pyke et al. 2015). In California's Mediterranean climate zone, chaparral ecosystems, fuel loads, and continuity (and hence fire severity) are naturally high, but lightning is rare. High numbers of human ignitions in some areas have increased fire frequency to the point that woody vegetation has difficulty reestablishing, and the resulting invasion of nonnative grasses and forbs is increasing fire risk and threatening a long list of species and ecosystem services (Underwood et al. 2018). Furthermore, those increases in fire frequency have been compounded by increases in other stressors, including nitrogen deposition. The combined effects threaten the viability of many animal and plant populations and amplify soil and carbon loss, stream sedimentation, and air pollution (D'Antonio and Vitousek 1992, Underwood et al. 2018).

In shrubland landscapes, postfire intervention is often restricted to immediate emergency actions (burned area emergency response, or BAER) related to erosion and sedimentation, flooding and debris-flow risk, and control of high-profile invasive species. Interventions for longer term ecological restoration purposes are comparatively rare because many shrub species resprout, and management focus tends to be on trees. Where shrubs do not rapidly resprout or otherwise recolonize, restoration efforts in California shrublands have had limited success (Allen et al. 2018, Svejcar et al. 2017). In sagebrush steppe, restoration success correlates with soil temperature and moisture regimes, and ecological rationales for longer term postfire restoration can range from reconnecting habitat patches or reducing tree cover to improve sensitive species habitat, to strategically reducing fuels to limit future wildfire spread, to invasive species control (Pyke et al. 2015). In chaparral shrublands, longer term restoration interventions are carried out for similar purposes, but often with more focus on ecosystem services related to human recreational uses, water provision, reduction of erosion and flooding, and human safety (Safford et al. 2018).

Semiarid forests—

Changes in fire-severity patterns are also presenting major challenges to the resilience and sustainability of California's forested ecosystems. In California's semiarid forests (i.e., most coniferous and mixed-conifer/hardwood forests that lie within the Mediterranean climate zone of California), wildfires before Euro-American colonization were dominated by low- and moderate-severity effects (Safford and Stevens 2017, van Wagtendonk and Fites-Kaufman 2006). Such effects were consistent with burning practices by indigenous peoples of California (Anderson 2018). High-severity (stand-replacing) burning was comparatively rare in these forests, and mean high-severity patch sizes were typically much less than 10 ac (4 ha) (Meyer 2015, Safford and Stevens 2017). Today, the likelihood of very large fires is increasing in response to warming climate as well as fuel accumulation resulting from a century of fire suppression (Stavros et al. 2014). Such large fires tend to have large stand-replacing burn patches (Miller et al. 2012, Reilly et al. 2017). A trend toward larger areas of high-severity fire has been reported for both the Sierra Nevada (Miller and Safford 2012) and northwestern California (Miller et al. 2012), and an increase in mean high-severity patch size is apparent across most of the state over the past 30 years (Steel et al. 2018). High-severity patches thousands of hectares in size have become common in recent years, with salient examples occurring in the 2007 Moonlight Fire, 2013 Rim Fire, and 2014 King Fire (fig. 1.3).

In semiarid forest types, large patches of high-severity fire are of management concern because they are outside the natural range of variation (NRV; see definition in box 1A) (Meyer 2015, Safford and Stevens 2017), are difficult for nonserotinous conifers to recolonize postfire (Shive et al. 2018, Welch et al. 2016), and may grow larger in subsequent wildfires (Lauvaux et al. 2016). In California montane forests,

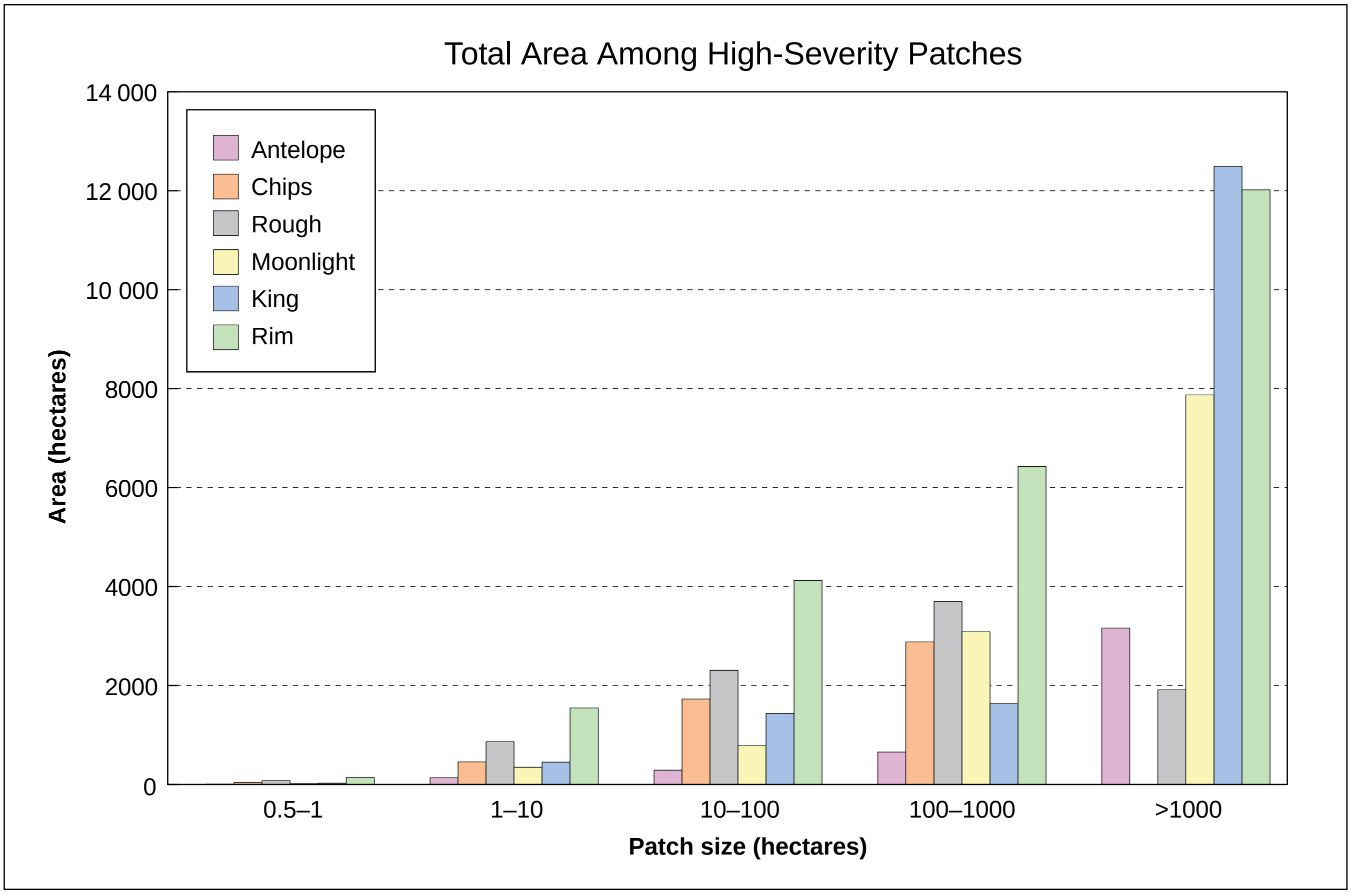

Figure 1.3.—Total area of large high-severity patches by patch size from recent wildfires (2007 to 2015) in dry mixed-conifer forests of California. Based upon data compiled by Jamie Lydersen.

shrub recruitment after high-severity fire is substantial, and the high flammability and continuity of postfire shrub-fields (also called montane chaparral) lead to a tendency for such sites to continue to support high-severity burning in subsequent fires. Such severe reburns can greatly inhibit conifer regeneration and lead to a persistent conversion away from conifer forest (so-called type conversion) (Coppoletta et al. 2016, Lauvaux et al. 2016, Tepley et al. 2017). This pattern is likely to be exacerbated as the climate warms and seasonal and annual droughts become more severe (Tepley et al. 2017, Welch et al. 2016). Large, contiguous and persistent areas of shrubs induced by high-severity fire can negatively affect a number of forest ecosystem services, including conifer recruitment (Werner et al. 2019, Young et al. 2019), snowpack retention (Stevens 2017), carbon sequestration (North and Hurteau 2011), and habitat for old-forest associated wildlife species (Stephens et al. 2016).

Arguments for long-term (years to decades) postfire restoration of forests can be based on both ecological and economic considerations (Lindenmayer and Noss 2006, Long et al. 2014, Sessions et al. 2004). Short-term (months to a few years) postfire

Box 1A:
Natural Range of Variation

The Forest Service 2012 Planning Rule places heavy emphasis on the concepts of sustainability and ecological integrity. In the rule, sustainability is defined as "the capability of ecosystems to maintain ecological integrity" (36 CFR 219.19: 21272). Ecological integrity is defined as follows:

> The quality or condition of an ecosystem when its dominant ecological characteristics (for example, composition, structure, function, connectivity, and species composition and diversity) occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influence (36 CFR 219.19: 21271).

Thus, assessments of ecological integrity inherently require the determination of the natural range of variation (NRV).

The NRV was defined by Landres et al. (1999) as "the ecological conditions and… spatial and temporal variation in these conditions that are relatively unaffected by people, within a period of time and geographical area appropriate to an expressed goal." Historical range of variation (HRV) is a related concept that was defined by Wiens et al. (2012) as "the variation of ecological characteristics and processes over scales of time and space that are appropriate for a given management application." The HRV was developed to permit explicit consideration of human influences on ecosystems. In practice, NRV and HRV assessments are often identical in the United States because it is often difficult to determine what system dynamics would have been in the absence of American Indian influences.

NRV is defined in the Forest Service Handbook 1909.12, the Land Management Planning Handbook:

> The variation of ecological characteristics and processes over scales of time and space that are appropriate for a given management application. In contrast to the generality of historical ecology, the NRV concept focuses on a distilled subset of past ecological knowledge developed for use by resource managers; it represents an explicit effort to incorporate a past perspective into management and conservation decisions... The pre-European influenced reference period considered may need to be several centuries to include the full range of variation produced by dominant natural disturbance regimes such as fire and flooding, while also considering short-term variation and cycles in climate. The NRV is a tool for assessing the ecological integrity and does not necessarily constitute a management target or desired condition. The NRV can help identify key

structural, functional, compositional, and connectivity characteristics, for which plan components may be important for either maintenance or restoration of such ecological conditions.

NRV and HRV assessments (hereafter called NRV) provide baseline information on ecosystem conditions (composition, structure, and function) that can be compared to current conditions to examine trends over time and to assess the level of departure of altered ecosystems from their "natural" state (Landres et al. 1999, Manley et al. 1995, Morgan et al. 1994). NRV assessments are used by managers to bring insights from historical ecology to resource management (Hayward et al. 2012). NRV characterizes variations in ecosystem function, structure, and composition over scales of time and space. The basic purpose of NRV is to define the bounds of ecosystem behavior or trends in those bounds. As Morgan et al. (1994) put it: "The concept of HRV (NRV) provides a window for understanding the set of conditions and processes that sustained ecosystems prior to their recent alterations by humans." In California, practical thresholds for when Euro-American influence became so profound as to constitute a significant departure vary considerably; a recent study noted important changes in fire dynamics around 1775, 1865, and 1904 just within the Sierra Nevada (Taylor et al. 2016). Morgan et al. (1994), Manley et al. (1995), Landres et al. (1999), and Wiens et al. (2012) list the purposes of conducting NRV assessments and the issues that must be considered in the assessment. These include the ecosystems of interest, the spatial and temporal scales of analysis, the ecological indicators to be assessed, whether or not to include human influences, and whether to use only historical information or to use contemporary reference conditions and modeling as well. Under rapidly changing environmental conditions, the applicability of reference conditions identified by NRV analysis will be reduced in many cases (Millar et al. 2007). In such cases, historical ecological information is still important (e.g., to define trends, to identify mechanisms for change, etc.), but NRV-based management targets may require modification, or they may be treated as "waypoints" rather than "endpoints" (Safford et al. 2012). The concept of future range of variation may be useful as a way to consider the interplay between how ecological indicators may vary owing to future drivers of disturbance as well as social acceptability, although it is inherently much more dynamic than NRV (Duncan et al. 2010). While these concepts are important, datasets based upon NRV are often relatively coarse, posing challenges for evaluating conditions within small analysis areas. Recent examples of general NRV assessments in California include Safford and Stevens (2017) and Meyer and North (2019). McGarigal et al. (2019) used forest successional models based on historical reference information to develop a spatial hypothesis of NRV for a watershed in the Sierra Nevada.

interventions such as tree harvest (salvage logging) and associated replanting efforts are often motivated by the desire to recover burned trees as wood products and longer term desires to guide or accelerate forest succession and manage fuel profiles (Leverkus et al. 2018). A major concern in California is the potential for severely burned forestlands to remain dominated by large shrub fields for long periods after fire and to be maintained as shrubs by subsequent fires (see above). Another key concern is the potential for insufficient conifer regeneration, particularly of pine species that may be dispersal limited or outcompeted by more shade-tolerant taxa such as white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) that can better tolerate rapidly expanding shrub canopies. Collins and Roller (2013) and Welch et al. (2016) reported that success of conifer regeneration, particularly of pine, was poor in many high-severity burn patches in recent wildfires in the Sierra Nevada and southern Cascade Range.

Need for New Framework

For many years, the U.S. Forest Service has relied on a set of relatively conventional approaches for managing postfire landscapes, especially those dominated by forests. These approaches were developed under past environmental conditions (e.g., cooler, more stable climate) to meet management objectives focused primarily on economic recovery, reforestation, fuels management, and community and infrastructure protection (Peterson et al. 2009, Ryan and Hamin 2008). In contrast, current national forest management considers even broader objectives to meet socially desired conditions for natural, cultural, and socioeconomic resources. Many of these objectives and desired conditions emphasize the restoration or maintenance of essential ecosystem services, such as water quality and quantity, soil productivity, watershed stabilization, biodiversity, wildlife habitat, wood products, renewable energy, community protection, recreation, aesthetics, and carbon sequestration (Underwood et al. 2018, USDA FS 2015). These diverse objectives are reflected in recent land management planning direction for national forests and other federal lands (Long et al. 2014, Miller et al. 2014, Pyke et al. 2015, USDA FS 2012), and in guidance for adapting to climate change (Joyce et al. 2009, Peterson et al. 2011, Swanston et al. 2016, Vose et al. 2019). However, a management framework focused on postfire landscapes where wildfires have resulted in conditions outside the NRV has been lacking for national forest lands in the United States. Such a framework is critical, especially in the Western United States, as climate warming accelerates, human populations grow, and the area of ecosystems burned by uncharacteristically severe wildfires increases (Westerling et al. 2006). Postfire restoration efforts to mitigate similar wildfire and ecosystem degradation trends in the Mediterranean

A management framework focused on postfire landscapes where wildfires have resulted in conditions outside the natural range of variation has been lacking for national forest lands in the United States.

Basin (e.g., Alloza et al. 2013, Moreira et al. 2012)—a region with similar climate and ecosystems to the westernmost United States—have partly inspired this effort in California.

Purpose of Framework

This document proposes a science-based, postfire ecological restoration framework for national forests in California. The framework is rooted in ecological restoration principles designed to enhance or recover ecological integrity and is guided by legislation and agency policy and direction (see below). The framework does not explicitly address safety and socioeconomic considerations (e.g., hazard tree removal, infrastructure improvements, and recreation), which are largely beyond the scope of this document, except where those concerns are inherently tied to ecosystem integrity and sustainability. The general concepts and approaches in this framework may be applicable to other jurisdictions and regions of the Western United States and across the globe (Lindenmayer et al. 2016). Although we focus on national forest lands, restoration of many landscape values (e.g., watershed function, habitat connectivity) depends upon approaches that facilitate management across ownerships. Such perspective considers the larger burned and unburned landscape, often including several contiguous watersheds or other landscape units (which might include terrestrial vegetation types or fire management units). For example, many national forests have engaged in planning strategic responses to fires based upon potential control locations, which leads to designation of potential wildland fire operational delineations, or "PODs" (O'Connor et al. 2016). Such landscape perspectives require not only considering broad spatial patterns, but also collaborative partnerships to engender successful management outcomes across administrative boundaries.

We focus on the postfire restoration of terrestrial rather than aquatic ecosystems but recognize the importance of streams, lakes, wetlands, and other aquatic ecosystems in the context of larger landscape-scale ecological processes and the delivery of numerous ecosystem services. This framework is focused on medium- and long-term, postfire management. The immediate response to severely burned landscapes on national forests is addressed through the U.S. Forest Service BAER program, which responds to the emergency need to protect life, property, and critical natural and cultural resources immediately postfire using emergency soil stabilization and other methods (Long et al. 2014). In contrast, this document addresses longer term (years to decades) restoration objectives. The framework is complementary to the BAER process as it builds from existing rehabilitation treatments and relies on initial BAER assessments for important postfire information (e.g., soil and vegetation burn severity data).

Applicability to Other Disturbances

This report focuses on post-wildfire restoration, because modern wildfires have become such a widespread and profound disturbance and have been the subject of considerable research. However, the framework and principles outlined in this report can translate to other kinds of major natural disturbances that affect wildlands, including blowdowns, volcanic eruptions, disease and insect outbreaks, and extreme droughts. Such disturbance events raise similar concerns about ecosystem recovery and appropriate management interventions. In recent years, there has been a renewed focus on restoration of natural fire regimes on national forests (North and Keeton 2008), often by striving to emulate the frequency, intensity, size, and arrangement of fires that occurred prior to Euro-American colonization. Such regimes have been described in recent reports for yellow pine (*Pinus ponderosa* Lawson & C. Lawson and *P. jeffreyi* Balf.) and mixed-conifer (Safford and Stevens 2017) and red fir (*Abies magnifica* A. Murray bis) (Meyer and North 2019) vegetation types. Postdisturbance interventions under such frameworks may be justified as a means of addressing the impacts of past or ongoing human impacts, such as the general lack of large trees due to logging, the excessive accumulation of fuels and high tree density due to long-term fire exclusion, air pollution and nutrient deposition, and the introduction of exotic species. Climate change adaptation may also be a major reason for intervening on landscapes after they are affected by large-scale or severe disturbances.

In recent decades, the combination of drought and bark beetle outbreaks has matched or even superseded wildfire as a cause of large-scale tree mortality in California. Both wildfires and beetle-driven mortality have potential to generate large and connected patches of heavy woody fuels that could fuel future large, high-severity fires (Stephens et al. 2018). However, the effects of bark beetles differ from wildfire in several important ways (box 1B).

Guiding Restoration Principles

The following science-based ecological restoration principles are fundamental to the development of restoration strategies on postfire landscapes:

Restoration Focuses on the Reestablishment of Key Ecological Processes to Provide for Long-Term Ecosystem Integrity and Function

In the 2012 Forest Service Planning Rule, ecological integrity is defined as "the quality or condition of an ecosystem when its dominant ecological characteristics occur within the natural range of variation and can withstand or recover from most perturbations imposed by natural environmental dynamics or human influence"

Box 1B:
Differences in the Effects of Wildfires and Bark Beetle Outbreaks on Forest Ecosystems

Forest dynamics can differ substantially on landscapes affected by high-severity wildfire versus bark beetle outbreaks:

1. Wildfire disproportionately kills smaller trees, while bark beetles (e.g., *Dendroctonus* spp.: western pine beetle [*D. brevicomis*], mountain pine beetle [*D. ponderosae*], Jeffrey pine beetle [*D. jeffreyi*), and fir engravers (e.g., *Scolytus ventralis*)—currently the most damaging insects in California's forest ecosystems—often selectively target larger trees and leave saplings and seedlings unscathed (Egan et al. 2016, Ferrell et al. 1994).
2. Beetle outbreaks rarely result in tree regeneration failure because of the high survival of small tree size classes even in heavily affected stands (Fettig et al. 2019, Young et al. 2020). In contrast, tree regeneration failure frequently occurs in larger patches of high-severity fire that can eliminate all tree age classes and a sizeable proportion of the conifer seed crop (Collins and Roller 2013, Welch et al. 2016).
3. Most beetle species selectively target specific host species, whereas fire tends to be a more generalist mortality agent (although fire-intolerant taxa like firs die at notably higher rates than pines). Recent major beetle outbreaks in California have featured major losses in medium- to large-diameter pines (particularly ponderosa pine and sugar pine), whereas fir engraver outbreaks proportionately reduce fir density across a range of tree size classes (Fettig et al. 2019, Restaino et al. 2019).
4. Soil and forest floor impacts are very different between the two disturbances. Wildfire consumes the forest floor, creating potential for erosion in the short term, as well as exposing mineral soil that is important for regeneration of trees and other plants. Loss of the forest floor temporarily breaks the carbon input link between vegetation and soil and reduces heterotrophic respiration in the litter layer and below ground. Carbon and nitrogen are volatilized, and cations are usually quickly lost in postfire runoff (although nitrogen and cations may be temporarily concentrated at the soil surface after the fire) (Safford and Vallejo 2019). On the other hand, beetle-driven mortality increases forest floor cover through input of dead biomass and accelerates the delivery of carbon to decomposers and the soil.
5. Unlike in wildfires, the surface fine-fuel component is not reduced by beetle-caused tree mortality and can even increase. In addition, although both disturbances ultimately contribute to increases in the large-diameter

Continued on next page

fuel component, fires consume some of the tree biomass (typically 10 to 25 percent of standing carbon is combusted in high-severity fires) (e.g., Maestrini et al. 2017).

6. Successional processes after the two disturbances may be very different and lead to alternative successional outcomes:
   a. In the case of bark beetle outbreaks, where broadleaf tree species are present they are not affected and can rapidly dominate the tree canopy.
   b. A lack of exposed mineral soil favors regeneration of firs (*Abies* spp.), incense cedar (*Calocedrus decurrens* (Torr.) Florin), and oaks (*Quercus* spp.), which may replace pines in postdisturbance forests, especially in untreated (not mechanically thinned or prescribed burned) ponderosa pine and mixed-conifer stands prior to beetle outbreaks (Young et al. 2020).
   c. Following moderate- or high-severity fire, broadleaf trees are usually top-killed, but their ability to resprout gives them a substantial head start on most western conifer species, only a few of which resprout (e.g., redwood [*Sequoia sempervirens* (Lamb. ex D. Don) Endl.], yew [*Taxus brevifolia* Nutt.], and bigcone Douglas-fir [*Pseudotsuga macrocarpa* (Vasey) Mayr]). Hotter fires kill proportionally more firs and incense cedar than pines (especially in smaller size classes), but this may make little real difference to forest succession in the long term, as shade-tolerant species make up most of the biomass and produce most of the seeds in modern, fire-excluded forests.
   d. Hot fires also tend to greatly stimulate postfire shrub response, which increases competition for light and water with regenerating conifers. Dense shrub layers that remain long-unburned can inhibit conifer survival and lead to an emergent canopy dominated by shade-tolerant and fire-intolerant species such as firs and incense cedar. Montane chaparral species are highly flammable at maturity and can create severe fires (when ignitions occur and live fuels are dry) that reset succession (Coppoletta et al. 2016).
   e. Strong shrub response to beetle-affected stands in California is generally rare, because regeneration and resprouting of many shrub species are stimulated by the direct effects of fire (e.g., heat, smoke, ash).
7. Effects on biodiversity are likely to differ between wildfire and bark beetle outbreaks because of the differential effects on ecosystems and habitats such as those described above (e.g., increased shrub and herbaceous plant response after wildfire but not bark beetle outbreaks).

(USDA FS 2012). The natural range of variation is generally defined in the Forest Service planning directives as spatial and temporal variation in ecosystem characteristics under historical disturbance regimes during a reference period or from a reference location (box 1A). Composition, structure, and function represent the dominant ecological characteristics of ecosystems. Although restoration efforts often focus on composition and structure, ecosystem function—the collective ecosystem processes and interactions that contribute to ecosystem self-maintenance and self-renewal—is most critical to ecosystem integrity (SER 2004). Some examples of key ecological processes in terrestrial ecosystems include soil stabilization (i.e., resistance to erosion) and development, microclimate regulation, nutrient and water cycling, decomposition, mycorrhizal symbiosis, pollination, seed dispersal, and natural disturbance regimes. Management approaches that sustain key ecological processes will contribute most to enduring ecosystem integrity and sustainability on postfire landscapes. Additionally, postfire restoration strategies that encourage spatial heterogeneity and other important structural and compositional features across the landscape may enhance ecological integrity, notably in forest ecosystems characterized by frequent fire regimes (North 2012, North et al. 2009).

Management approaches that sustain key ecological processes will contribute most to enduring ecosystem integrity and sustainability in postfire landscapes.

Restoration Is Planned on a Landscape Scale With Locally Implemented Restoration Projects Contributing to Landscape Restoration Goals

Restoration on postfire landscapes is ideally planned and implemented considering the larger landscape context and biophysical features encompassing the burned area (Long et al. 2014). This spatial context would be sufficiently large to include surrounding watersheds, potential operational delineations, wildlife habitat core areas, and other topographic features or management areas relevant to the postfire landscape. This may include fire-excluded areas outside the fire perimeter that are spatially connected to the burned area but substantially departed from their natural fire regimes, requiring a combination of pre- and postfire restoration approaches across the landscape. This broader context is important because wildfires influence landscape-scale processes beyond their perimeters, such as runoff, sedimentation, smoke dispersion, future wildfire spread, nutrient cycling, propagule dispersal, and plant and animal population dynamics (Okin et al. 2015). Many individual restoration projects will be designed based on localized conditions, but ideally they would collectively contribute to landscape-scale restoration goals.

Restoration Supports Regional Native Biodiversity and Habitat Connectivity

Critical to restoration efforts on postfire landscapes is the maintenance or enhancement of biodiversity and habitat connectivity (Lindenmayer et al. 2016). Species conservation strategies and recovery plans may guide restoration efforts designed to maintain or restore habitat for species of conservation concern. Alternatively, regional native biodiversity goals may emphasize heterogeneous habitat conditions that support diverse flora and fauna across the landscape, including species associated with early-, mid-, and late-successional habitats and uncommon vegetation types (e.g., aspen, wet meadows). This emphasis on community diversity serves as a counterweight to single-species management approaches that emphasize species of conservation concern (e.g., California spotted owl [*Strix occidentalis occidentalis*]) or other unique species. Such focal species tend to be poor indicators of species diversity patterns in terrestrial communities (White et al. 2013) or unrepresentative of ecosystem integrity or function (Caro 2010, Simberloff 1998). An emphasis on "regional" biodiversity underscores the importance of broad scales when attempting to meet goals related to biodiversity. Part of this consideration of species habitat includes regard for dynamic habitat connectivity within and among landscapes under current and future conditions, including climate change scenarios (e.g., Spencer et al. 2016).

Restoration Employs a Pragmatic and Balanced Approach to Sustain Diverse Ecosystem Services

California's national forests provide critical ecosystem services to the state's growing population, which is approaching 40 million people. Many of these ecosystem services support important economic activities (e.g., wood products, recreation), help to safeguard the environment (e.g., carbon sequestration, soil formation, and sediment retention), maintain cultural resources (e.g., plants of importance to American Indian tribes), and provide many other benefits for human well-being (e.g., air and water quality) (Patterson 2014). However, on severely disturbed landscapes, ecosystem services can be substantially affected, resulting in important socioeconomic and other consequences that may be exacerbated by climate change (Hurteau et al. 2014; Stephens et al. 2013, 2014). On postfire landscapes, it is important to sustain or enhance ecosystem services to continue to provide long-term benefits to the public. Recognizing potential tradeoffs and constraints relevant to burned and unburned landscapes (Patterson 2014), we recommend a pragmatic approach that considers priority ecosystem services to maximize public benefits (e.g., Clewell and Aronson 2006, Nelson et al. 2009). This balanced approach is designed to consider multiple ecosystem services in restoration planning and implementation. It also recognizes that practical constraints common to large, disturbed landscapes (e.g., insufficient agency capacity, funding, and site accessibility) may limit the scale and scope of restoration efforts, as discussed in North et al. (2015) and Ryan et al. (2013). Even under constrained scenarios, postfire restoration efforts can be strategically designed to contribute to long-term ecosystem integrity and resilience that will sustain essential ecosystem services for future generations under scenarios of global change (Hurteau et al. 2014, Pace et al. 2015).

Restoration Is Based on Prioritization

Numerous constraints limit the ability of land managers to achieve all restoration objectives on postfire landscapes, especially when considering multiple, interacting agents of change. Consequently, managers often establish restoration priorities (i.e., key resources, priority areas on the landscape) to provide a focused and effective management response. One prioritization approach would be to concentrate management on resources and areas where there may be a higher probability of success (e.g., focusing reforestation efforts on severely burned forest in areas of low moisture stress, or treating invasive species where they have recently appeared) to encourage successful restoration outcomes. Another approach is to prioritize the most vulnerable areas or resources for intervention, such as facilitating vegetation recovery in severely burned patches where moisture stress is high, or treating invasive species where they are most likely to cause degradation. A third approach is based on bet hedging, or testing a portfolio of different or climate adaptation actions (see below) on different parts of the landscape and evaluating the outcomes to maximize learning and the probability that at least some of the efforts will have success. This third method has been recommended in situations of high uncertainty, such as on altered landscapes or in areas greatly affected by climate change (Millar et al. 2007, Swanston et al. 2016). Managers may consider combinations of these different approaches in an attempt to balance overall risks and rewards. Under any approach, effective prioritization will require consideration of restoration goals, landscape condition, adaptive capacity of target ecosystems, feasibility, and other factors.

Restoration Recognizes and Adapts to Agents of Change, Including Climate Change

Thoughtfully planned, ecological restoration in the 21st century involves preparation for the future more than a re-creation of the past (Clewell and Aronson 2006, Hanberry et al. 2015, Safford et al. 2012b). Altered fire regimes, insect and pathogen outbreaks, invasive species, air pollution, habitat loss and fragmentation, and climate change are major agents of change in California's ecosystems. These agents interact in synergistic ways that can greatly complicate restoration efforts. For example, forest stands infested by the sudden oak death pathogen (*Phytophthora ramorum*) in coastal northern California are made much more susceptible to subsequent severe wildfires because of elevated fuel levels, and such fires are more likely to occur under climate warming and longer fire seasons (Forrestel et al. 2015).

Climate change adaptation refers to responses that can reduce the impacts of climate change rather than mitigate its causes. Climate change adaptation strategies include actions that promote ecosystem resistance (the ability to withstand a perturbation with minimal change in essential characteristics), enhance resilience (the ability to rebound from major perturbations), or guide ecosystem realignment in response to climate change (Peterson et al. 2011, Stephens et al. 2010). Because much of the landscape may be in early-seral conditions, postfire landscapes can represent key opportunities to influence trajectories toward more ecologically and socially desirable conditions. Postfire landscapes may present important opportunities to apply, monitor, and test a variety of adaptation actions designed to improve landscape resilience. This may include implementation of current approaches, such as carefully timed prescribed burning of planted areas; modification of existing techniques, such as selecting fire- and drought-adapted genotypes for planting and planting in variable spatial arrangements; and potentially more novel climate adaptation strategies, such as translocation of species or genotypes from outside a geographic region (Safford et al. 2012a, Vose et al. 2019). It may also include an adjustment to management goals for severely burned landscapes rather than managing for the historical range of variation. For example, there could be persistent conversion of forest to nonforest if trees cannot feasibly be reestablished under a warmer and potentially drier climate (Stephens et al. 2010, 2013). Additional tools such as postfire ecological assessments, scenario planning exercises, climate vulnerability assessments, future range of variation assessments (box 1A), traditional ecological knowledge, and other adaptation planning tools (Nydick and Sydoriak 2011, Wiens et al. 2012) can help enhance the ability of ecosystem managers to build adaptive capacity on burned landscapes (Meyer et al. 2015).

Postfire landscapes may present important opportunities to apply, monitor, and test a variety of adaptation actions designed to improve landscape resilience.

Collectively, these guiding restoration principles provide a foundation for developing effective postfire restoration strategies in the national forests of California that is responsive to the rapid changes and emerging challenges of the 21st century.

Elements of This Report

Based on the six guiding restoration principles described above, our conceptual framework for postfire restoration involves five steps, which are described in chapter 2, to support restoration project planning and implementation (fig. 1.4).

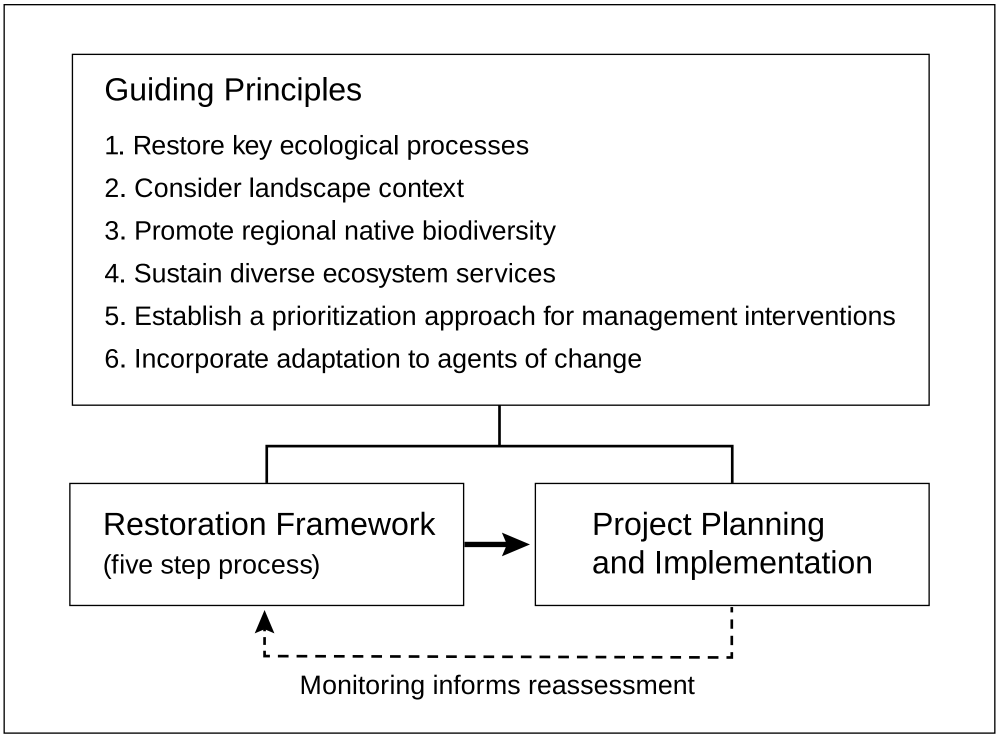

Figure 1.4—The postfire restoration framework is a five-step process that is founded on six guiding principles and leads to the development of project planning and implementation.

With this framework, teams of specialists identify restoration opportunities by answering sequential questions (the postfire flowchart) and develop a restoration portfolio with priority restoration activities for the postfire landscape (chapter 2). This is accomplished using relevant spatial data to evaluate landscape condition and trends (chapter 3), planning information (e.g., forest plans, conservation strategies), and input from an interdisciplinary team to identify and rank resource priorities and feasibility constraints. The restoration framework provides interdisciplinary teams with the information necessary to develop comprehensive project plans, identify tactical approaches (e.g., assisted regeneration), and execute focused ecological monitoring (for reassessment and adaptive management) that will support landscape restoration goals. During project planning, additional considerations outside the scope of this document (e.g., safety, economics, organizational capacity, operational constraints) will be considered. Additional efforts are underway to illustrate how specific strategies and tactics may be applied based upon the restoration framework.

Chapters 4 through 6 present case studies that illustrate the development of postfire restoration strategies using the framework in different California ecosystems. Each case study follows the approach outlined in this publication with a focus on a single ecosystem type. However, restoration goals and objectives may be developed for multiple ecosystem types simultaneously under a single restoration strategy in more complex landscapes. The specifics of each case exemplify the diversity of issues and potential approaches that exist, and none of these case studies have yet been applied on a national forest to inform project planning. The first case study (chapter 4) is focused on coniferous forest ecosystems of the montane and coastal regions of California, historically dominated by frequent fire regimes within the Sierra Nevada, Southern Cascades, North Coast Range, and higher elevations of the Transverse and Peninsular Ranges. This example presents distinctive ecological considerations and challenges unique to forests, such as stand densification associated with long-term fire exclusion, postfire tree regeneration failure, operational and administrative constraints associated with conifer removal, and habitat management for forest-dependent wildlife species. The second case study (chapter 5) highlights chaparral and coastal sage scrub ecosystems in the southern and central coastal regions of California. This example presents unique issues and concerns related to elevated fire frequencies due to frequent human-caused ignitions, type conversion to invasive annual grassland, and amplified nutrient deposition from regional air pollution. The third case study (chapter 6) examines sagebrush steppe ecosystems in the eastern Sierra Nevada and parts of the Modoc Plateau. This example discusses various issues and challenges of sagebrush steppe, including tree encroachment after fire exclusion, management of habitat for the greater sage-grouse (*Centrocercus urophasianus*), and type conversion to cheatgrass (*Bromus tectorum* L.). Each case study provides a summary of key findings and recommendations that sets the stage for project planning and implementation.

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Chapter 2: Postfire Restoration Framework

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Introduction

Land managers grapple with a variety of questions concerning the management of burned landscapes. All fires more than 500 ac (200 ha), and smaller fires if critical values are involved, trigger a Burned Area Emergency Response (BAER) program assessment that addresses emergency stabilization in the first year, with possible maintenance treatments for up to 3 years. After assessments for BAER and postfire reforestation have been completed, years of rehabilitation and restoration may be conducted, including planting trees, reestablishing native species, restoring habitats, and treating invasive plants. These actions are expected to be consistent with the directions in individual forest plans and to meet requirements under the National Forest Management Act, the National Environmental Policy Act (NEPA), and other statutory authorities (see app. 1). As part of planning for recovery of burned landscapes, land managers may consider many key questions:

- What are the long-term restoration goals and key objectives for the landscape where the burn occurred?
- What management actions will be needed to address long-term forest sustainability?
- Will natural regeneration meet forest management objectives, or will active reforestation efforts be needed, and if so, where?
- Do residual fuel loads require management activities to mitigate future wildfire risk?
- Is habitat connectivity for forest-dependent species impaired?
- Are there administrative, logistical, or other constraints for particular restoration activities?

Answering these questions may be facilitated by the use of a logical, intuitive framework that helps to provide appropriate context and focus to the management of burned landscapes. This chapter describes one such framework. Ideally, an interdisciplinary team would apply this framework within a timeframe that aligns with BAER activities and informs potential postfire treatments (e.g., salvage,

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reforestation) that may be proposed and evaluated under NEPA. Moreover, the framework may be applied to other contexts, including slower moving disturbances such as drought-induced tree mortality.

This chapter presents a series of steps that lead to the development of a postfire restoration portfolio. These include (1) assembling a team and identifying priority resources and desired conditions, (2) gathering and analyzing relevant spatial data (see chapter 3), (3) using a postfire flowchart to identify restoration opportunities, (4) developing and integrating a list of potential management actions that take advantage of these opportunities, and (5) building a portfolio of potential restoration actions and prioritizing these actions based on timing, feasibility, opportunity cost, and level of integration. The restoration portfolio provides a sequential plan for project implementation, including both long- and short-term actions. The restoration portfolio also documents management considerations that can be used to develop and refine additional restoration actions. This process is shown in figure 2-1; individual steps are described in more detail below.

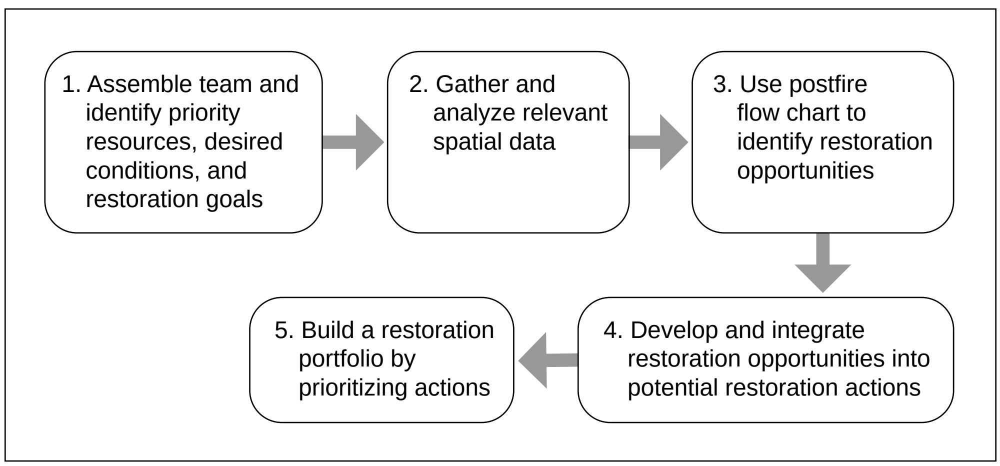

Figure 2.1—Process diagram of the postfire restoration framework.

Step 1: Assemble a Team and Identify Priority Resources, Desired Conditions, and Restoration Goals

The first step is to assemble a knowledgeable team of specialists. Important team skills include familiarity with the local ecological setting (including unique and valued natural resources), understanding of vegetation succession and restoration, knowledge of forest priorities and constraints, and ability to analyze Geographic Information Systems (GIS). Assembling a team with diverse resource specializations (e.g., ecology, GIS, fuels, silviculture, wildlife, botany, soils, hydrology, aquatics, and others) would help to address the many dimensions of postfire environments, and ideally the team will include individuals familiar with BAER efforts for the fire. Collaboration, effective communication, and clear documentation of methods and decisions would help to explain the approach and facilitate future evaluations.

Once a team of specialists is assembled, priority resources and desired conditions can be identified, often with direction from line officers. Priority resources are high-value natural resources and assets located within the management area of interest, which may include one or more land management units such as ranger districts or national forests. Desired conditions are specific ecological characteristics or conditions that may be maintained or restored through management. Desired conditions, priority resources, and other important land management direction (e.g., standards, guidelines, potential management approaches) are provided in land and resource management plans (LRMPs), with supplementary information available in supporting planning documents such as forest or bioregional assessments, landscape or watershed assessments, environmental impact statements, fire management plans, natural range of variation (NRV) assessments, and science syntheses (e.g., Long et al. 2014, Safford and Stevens 2017). Reducing the list of priority resources and desired conditions to those most relevant for the landscape being evaluated will help focus the effort. Lastly, the identification of overarching ecological restoration goals and objectives (hereafter referred to collectively as "goals") is critical for a comprehensive vision for postfire management. These goals can be obtained from LRMP direction (e.g., forestwide desired conditions, goals, and objectives for terrestrial ecosystems) and other planning documents noted above and refined for the landscape of interest based on interdisciplinary team discussion. In later steps (step 3 or 4), restoration goals can be linked with specific restoration opportunities or more broadly applied across opportunities.

Identifying overarching ecological restoration goals and objectives is critical for a comprehensive vision for postfire management.

Step 2: Gather and Analyze Relevant Spatial Data

The process of gathering and analyzing relevant spatial data is described in chapter 3. Spatial data and other information are needed to identify restoration opportunities (step 3).

Step 3: Use the Postfire Flowchart to Identify Restoration Opportunities

The postfire flowchart (fig. 2.2) provides a rationale for developing a suite of restoration actions in response to the range of effects caused by the fire. Using the postfire flowchart will help the team identify specific spatial data outputs necessary

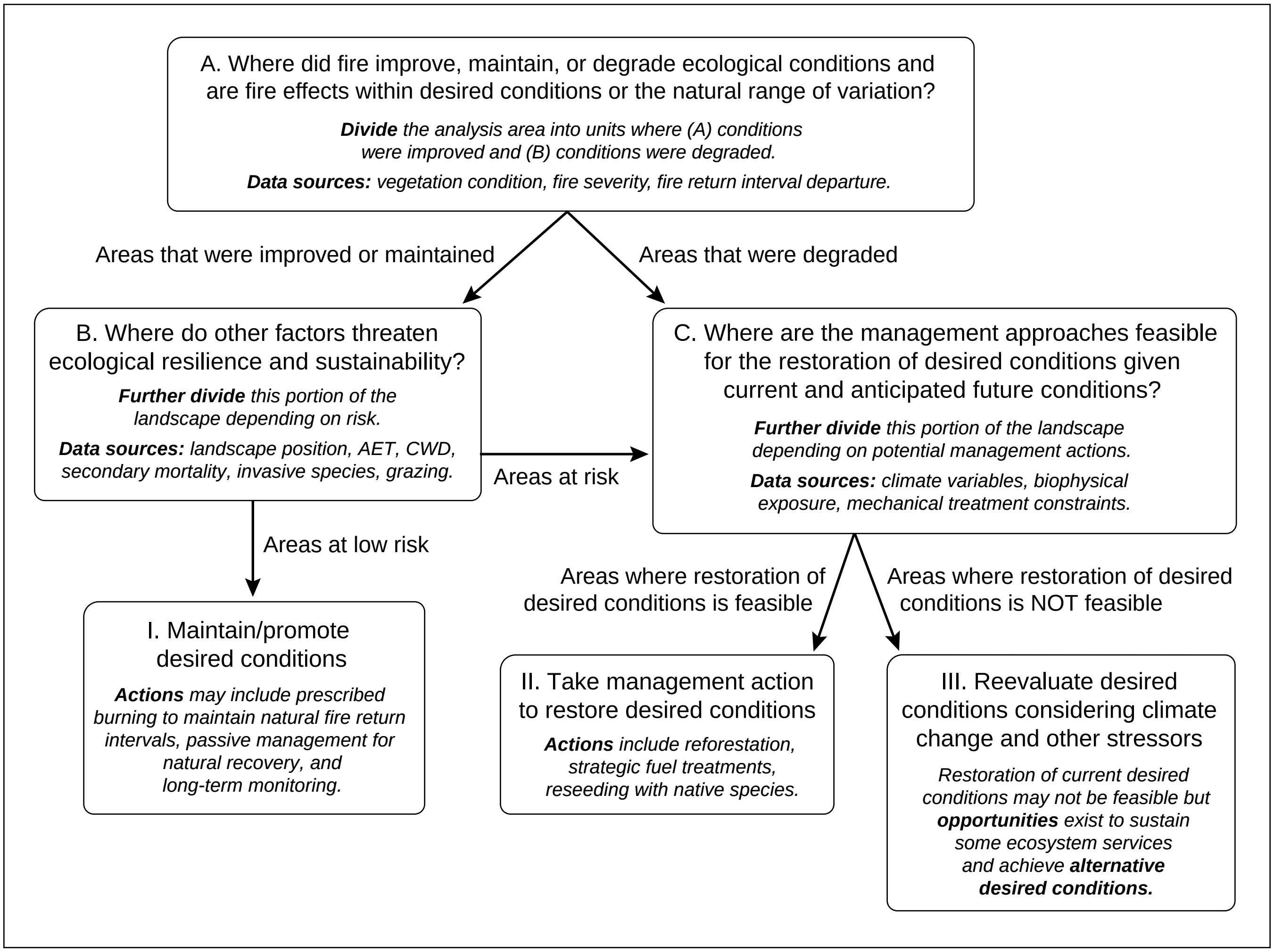

Figure 2.2—The postfire flowchart is based on three questions (A, B, and C) for the identification of management responses or “restoration opportunities” (1, 2, and 3) that support overarching restoration goals (e.g., promote or maintain native vegetation cover) in different portions of the postfire landscape. This framework represents the third step in the process diagram of figure 2.1.

to divide the postfire landscape into areas where fire improved or maintained ecological condition and areas where fire degraded ecological condition. Detailed methodologies for developing these outputs are described in chapter 3. Once the team has categorized the affected landscape according to fire effects, they can then consider restoration opportunities for these areas separately, allowing for the development of a diverse range of postfire restoration actions based on clearly articulated desired outcomes and restoration goals. Using the postfire flowchart will improve the quality of the decisionmaking process by analyzing ecologically similar areas separately while at the same time considering their role in the larger landscape.

Outputs from the data gathering and analysis step (chapter 3) that describe ecological conditions and stressors (i.e., current, future, and refined local conditions) are a primary data source for answering questions posed by the postfire flowchart. In addition to relying upon data products developed during the data gathering and analysis step (chapter 3), answering questions posed by the postfire flowchart will also require nonspatial data and local knowledge and expertise. In the following sections, we discuss each question posed by the postfire flowchart and provide examples of how these questions might be answered.

Question A: Where Did Fire Improve or Maintain Ecological Conditions, and Are Fire Effects Within Desired Conditions or the Natural Range of Variation?

The fundamental question posed by the postfire flowchart is "how did the fire affect ecological condition?" There are multiple answers to this question, depending on the resources identified in step 1, and by spatial variability in fire effects. Some parts of the landscape will have been negatively affected by the fire. Modern fires often degrade ecological conditions and move portions of the landscape away from desired conditions or outside the NRV. Common examples include large patches of high-severity fire in conifer forests (i.e., high proportion of overstory mortality) where desired levels of natural conifer regeneration are unlikely to occur over much of the area, areas where severe fire effects have homogenized vegetation and biodiversity, locations where soil erosion and stream sedimentation have drastically increased, or places where high fire frequency is overwhelming the ability of native species to regenerate successfully (e.g., in shrublands, vegetation dominated by serotinous species).

On the other hand, some parts of the landscape may have benefitted from fire. Although many people associate fire and other ecological disturbances with negative outcomes, many California ecosystems evolved with and depend on such processes (Keeley and Safford 2016). Despite the alteration of fire regimes across most ecosystems, the occurrence of wildfire can often have positive (or at least neutral) effects on ecological conditions, depending on factors such as weather, fuels, topography, and the ecosystem (and its condition) in question. For example, in areas with a long history of fire suppression, the occurrence of a single fire may move the landscape closer to the NRV for fire return interval, structural diversity, and the abundance of early-successional habitats and species. Because fires tend to have highly heterogeneous effects, even those that were catastrophic in their effects on human infrastructure may result in ecological benefits in some part of their footprint. By dividing the postfire landscape into areas that were negatively affected and those that were positively affected or not changed, the postfire flowchart permits customization of restoration and management opportunities for different portions of the landscape.

The question, “where did fire improve or maintain ecological conditions and are fire effects within desired conditions or the natural range of variation?” may be answered by reviewing the current vegetation condition, fire severity, and other data outputs described in chapter 3. These outputs can then be compared to desired conditions or NRV information as identified in step 1 above. The team clearly identifies what components of the ecosystem were affected by the fire, including consideration of factors for such priority resources:

- Is there a lack of essential structural components (e.g., sufficient tree or shrub cover, large trees, snags) to meet desired conditions?
- Are vegetation patch sizes, spatial heterogeneity, and habitat connectivity for forest-dependent wildlife species radically departed from NRV or desired conditions?
- Were current and expected future species compositions fundamentally altered? This includes evaluating not only the current suite of species present, but also factors that allow these species to persist, such as reproductive pathways (e.g., obligate seeding species) and key ecosystem components (e.g., specialized habitat features).

By separating the landscape into different units based on fire effects, the team can begin to identify where different restoration opportunities exist on the postfire landscape.

Question B: Where Do Other Factors Threaten Long-Term Ecological Resilience and Sustainability?

For areas where the fire improved or maintained ecological condition, the postfire flowchart asks whether other conditions, not directly related to the fire, may ultimately jeopardize the potential success of restoration efforts. To answer this question, the team considers factors that could affect restoration outcomes, recognizing that these factors may have different impacts depending on the time scale. Important factors that can influence restoration outcomes over the long term are current and probable future climatic conditions, and secondary mortality resulting from insect and disease outbreaks. Other factors that might be considered include the following:

- Fuel development—could be initially low, but depending on inputs such as snag and coarse woody debris production, could increase high-severity reburn potential and affect mid- to longer term forest sustainability (Stephens et al. 2018).
- Anthropogenic ignitions—could result in repeated fires at unnaturally short intervals or at inappropriate times of year when species are most vulnerable.

- Grazing regimes—could affect native plant species recovery or facilitate nonnative plant invasion, alter herbaceous fuel loads, and help to reduce nonnative species cover and thatch in annual grasslands.
- Invasive species—could displace native species, modify habitat, and result in fairly rapid development and connectivity of fuel, allowing for unnaturally frequent fire.

Identifying and analyzing data relevant to these questions are described in chapter 3.

Question C: Where Are Management Approaches Feasible for the Restoration of Desired Conditions Given Current and Anticipated Future Conditions?

This branch of the postfire flowchart addresses two areas on the postfire landscape: (1) areas where fire effects did not improve ecological condition and (2) areas where fire effects were positive, but where other factors jeopardize the probability of successful restoration (see questions A and B above). This question asks whether desired conditions can be restored through management actions, but it also invites the team to consider other factors (current and anticipated future conditions) that may affect the effectiveness of management. The data gathering and analysis step (chapter 3) includes an evaluation of some of these factors, such as biophysical exposure and changing climatic conditions. For example, fencing may be a feasible management approach to protect regenerating aspen (*Populus tremuloides* Michx.) from browsing until they can mature. However, in areas with high climatic risk where future climate projections suggest that aspen are unlikely to persist over the long term, the team will want to consider how this might alter the prioritization of these stands for fencing.

It is important to identify areas where the fire improved ecological conditions, areas where restoration of desired conditions is important and feasible, and areas where desired conditions may need to be reconsidered.

Restoration opportunity 1: maintain or promote desired conditions—An important step in planning restoration is to identify areas where the fire improved ecological conditions. For example, a fire may have promoted a more natural fire regime and desirable ecological heterogeneity. Conventionally, we concentrate our efforts on highly degraded areas, when instead our greatest restoration opportunities may be in places where ecological conditions improved or remained unaltered. It may be more effective to maintain or enhance an area in good condition than it is to restore one that has been heavily degraded (Hobbs et al. 2009). In addition to providing an opportunity to capitalize on positive effects where they occurred, these areas also present an opportunity to develop and implement a robust monitoring plan to evaluate fire effects and ecosystem function over the long term. For example, as part of an adaptive management framework, ecological monitoring could examine vegetation successional trajectories following fire (i.e., are existing conditions trending toward or away from desired conditions) or evaluate the effectiveness of pre- or postfire management actions.

Restoration opportunity 2: take management actions to restore desired conditions—

In areas where management approaches are feasible, especially where future anticipated conditions are auspicious, the team will likely have the greatest suite of opportunities for postfire restoration. Most teams will have a large and robust set of tools to apply in this situation. However, even in areas where anticipated future conditions may put restoration at risk, management actions may be able to address that risk, for example, by considering climate-smart reforestation (Nagel et al. 2017), strategic fuel treatments, or other approaches that address predicted future conditions (Millar et al. 2007a, Peterson et al. 1998, Swanston et al. 2016), including experimental approaches where outcomes are uncertain (box 2A).

Box 2A:
Experimental Approaches

There is considerable uncertainty in postfire ecosystem trajectories with and without management intervention. Experimentation using the following types of approaches can address this uncertainty and provide major insights into the management of postfire landscapes:

- Develop and test new and innovative approaches.
- Provide a logical framework for testing hypotheses, examining foundational assumptions, and addressing applied ecological questions.
- Encourage creativity, teamwork, and collaboration with researchers through science-management partnerships.
- Support the development of bet-hedging strategies that spread management risk and reduce overall impacts from large disturbances.

Experimental approaches frequently require active partnerships to integrate research and boundary-spanning science organizations for effective translation and integration of science information in postfire management activities. Yet, experimentation can fill critical information gaps and provide robust evaluations of restoration techniques and approaches before they are applied across larger project areas. These approaches can be embedded within a larger project, and are contingent on sufficient time, funding, and other resources to accomplish. For example, partnerships between researchers and managers on the Eldorado National Forest within the 2004 Power Fire (fig. 2.3)

Continued on next page

Restoration opportunity 3: reevaluate desired conditions considering climate change and other stressors—

In some areas, restoration of desired conditions may not be feasible, or alternatively, desired conditions may need to be reconsidered. For example, areas that burned at high severity with large patch sizes in lower elevation forests with low site potential or higher climatic water deficit may be at high risk of conifer-regeneration failure and type-conversion, especially under continued climate warming. In this case, restoring desired conditions for coniferous forest vegetation may not be feasible. However, many ecosystem services may continue to be provided by these landscapes if they can be realigned (sensu Millar et al. 2007b) with a trajectory that is more stable under developing conditions. For example, conversion of conifer- to hardwood-dominated vegetation often may maintain (or even improve) some specific ecosystem services, such as wildlife habitat, soil nutrient status, regional biodiversity, and watershed or landscape integrity, despite major changes

will compare trends with and without postfire treatments, including prescribed burning and thinning of resprouts on multistemmed black oaks (*Quercus kelloggii* Newberry). It is important to understand results from this experiment, such as, among other things, the impacts of reburns on forest vegetation under more moderate conditions associated with prescribed burning. Additional experimental interventions could be designed to elucidate patterns such as vegetation trajectories in riparian areas, the effectiveness of cluster planting for reforestation, and the impacts of climate change on postfire restoration efforts.

Jesse Plummer

Figure 2.3—Experimental prescribed burn in an area burned 14 years earlier by the Power Fire on the Eldorado National Forest.

in vegetation composition and structure (Millar and Stephenson 2015). Alternately, lost values associated with highly degraded ecosystems may potentially be restored elsewhere on the landscape, within the fire perimeter or outside it. Once a new suite of desired conditions have been developed for these portions of the landscape (often based on forest plan direction to help guide modification of desired conditions), the postfire flowchart can be reevaluated to identify restoration options for these newly defined conditions. The reevaluation of desired conditions may require adaptive management to guide plan shifts, and ultimately plan amendments if necessary.

Step 4: Develop and Integrate Restoration Opportunities Into Potential Restoration Actions

This step ideally begins with team brainstorming, literature reviews by individual resource specialists, and consultation with researchers and other experts. Encouraging open and creative thinking, including both known and experimental approaches, may be particularly important at this step to avoid prematurely discounting options based upon feasibility and logistics. This step is intended to generate an extensive list of potential actions that can take advantage of the restoration opportunities that address restoration goals identified in earlier steps. In some cases, a restoration opportunity exists only by targeting a specific place on the landscape, while in other cases, there may be multiple options for restoration and several pathways to success. Identifying multiple actions for each restoration opportunity and associated restoration goal will help identify avenues for project integration and allow for the development of a comprehensive restoration portfolio.

Potential restoration actions can be integrated in a number of ways, including grouping actions together according to geographic location, type of resource, or type of action. Organizing actions according to common restoration goals provides another foundation for integration. For example, actions with a similar goal of reducing the risk of future high-severity fire, such as reducing fuels in high-severity stands and reintroducing fire into areas that burned at low or moderate severity, could be logically integrated into a single potential action. The integration step is also a chance to identify when management actions proposed to address one goal may be counterproductive vis-à-vis another goal. For example, reducing fuels in high-severity stands (action) could reduce the risk of future high-severity fire (goal), but may not maintain habitat features for snag-dependent wildlife species (goal) unless the two goals are explicitly linked. In these cases, the team can revise and refine its list of management actions to develop a cohesive, integrated list.

Step 5: Build a Restoration Portfolio by Prioritizing Actions

The number of potential restoration actions that can be implemented will be limited by a number of factors, including staff capacity and financial and logistical constraints. These actions can be evaluated and prioritized according to their costs and benefits. A restoration portfolio is a way to identify and prioritize among potential restoration actions in order to develop a cohesive, integrated restoration strategic plan with a high probability of success (table 2.1). The section below provides some examples of the types of information that may be considered in the restoration portfolio, but is not meant to be comprehensive. Factors such as timing, feasibility, opportunity cost, and level of integration may vary considerably among ecoregions and vegetation types and will be dependent on the capacity of individual management units.

A restoration portfolio should identify and prioritize actions that can accelerate the scale, pace, and impact of restoration.

Timing

There is a specific timeframe within which a given restoration action is likely to be effective. It is particularly important to identify opportunities where immediate action is required before an area or resource crosses a threshold such that potential restoration actions may no longer be feasible or effective, whether it be from ecological, socioeconomic, or political viewpoints. Many restoration projects will require multiple, sequential steps (initial, intermediate, and longer term) to succeed, and if the incipient steps are delayed, longer term goals may not be met. Although some projects are best implemented soon after the fire, others may need to be implemented years after the fire (and may depend on earlier steps having been accomplished). Project plans will be more useful if they specify the timing of restoration actions and the timeframe within which a project and its steps would be implemented.

Feasibility

Consideration of policies, logistics, capacity, access, operability, land allocation, public support, and cost are all critical components to consider when prioritizing restoration opportunities. Are there regulations that make the project infeasible or ineffective? Are there external factors outside of the control of the manager that may threaten the success of the project? What level of planning is required? Does the project have measurable outcomes that can be used to build support? Does it have public or collaborative backing?

Table 2.1— Simplified example of a restoration portfolio, a suite of potential actions developed using the postfire flowchart (fig. 2.2) as indicated by letters and roman numerals corresponding to figures

Restoration opportunity	Restoration goal	Potential restoration actions	Target areas	Postfire flowchart Path	Timing	Feasibility	Cost of inaction	Level of integration
Maintain/ promote desired conditions (I)	Keep fire return intervals within natural range of variation	Prescribe burning at low to moderate severity, use of wildland fire	Where fire return interval, severity, and patch sizes are now within natural range of variation; biophysical and future climatic risk low	B→I	Variable depending on natural range of variation fire return interval	Low to moderate	Moderate to High	Meets desired outcomes for forest health, fuel reduction, wildlife, and rare plants
Take management actions to restore desired conditions (II)	Reduce the risk of future high-severity fire	Reduce fuels via mechanical removal and grapple piling	High-severity patches with low biophysical exposure	C →II	Mid term (5 to 10 year)	Low to moderate	Moderate	Meets desired outcomes for fuel reduction; needs specific design criteria to meet wildlife desired outcomes
	Reduce browsing in regenerating aspen stands	Fence aspen for 3 to 5 years	Aspen stand where fire promoted suckering, browsing pressure is high, and future climatic risk is low to moderate	B→C→II	Short term (3 to 5 years)	Moderate	High	Meets desired outcomes for forest health and wildlife
Reevaluate desired conditions considering interacting stressors	Maintain diverse shrub communities, nutrient cycling, soil stability	Long-term monitoring	Large, high-severity patches where future climatic risk is high, reforestation unlikely	C→III	Long-term (>10 years)	High	Low	Meets some wildlife habitat and watershed desired outcomes

Cost of Inaction and Opportunity Costs

When evaluating the need for potential restoration actions in postfire landscapes, it is important to consider the cost of inaction. To answer this, the team could evaluate the need for restoration in a broader context. For example, a small portion of the landscape degraded by the fire may be a low priority for restoration based on vegetation conditions alone (low cost of inaction). However, when evaluated in the context of habitat connectivity for a rare species, restoration of such an area may be considered important to avert local extirpation (high cost of inaction). In addition, because there are usually finite resources available for restoration, any choice made is at the expense of alternative choices. The magnitude of these opportunity costs can be minimized when projects serve multiple purposes and are linked to longer term desired outcomes (see next section).

Level of Integration

Potential restoration actions aim to achieve multiple goals, serve long-term purposes when possible, and reconcile competing goals. For example, reintroducing fire into areas that burned at low or moderate severity could, among other things, reduce fuels and the risk of future high-severity fire, safeguard large trees that store carbon and provide wildlife habitat, increase the probability of successful germination of fire-tolerant trees, promote broadleaf species such as oak or aspen, release important nutrients such as nitrogen, and increase understory biodiversity. Reintroducing fire would therefore be considered highly integrated because it achieves multiple goals. Documenting decisionmaking during the integration process will be important to communicate the level of integration to other stakeholders. Other questions to consider include the following: Does this action address multiple resource concerns? Does it consider other projects that have already occurred or are being planned in the area? Does it support the goals of one or more species conservation strategies? In most cases, an interdisciplinary and collaborative approach can accelerate the scale, pace, and impact of restoration.

Potential restoration actions aim to achieve multiple goals, serve long-term purposes, and reconcile competing goals.

Conclusions

The postfire restoration framework includes five steps that leads to the development of a postfire restoration portfolio. These steps include (1) assembling a team and identifying priority resources and desired conditions, (2) gathering and analyzing relevant spatial data, (3) using a postfire flowchart to identify restoration opportunities, (4) developing and integrating a list of potential management actions that take advantage of these opportunities, and (5) building a portfolio of potential restoration actions and prioritizing these actions based on several considerations. The restoration portfolio identifies three types of restoration opportunities for postfire landscapes (maintain or promote desired conditions, take management actions to restore desired conditions, and reevaluate desired conditions considering interacting stressors). This framework provides the basic building blocks for creating a postfire restoration strategy. The next chapter will cover the second step in this process (i.e., gathering and analyzing relevant spatial data) in greater detail.

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Chapter 3: Data Gathering and Analysis

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Introduction

A critical step in the development of a postfire restoration strategy is the acquisition and analysis of relevant data and other information. This information is essential to answering questions posed in the postfire flowchart that, in turn, informs the restoration portfolio (both addressed in chapter 2). Spatially explicit information helps us to evaluate the ecological condition of a postfire landscape, including the capacity of a particular area to support ecosystems in the future and the ecological processes that may affect ecosystem succession. Acquired and analyzed at a meaningful scale, spatial and other information—and incorporation of field verification whenever possible—will assist us in understanding past, present, and future ecological conditions.

Data requirements will vary, but adopting a consistent workflow for delineating ecologically significant units in the analysis area will be helpful. Spatial data layers presented in this document for current and future ecological conditions are available for the entire region with minimal analyst involvement (app. 2). Managers might draw upon data gathered for Forest Service watershed condition assessments or for terrestrial condition assessments, although the relatively coarse scale used in such assessments (Cleland et al. 2017) may not translate well to the more targeted needs of postfire assessment. There are four steps (establish, consider, obtain, and prioritize [ECOP]) to perform in this process (fig. 3.1). Some of these steps can be completed prior to a disturbance so that the unit is prepared to complete the data gathering and analysis portion in a timely fashion. In this chapter, we describe each of these steps in detail, using the Eiler Fire (2014) on the Lassen National Forest to illustrate the entire process.

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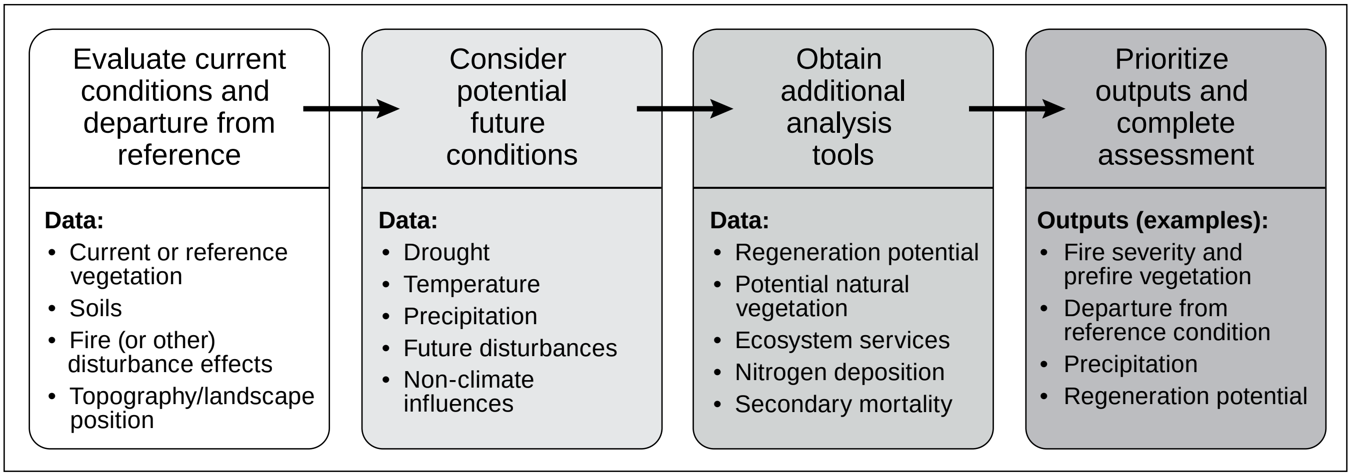

Figure 3.1—Flowchart of the data gathering and analysis step that feeds into the postfire flowchart (step 2 in fig. 2.2).

1. Establish baseline current conditions and departure based on recent vegetation data, biophysical features (such as topography and soils), and fire disturbance (such as severity, frequency) on the postdisturbance landscape.
2. Consider potential future conditions that may influence postfire recovery, such as climate, fire risk, grazing, human uses, and other potential stressors.
3. Obtain additional analysis tools relevant to the location of the fire to help refine departure from reference or desired conditions or to provide more detailed information for specific resources and to integrate novel resource issues that pertain to specific regions or vegetation types.
4. Prioritize outputs and complete spatial analysis that informs the postfire flowchart (chapter 2).

The ECOP Process and Important Considerations

Scale

An appropriate boundary for the analysis area would consider landscape context, priority resource concerns, and desired conditions (see guiding principles in chapter 1). It may be important to consider desired conditions over an area larger than the fire perimeter and we recommend including a buffer of at least 1 mi (1.6 km) that captures the area of interaction between the burned and unburned landscape. As ecological processes are not confined to the fire perimeter, it is important to consider postfire effects on watersheds or terrestrial landscape features outside of the fire footprint and the effects of additional fires that might burn in the future. Accordingly, watershed potential operational delineation, or wildlife habitat units (e.g., habitat cores or corridors) that contain the area of interest may be an appropriate unit of analysis, especially when considering large-scale ecological processes (see the "Guiding Restoration Principles" section on p 12).

Establish Current Conditions and Departure From Prefire Conditions and the Natural Range of Variation

Current ecological conditions, including vegetation structure and species composition, are influenced by fire (Sugihara et al. 2006). To conserve or restore natural ecosystems and their ecological processes, it is important to understand their current conditions. The analysis area can be stratified into ecologically similar landscape units for assessing current condition (prefire vegetation type, topography, and level of disturbance—e.g., fire severity) using a segmentation (i.e., partitioning) process.

The ecological units provide a simplified and more manageable ecological overview of the landscape. These ecological units can be used to inform decision-making at a variety of scales. The minimum size of a unit is identified during the analysis; 5 ac (2 ha) was used in the example provided in this chapter and is a good preliminary size for postfire landscapes. Additional data layers can be appended to the ecological landscape units and appear as columns in the attribute table to inform future conditions and specific reference or desired conditions (e.g., mean climatic water deficit for an ecological unit). The ECOP analysis process can be automated, tracked, and packaged by a geographic information system specialist or the U.S. Forest Service Pacific Southwest Region Remote Sensing Lab (see app. 2). Alternatively, there are other products available for classifying ecological units at the landscape scale that could inform current ecological conditions in postfire landscapes (box 3A).

Determining departure from the natural range of variation (NRV) would require determining both the baseline current conditions and the historical or reference conditions as a comparison. The NRV (also referred to as the historical range of variation) can be used to identify restoration goals and set decision thresholds within the analysis area, but it is important to understand how future climatic and socioeconomic conditions may differ from the NRV reference period, and future desired conditions may often need to be modified from NRV (box 1A).

The natural or historical range of variation can be used to identify restoration goals and set decision thresholds, but it is important to understand how future climatic and socioeconomic conditions may differ from the reference period.

Where NRV assessments have not been done, historical information, current reference sites, and modeling can be used in combination to approximate NRV. This information can help identify desired conditions/targets such as patch size, tree density, species composition, fuel loadings, disturbance process frequencies, and many other metrics useful to restoration. At this time, NRV has been synthesized for the major terrestrial ecosystem types in the Sierra Nevada (Safford and Stevens 2017) and NRV syntheses for northwestern California forests under the Northwest Forest Plan are nearly complete.

The data sources identified in appendix 2 constitute much of the best data available for the region at the time this report was prepared and can be supplemented

Box 3A:
Terrestrial Ecological Unit Inventory

Ecological classification and segmentation is a mapping process that stratifies landscapes into discrete, mapped terrestrial ecological units with similar biotic and abiotic features. One example of this mapping process is the U.S. Forest Service Terrestrial Ecological Unit Inventory (TEUI) program, whereby "ecological units are map units designed to identify land and water areas at different levels of resolution based on similar capabilities and potentials for response to management and natural disturbance" (Winthers et al. 2005). Terrestrial ecological units are classified based on geology, geomorphology, soils, vegetation (both existing and potential natural), and (in the more modern TEUIs) climate, and maps are generated to depict the distribution of these broadly homogeneous units on the landscape. Information on the means and range of conditions in the background data are also available. Most of The Pacific Southwest Region is mapped to the "landtype association" level of resolution, with mapped polygons ranging from thousands to hundreds of thousands of acres (the only units without land type association-level mapping at the national forest scale are the Six Rivers, Klamath, Shasta-Trinity, Lassen, Plumas, and Tahoe National Forests in northern California). This resolution is useful for forest planning. Land types, where mapped polygons are tens to thousands of acres and attribute resolution is higher than for land type associations, have been mapped for the Lake Tahoe Basin Management Unit; the Inyo, Eldorado, and Mendocino National Forests; and the Monterey District of the Los Padres National Forest. Land type-level mapping has also been completed for portions of the Six Rivers, Klamath, and Shasta-Trinity National Forests, but much of this mapping is not found in corporate data storage (app. 2).

with the most up-to-date data layers. One of the main goals of this step is to inform the restoration of desired conditions in a spatial context. However, spatial data would be considered in the context of other information sources, such as field data, old photographs, or written descriptions of the area. When available, finer resolution or richer data sources can improve analysis outputs allowing for a more accurate postfire evaluation. Below are examples of the spatial data that would be used to establish a baseline and determine departure.

Vegetation

The condition of vegetation within the landscape both before and after fire is important for evaluating the need for restoration intervention. The ECOP process allows users to combine pre-fire vegetation layers with fire and topography layers to infer postfire vegetation conditions. Prefire vegetation is important in assessing site capability.

However, it may not necessarily indicate a sustainable condition or an appropriate target for postfire restoration. Analyses that show change from prefire vegetation may reinforce assumptions that prefire conditions were desired, which in turn discounts the potential for fire itself to be restorative. For this reason, examining maps of reference conditions, perhaps including biophysical setting (BpS) or data on historical vegetation conditions (e.g., the 1930s Wieslander vegetation type maps, completed for about 60 percent of national forests within Forest Service Pacific Southwest Region), may be important for evaluating departure. However, maps of reference conditions, if available, are likely to be much less precise than modern maps, so they may be more useful for evaluating general patterns rather than evaluating departure in specific locations (see the "Potential Natural Vegetation" section below).

There are multiple vegetation classifications with varying levels of detail that have been generated for the region (app. 2). For example, vegetation classifications based on the wildlife habitat relationships (WHR) system for California are frequently used for mapping vegetation at the landscape scale. WHR may facilitate analyses for species of concern and may help evaluate forest plan guidance based on WHR types. Alternatively, vegetation classified by pre-Euro-American settlement (or pre-Euro-American colonization) fire regimes (PFR) can be mapped as part of the fire return interval departure (FRID) spatial dataset (Van de Water and Safford 2011). The PFR classification is particularly useful on postfire landscapes because it represents prefire vegetation types that are linked to historical fire regimes (fig. 3.2). These data are important when considering long-term restoration planning that includes both revegetation and restoration of the historical fire regime. Van de Water and Safford (2011) provided data on the historical mean, median, mean minimum, and mean maximum fire return interval by PFR type. In our 2014 Eiler Fire example, we elected to use the PFR classification because of its greater linkage to historical fire regimes.

Topography

Topography or fixed landscape physical attributes (including elevation, slope, topographic position, aspect, complexity) influences biophysical gradients such as solar radiation and topographic moisture, which can be primary drivers for productivity and species composition. Topographic location can be a surrogate for (correlate of) microclimatic conditions and fire susceptibility (Holden et al. 2009, Lydersen and North 2012, Underwood et al. 2010, Weatherspoon and Skinner 1995).

Topographic variation can be determined using the Landscape Management Unit (LMU) tool (app. 2), which allows the user to define topographical breaks based on slope position and aspect (North et al. 2012a). This tool requires a Digital Elevation Model (DEM) (app. 2). DEMs are readily available at 30- or 10-m (100- or

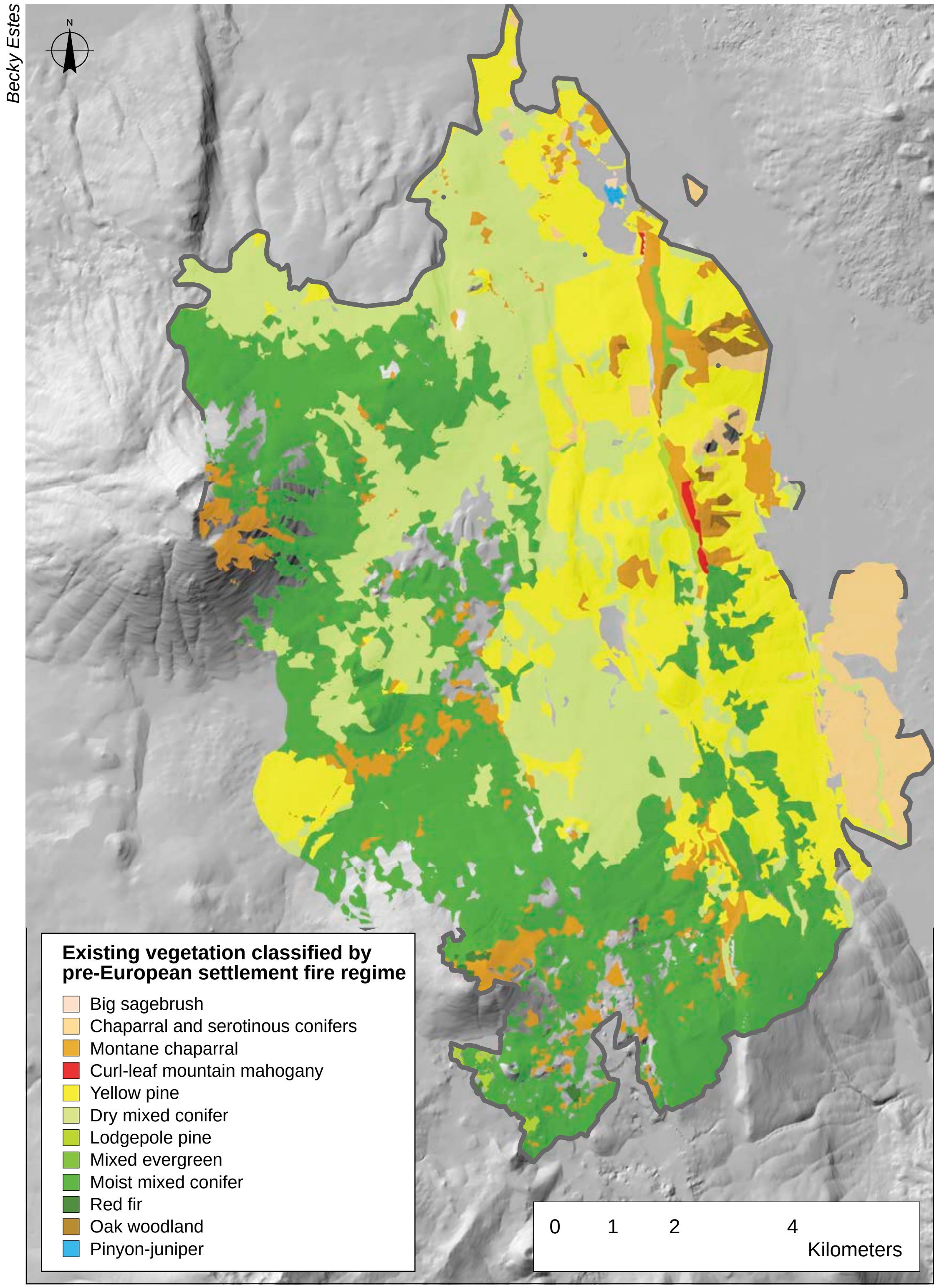

Figure 3.2—Prefire existing vegetation reclassified as pre-Euro-American settlement fire regimes within the Eiler Fire (2014) perimeter on the Lassen National Forest.

33-ft) resolution, while many LiDAR informed DEMs can be generated at submeter scales. Based on prior experience, a 4-m (13-ft) DEM may be preferable for defining the LMU as this captures fine-scale features without breaking up topographical units into overly detailed ecological units. The LMU tool classifies the landscape into ridges, mid-slopes on both south-facing and north-facing aspects, and canyons (fig. 3.3). This information can be further refined to represent slope percent or changes in topographic position. The LMU tool can also be used to inform (1) restoration targets, (2) susceptibility to fire, (3) prominent fire management areas, and (4) constraints on mechanical treatment (North et al. 2012b, Ritchie et al. 2013). Vegetation composition or density is likely to change with landscape position, therefore restoration strategies within a specific vegetation type may vary depending on landscape position. For example, yellow pine and mixed-conifer forests that burn at high severity may be a target for reforestation, and landscape position can help inform tree density objectives (e.g., forests along ridges tend to support lower tree density compared to drainages).

Fire

Vegetation burn severity data provide insights into the degree of postfire ecological change, including changes in stand structure (e.g., canopy cover or basal area loss). Postfire vegetation severity data can be acquired from three sources, depending on the type of information needed for an analysis (see app. 2). The most immediate postfire data source is Rapid Assessment of Vegetation Condition after Wildfire (RAVG) data, which is often available within 1 month of request (fig. 3.4); RAVG maps are sometimes referred to as initial assessment vegetation burn severity maps. Other sources of postfire severity data include extended assessment (one year postfire) vegetation burn severity, and soil burn severity maps that are produced by the BAER team based on the RAVG outputs (app. 2). Because soil burn severity maps do not represent fire effects on vegetation, those two maps may be quite different, especially in depicting areas of high-severity burn (Safford et al. 2008). However, both maps are critical in determining postfire effects on the landscape.

Vegetation burn severity data provide insights into the degree of postfire ecological change, including changes in stand structure (e.g., canopy cover or basal area loss).

The size and arrangement of high-severity patches influence future disturbance events and postfire succession (Collins and Roller 2013, Sugihara et al. 2006, van Wagtendonk et al. 2018). Disturbance patterns can be compared to the NRV to assess the landscape and prioritize restoration needs. For example, edges of large patches experience different successional processes compared to the interior of large patches (Steel et al. 2018). Postfire conifer regeneration can be more limited within the interior of large high-severity patches compared to their edges where seed sources are more readily available (Crotteau et al. 2013, Donato

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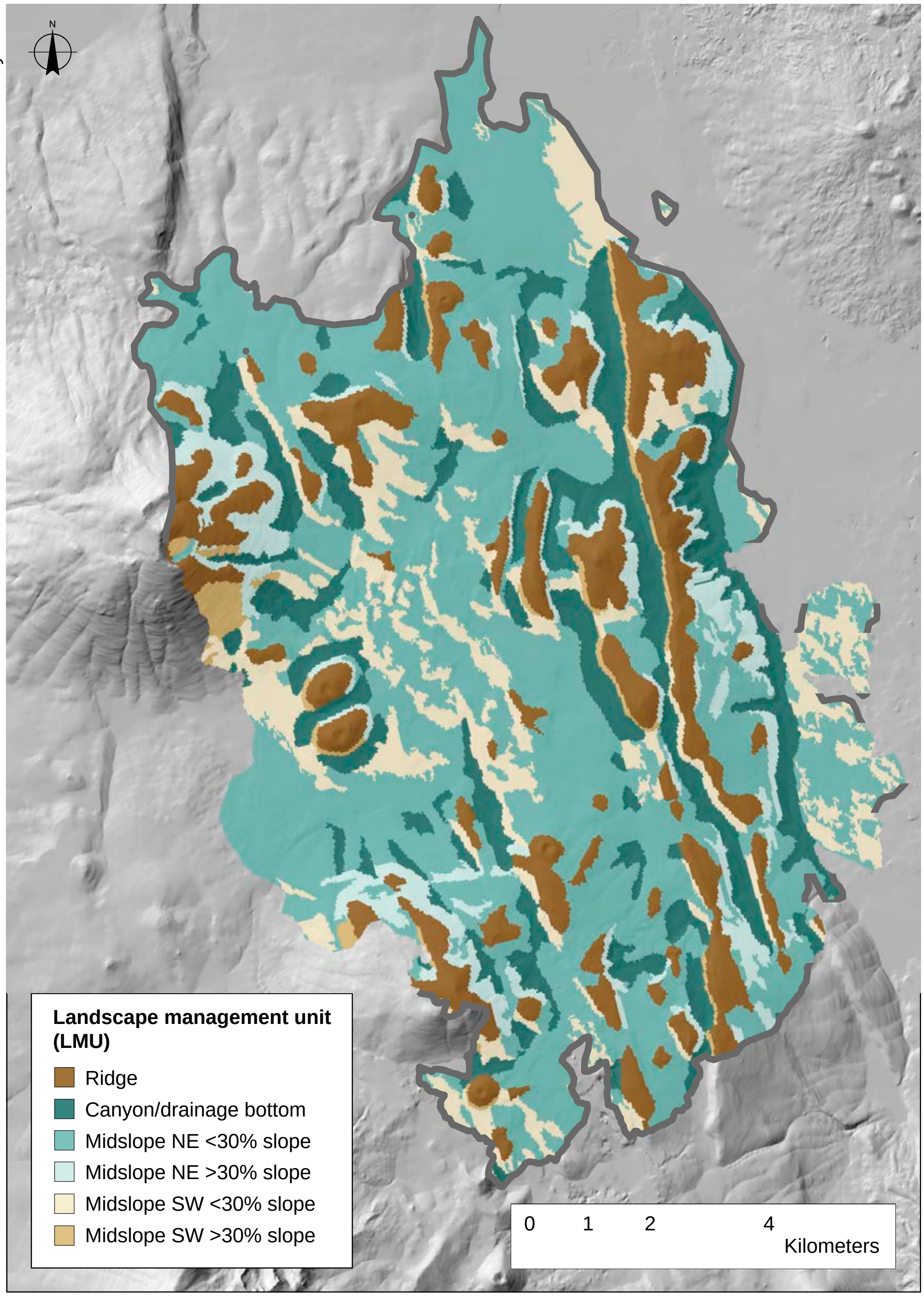

Figure 3.3—Landscape position classified by the landscape management unit tool within the Eiler Fire (2014) perimeter on the Lassen National Forest. Canyons and drainages are shown in dark blue and ridges are shown in dark brown.

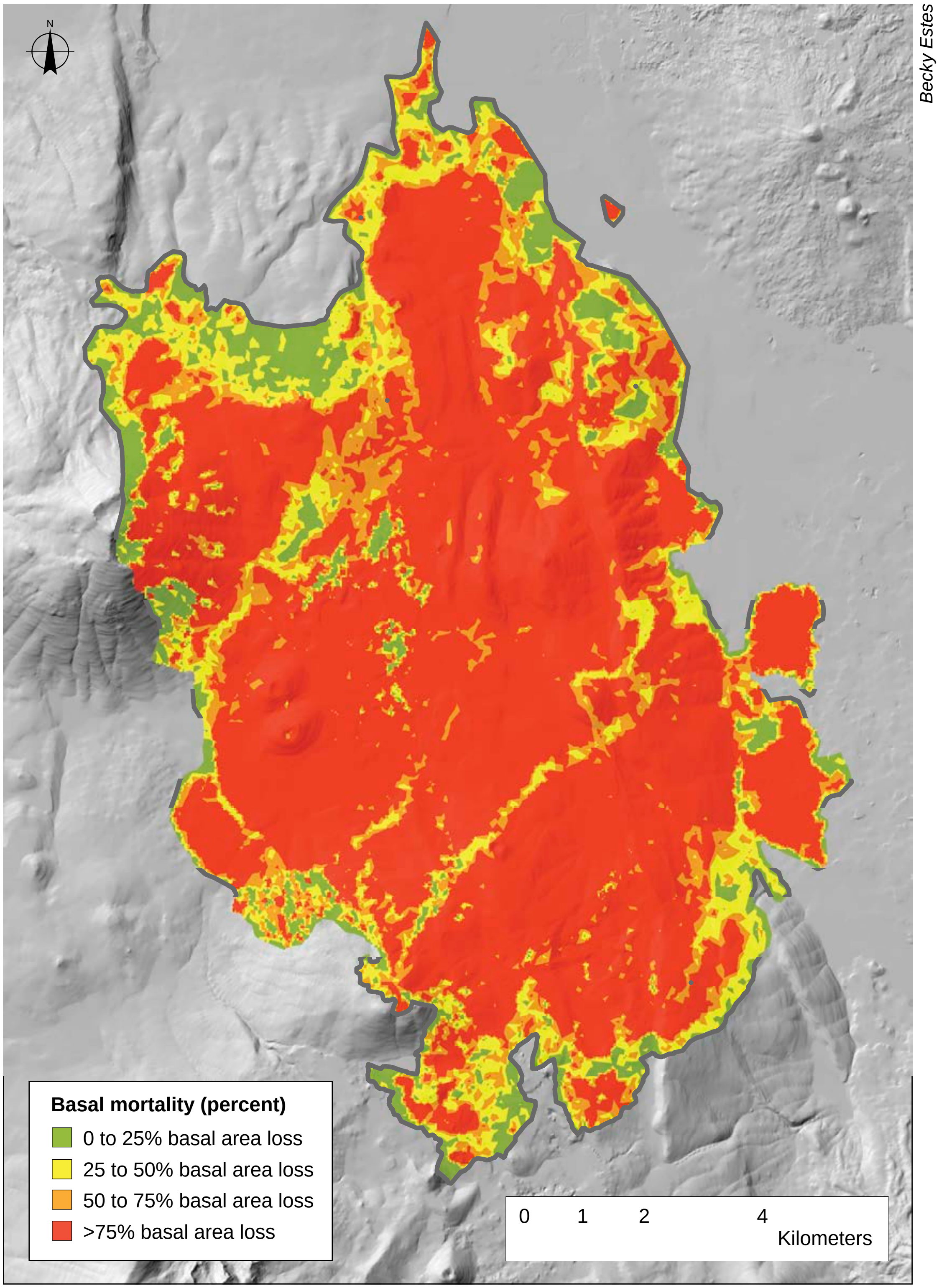

Figure 3.4—Percentage of tree basal area mortality after fire, classified into four classes, within the Eiler Fire (2014) perimeter on the Lassen National Forest.

et al. 2009). Additionally, patch sizes on postfire landscapes are also important in determining wildlife habitat for species that rely on both short- and long-term effects of fire. For example, forested areas that burned in high-severity patches consistent with the NRV (i.e., in terms of their range of sizes and distribution on the landscape) can provide much needed habitat for species that rely on early-successional postfire conditions, such as regenerating shrubs or standing dead trees (Fontaine and Kennedy 2012). In forested areas, protecting pockets of remaining green trees will become increasingly important because they may provide source habitat for colonizing wildlife and refugia for species that are not benefitted by severely burned habitat (McKenzie et al. 2004). In the analysis example, patch size was calculated in ArcGIS based on RAVG data. FRAGSTATS analysis (McGarigal et al. 2012), landscape patch statistics in the open-source statistical package R, or an alternative stand-alone tool (see app. 4) would provide a fine-scale patch analysis that would allow the user to define a contiguous patch. This analysis can help identify areas to prioritize for restoration. For example, yellow pine forest in uncharacteristically large, high-severity patch sizes could be a priority for management activities such as reforestation (White and Long 2019). Areas of yellow pine forests that were burned at high severity and located on ridges might also be priorities for future fuel reduction efforts to maintain them as potential wildland fire operational delineations (fig. 3.5).

The FRID data layer provides specific fire frequency information for the major vegetation types on the national forests and larger national parks in California (app. 2). Comparisons are made between pre-Euro-American settlement (pre-1850) and contemporary (1908 to today) fire return intervals. Current departures from the pre-Euro-American settlement fire return intervals for each PFR are calculated based on mean, median, minimum, and maximum fire return interval values, as well as on time since last fire scaled to the historical mean fire return interval (Safford and Van de Water 2014). Areas with large deviations from historical fire return intervals may be at a higher risk of ecosystem degradation and type conversion, making them priorities for postfire restoration. For certain PFR types and conditions (e.g., shrubland and serotinous conifer), FRID may be a better predictor of postfire restoration need than fire severity or size.

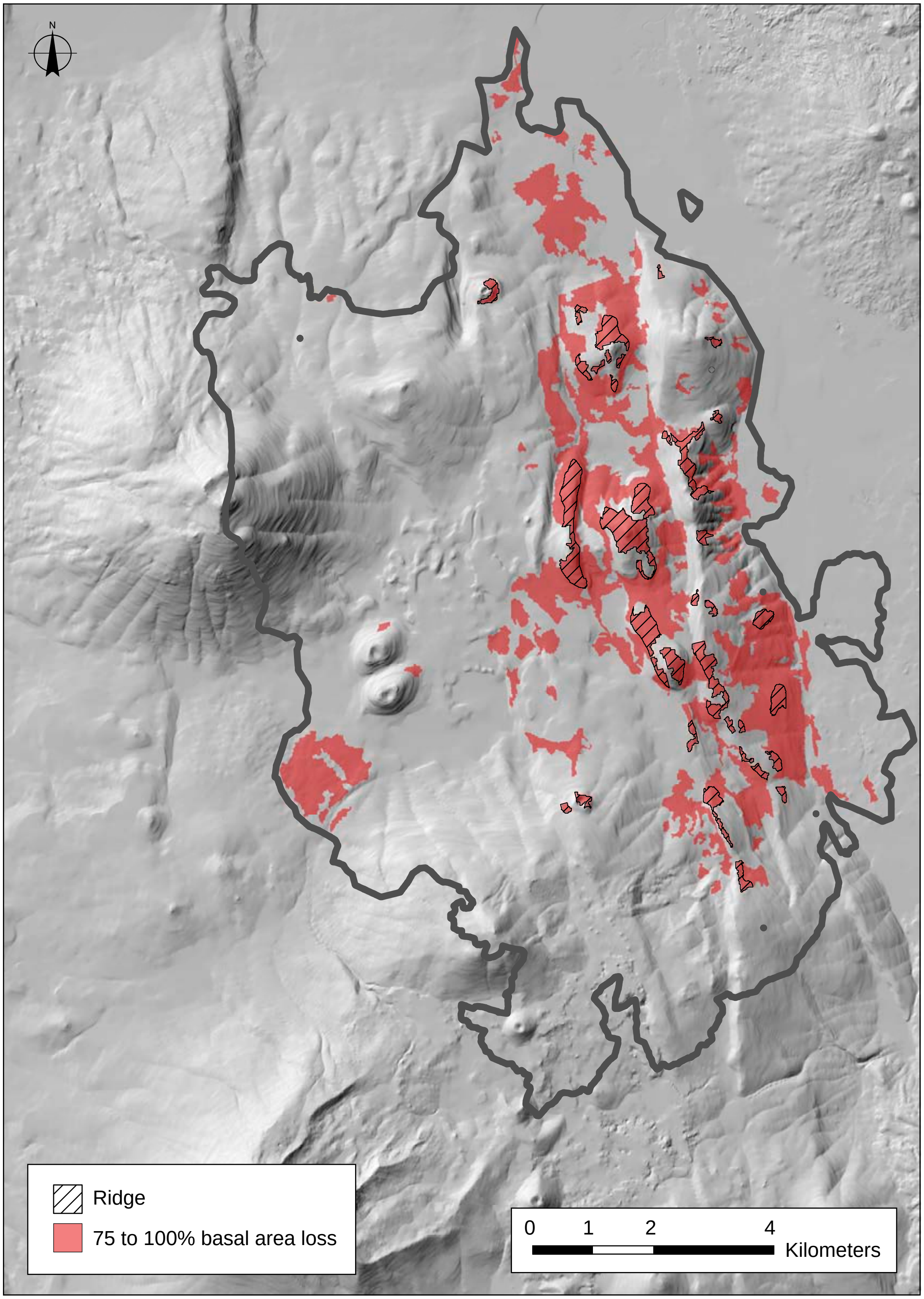

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Figure 3.5—Segmented landscape displaying yellow pine forests on ridges that burned at high severity within the Eiler Fire (2014) perimeter on the Lassen National Forest.

Consider Potential Future Conditions

Determining which areas are most vulnerable to future mortality from climate change can help to improve the likelihood of successful restoration for the burned area and surrounding unburned regions.

Determining which areas are most vulnerable to future mortality from climate change can help to improve the likelihood of successful restoration for the burned area and surrounding unburned regions. These data can be combined with previously described segmentation products to help refine postfire restoration strategies. The composition, structure, function, and distribution of California vegetation are fundamentally shaped by water availability over both short (e.g., short or long periods of drought) and long (e.g., climatic changes) temporal scales (Kane et al. 2015, Lutz et al. 2010). Water availability and fire also interact across the landscape to determine the trajectories of vegetation through time (Kane et al. 2015).

Although climate data can be used to assess plant water stress and ecosystem productivity (e.g., Thorne et al. 2015), the coarse scale of most currently available climate data (downscaled to 270 m (886 ft) resolution) is not always useful in delineating areas for potential management action. Spatial variation in slope, aspect, topographic shading, and water holding capacity requires operation at finer scales than most climate models can manage (Kane et al. 2008, Lutz et al. 2010). Nonetheless, downscaled climate metrics may still be informative in identifying broader scale spatial patterns of future climate exposure across burned landscapes.

Teams may need to evaluate the different climate metrics and models to determine the most appropriate ones for the analysis (app. 2, box 3B). Determining the appropriate metric depends on the question of interest and spatiotemporal scale of analysis. Climate vulnerability analysis can be conducted on observed historical climate, future modeled projections, or a combination of the two. Historical climate patterns will best indicate the current and near-term vulnerability, while future climate projections can provide insights into climate exposure decades into the future. For example, the average annual climatic water deficit (CWD) from the 1981–2010 climate period or CWD projected to 2010–2039 by the Parallel Climate Model Global Circulation Model (emissions scenario A2) can potentially identify areas at high risk of water stress (fig. 3.6). Recent historical or projected future climate variables may be informative for evaluating the effects of climate on vegetation (i.e., climate exposure) at spatial scales relevant to postfire landscapes. In contrast, projected changes between historical and future climate are generally more informative for evaluating long-term climate exposure across vegetation types at larger bioregional scales. Using climate projections that extend two to three decades may better fit with forest planning windows and avoid potential inaccuracy of longer projections.

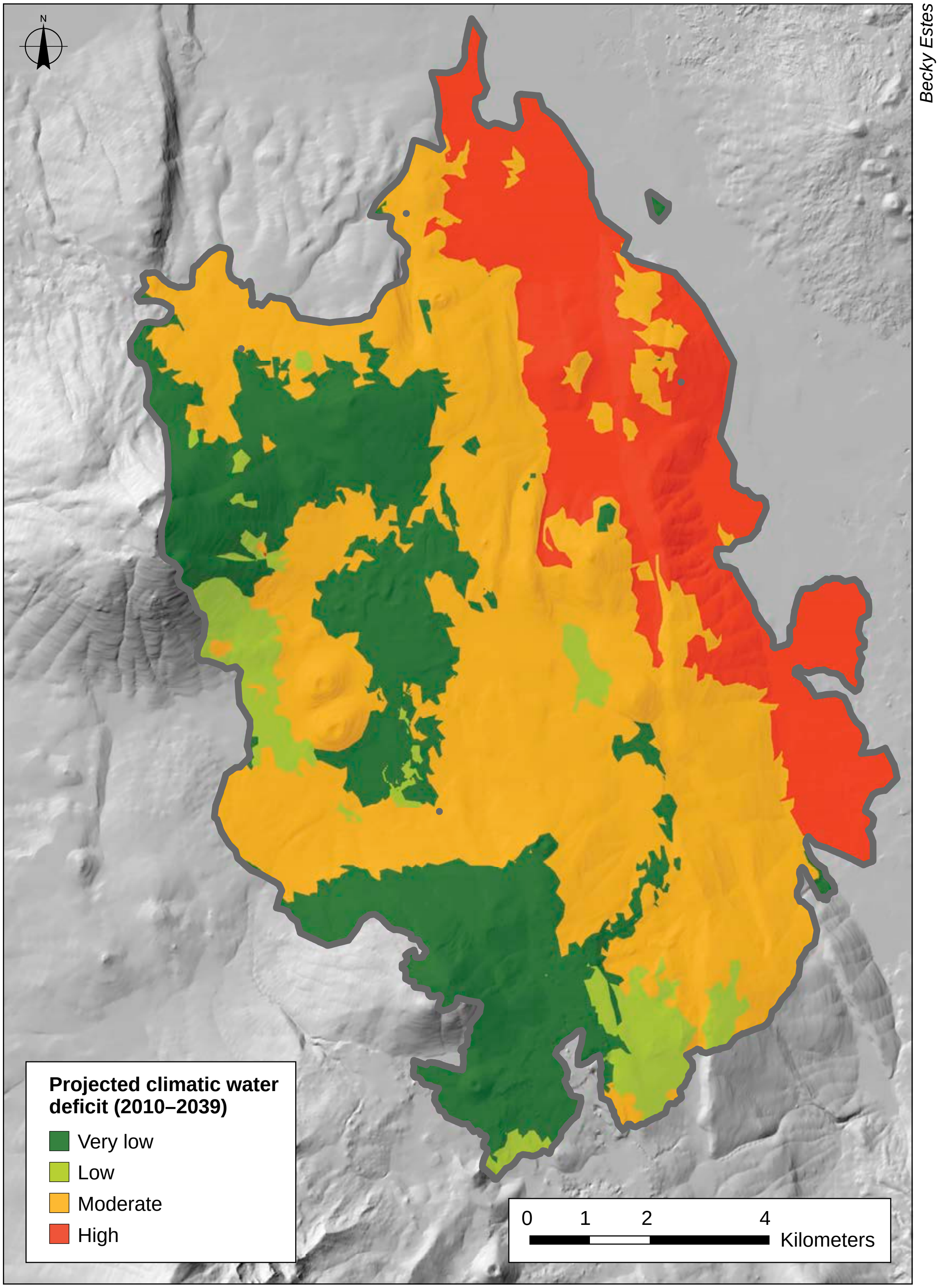

Figure 3.6—Future projected climatic water deficit (CWD) for the 2010–2039 climate period, provided by the Parallel Climate Model Global Circulation Model (emissions scenario A2) shown within the Eiler Fire (2014) perimeter on the Lassen National Forest. Areas in red would be expected to be at relatively high risk of water stress, while areas in dark green would be considered at relatively low risk. Mapped CWD data could further refine priority areas for potential management intervention shown in figure 3.5.

Box 3B:
Using Climatic Water Deficit to Assess Climate Exposure

Downscaled hydro-climatic predictor variables are available across the Pacific Southwest Region (Thorne et al. 2012). Water balance metrics such as actual evapotranspiration (AET) and climatic water deficit (CWD) are biologically meaningful and are well correlated with tree species distribution, tree mortality, forest structure, and fire patterns (Kane et al. 2015). AET is the amount of water a given place on the Earth's surface loses to evaporation and transpiration under actual field conditions. Assuming a certain type of vegetation and soil, AET integrates precipitation input and energy input from the sun. CWD is the difference between potential evapotranspiration (the amount of evapotranspiration that would occur on a site if water was not limiting) and AET (or the actual evaporative water loss from a site) (Stephenson 1998) (app. 2). The CWD metric thus integrates effects of solar radiation, air temperature, evapotranspiration, precipitation, and soil on the current vegetation (Stephenson 1998). For example, shallow and porous soils may have limited water holding capacity, and much precipitation may be lost to runoff rather than held in the soil. In such cases, CWD tends to be high, especially during the dry season. To evaluate future climate exposure (the degree of stress on an ecosystem resulting from climate change), the team evaluating the spatial data may decide to quantify current or future water metrics (Glick et al. 2011).

Continued on next page

Additional Analysis Tools

To develop useful recommendations for achieving desired conditions, analyses may consider other issues that relate to specific postfire landscape conditions and specific management activities. Additional data layers and tools can help to evaluate ecological processes and management issues in a postfire landscape. Here we describe several spatial tools and data layers that may be relevant. However, it is important to note this is not an exhaustive list and new tools are continually being developed. The data layers described below, along with even more localized spatial data (e.g., rare species occurrence, nonnative species presence, fuel treatment activities), can help refine postfire restoration strategies.

Regeneration potential for forested landscapes—
Although the ability of forests to regenerate after stand-replacing fire is driven by a series of biotic and abiotic factors (e.g., available moisture, soil insolation, rodent herbivory, seedling pathogens), the foremost requirement for most natural conifer

This would allow recommendations to focus on those areas that are projected to be at greatest risk of increased water stress in the future. For example, to quantify exposure to climate change, projected future CWD (e.g., 2010–2039) locations can be classified into bins (e.g., very low, low, moderate or high risk) to make interpretation easier (fig. 3.6). Areas at high risk for increased CWD are locations where the magnitude of drought stress experienced by vegetation is projected to be much greater than surrounding areas.

Assessing current and future projected CWD allows for the identification of areas that have high or low climatic likelihood of maintaining or allowing reestablishment of prefire vegetation assemblages. For example, areas with large projected CWD may be locations where restoration targets based on prefire or historical conditions are unreachable. Such locations may require development of new desired conditions (i.e., realignment) based on projected future conditions. In contrast, areas with small projected CWD may be in a better position to survive coming climatic changes more or less intact. Areas with relatively higher projected water availability may represent potential climate change refugia, where restoration of prefire (or historical) conditions could be tenable for the time being. It is important to consider the long-term trajectory of such sites—which could include locations where complex late-seral forest might be maintained—and how management may or may not be able to maintain historical and future conditions.

regeneration is a seed source (Bonnet et al. 2005). Areas that have experienced high-severity fire have been shown to have dramatically lower regeneration rates for nonserotinous conifers (especially pines) compared to areas burned at moderate or low severity (Crotteau et al. 2013, Welch et al. 2016). Higher conifer regeneration densities in low- and moderate-severity burns are due primarily to nearby seed-bearing trees that survived fire. In addition to seed production, the remnant overstory in low- and moderate-severity burns produces intermittent canopy shading, a factor that may limit shrub competition and lower water stress, further permitting certain conifer seedlings to establish (Dobrowski et al. 2015, Smith et al. 1997). Uncharacteristically large high-severity patches (identified based upon NRV), on the other hand, have so few surviving mature trees that distance to seed source becomes a limiting factor (Bonnet et al. 2005) (see chapter 4). High-severity burned areas may be less likely to naturally reforest if the patch size is sufficiently large to preclude seed-tree adjacency (Bonnet et al. 2005, Sessions et al. 2004, Turner et al. 1997). Although only a few studies have directly associated tree regeneration patterns in stand-replacing patches with patch characteristics (size, perimeter-to-area ratio, or distance to edge), seedling regeneration and especially pine regeneration are clearly reduced in patches of high-severity fire (Collins and Roller 2013, Crotteau et al. 2013, Shive et al. 2018, Welch et al. 2016). Considering the probability of natural regeneration can help to identify and prioritize reforestation needs postfire, especially for lands with considerable acreage of high-severity fire and large high-severity patches. Spatial tools to assess the natural regeneration potential on postfire landscapes are discussed in the case studies, appendices, and associated references in this document (apps. 3, 4, and 5), and related publications.

It may be important to evaluate departure by considering data on reference vegetation condition and spatial arrangement rather than only focusing on predisturbance conditions.

Potential natural vegetation—
It is important to understand current biophysical processes as well as historical and future disturbance regimes because an understanding of successional processes can help identify where restoration actions may be a priority. It may be important to evaluate departure by considering data on reference vegetation condition and spatial arrangement rather than only focusing on predisturbance conditions. Potential natural vegetation (PNV) data provide information on what late- seral vegetation the landscape could support based on the environmental conditions (e.g., geology, soils, and climate). PNV mapping by the Forest Service in California was only completed for a few national forests (e.g., Six Rivers, Mendocino, and Modoc National Forests) and it was based on late-successional, climatic climax vegetation, i.e., it did not consider the effects of disturbances such as fire in influencing vegetation potential. Because fire plays such an outsized role in California ecosystems, the usefulness to managers of mapping vegetation types that only rarely or will never occur on the landscape is questionable (although it is certainly useful for understanding successional relationships). At this point, the only standardized and statewide PNV datasets that are available are those provided by the LANDFIRE program. The LANDFIRE environmental site potential (ESP) layer is driven purely by the biophysical environment (equivalent to climatic climax vegetation), while the BpS layer is the result of applying modeled pre-Euro-American settlement fire regimes to the ESP data. The BpS layer is supported by state-and-transition models and type descriptions that include modeled seral stage proportions for equilibrium landscapes. The BpS data were designed to be used at broad scales for national and regional reporting of fire regime and vegetation structural departure. As such, the minimum landscape size for comparing modern versus modeled pre-Euro-American seral stage proportions in California montane forests is about 10,000 ha (24,710 ac) (Karau and Keane 2007, Pratt et al. 2006). The mapped BpS vegetation types were derived from modeling of vegetation plot data against biophysical gradients and are produced at the 900 m^2 (0.22 ac) Landsat pixel scale. However, some of the

modeling input datasets were at much broader scales (e.g., climate data from a 0.38-mi^2 [1-km^2] grid, soil texture data with 3.85 ac [1.56 ha] minimum mapping unit) and the LANDFIRE website warns that "the appropriate application scale [of BpS] is much larger than 30 meters [100 ft]" (LANDFIRE 2019).

Ecosystem services—

A tool is currently being developed that will allow U.S. Forest Service staff to interface with the spatial data from an ecosystem services assessment (Underwood et al. 2018). As an example, six ecosystem services (water runoff, water recharge, soil retention, carbon storage, recreation, and biodiversity) have been quantified and mapped for the Cleveland, San Bernardino, Angeles, and Los Padres National Forests in southern California. Such data layers can be integrated into analyses when specific goals related to human-derived benefits are being considered to prioritize areas for restoration (see "California Chaparral Case Study" below for a detailed example).

Nitrogen deposition—

Wildlands in southern California experience the highest nitrogen deposition in North America (Fenn et al. 2010). Nitrogen deposition in southern California shrublands (downwind from large metropolitan areas) can exceed critical loads, resulting in landscape-level changes, including the loss of species diversity and shifts in species composition toward dominance by nonnative grasses and forbs (Bobbink et al. 2010, Fenn et al. 2010). Consideration of nitrogen deposition data can help to identify areas with a high probability of invasion and low probability of native shrub recovery postfire. Areas identified as being at high risk to invasion by nitrophilic (often nonnative) species may be areas targeted for active restoration postfire, such as removal of exotic species or reseeding with native species (Engel et al. 2019, VinZant 2019). Alternatively, high nitrogen deposition areas that are already heavily invaded may not be cost- or effort-efficient places to spend restoration funds given the likely infeasibility of reducing nitrogen deposition.

Secondary mortality via insects and disease—

Native insects and diseases create small minor disturbances at low, endemic levels, but will respond rapidly when conditions change that are conducive to epidemic expansion (Raffa et al. 2008). Fire-damaged trees are prime candidates for pest infestation as these types of injuries allow pathways for infection and weaken resistance to insect attack. When trees are injured, they can emit volatile organic compounds that attract bark beetles (Hood et al. 2010, Lombardero et al. 2006). Subsequent mortality varies because of the type and degree of injury to the tree, with the highest risk occurring within the first 5 years postfire (Hood et al. 2010). Regional guidelines (nonspatial) were developed for land managers to determine the mortality probability of trees still alive after fire (Smith and Cluck 2011). Aerial detection survey data and 2014 Farm Bill Insect and disease designations can help to identify existing mortality and thus identify additional areas for removal of dead trees (app. 2). Hyperspectral imagery that can help to define moisture content of trees may be a useful tool in identifying secondary mortality on postfire landscapes (Asner et al. 2016). Additionally, change detection algorithms can identify landscape-scale changes in stand structure after drought and insect outbreaks (i.e., primary mortality) (app. 6) and assist in prioritizing areas for management actions (e.g., reforestation) after tree mortality events (app. 7).

Prioritize Outputs for Developing the Restoration Portfolio

Prior to this step, the team has established baseline current conditions and departure, considered potential future conditions, and obtained additional tools to further refine the analysis. All of these outputs will be provided as tabular and spatial data to allow for ease of transfer to the restoration strategy. The next step allows the team to consider and prioritize the outputs for use in the postfire flowchart and for development of the postfire restoration portfolio. For example, departure assessments that compare current conditions to NRV or desired conditions can help inform where current conditions might be maintained or improved. Potential future conditions (e.g., under climate change scenarios) can help us understand where management approaches for the restoration of desired conditions may or may not be reasonable, suggesting that either management approaches or desired conditions may need to be reconsidered.

Conclusions

The data gathering and analysis phase is a multistep process that includes (1) establishing current conditions and departure from prefire conditions and the NRV, (2) considering potential future conditions, (3) obtaining additional analysis tools, and (4) prioritizing outputs for developing the restoration portfolio. These steps are necessary for addressing questions in the postfire flowchart and locating areas to apply restoration opportunities and potential management actions for the analysis area, which are necessary for developing a restoration portfolio (covered in chapter 2). The next three chapters provide case studies of this multistep process.

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Chapter 4: Mixed-Conifer Forest Case Study

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Introduction

Sierra Nevada Mixed-Conifer Forest Ecosystems

Mixed-conifer forests are widely distributed throughout the mountainous regions of California, occurring just below the upper montane elevation belt and typically ranging from 1,000 to 7,000 ft (300 to 2000 m). Common tree species include ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) and Jeffrey pine (*P. jeffreyi* Balf.), white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.), sugar pine (*P. lambertiana* Douglas), incense cedar (*Calocedrus decurrens* (Torr.) Florin), Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco), and black oak (*Quercus kelloggii* Newberry), and there are numerous, less common hardwood and conifer species, including the rare but iconic giant sequoia (*Sequoiadendron giganteum* (Lindl.) J. Buchholz). These tree species are differentially adapted to the physical and biotic environment, and forest composition and structure are driven by topographic gradients that influence soil water availability and solar exposure as well as ecological disturbances such as fire, drought, and insect outbreaks (Safford and Stevens 2017). Fire exclusion and logging have been primary drivers in altering composition and structure in mixed-conifer forests. Changes have included loss of fire-tolerant/shade-intolerant species (e.g., pines, giant sequoia), reduced structural heterogeneity, and increased canopy cover and tree densities (especially in the smallest size classes), leading to elevated woody fuel loads, and reduced habitat quality and diversity (Knapp 2015, Knapp et al. 2013, North et al. 2009, North 2012). Prior to Euro-American colonization, Sierra Nevada mixed-conifer forests experienced frequent (every 11 to 16 years, on average), low- to moderate-severity (mostly surface) fires, but today these fires are relatively rare (Safford and Stevens 2017). In concert with climate change, these changes have catalyzed a trend of larger and more severe fires and bark beetle outbreaks over the past several decades, leading to habitat fragmentation and broad-scale and potentially long-term forest loss (Kolb et al. 2016, Westerling et al. 2006).

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Giant sequoia groves represent a specific type of moist mixed-conifer forest that is primarily restricted to the southern half of the western slope Sierra Nevada (Stephenson 1999). Giant sequoias are an iconic species and groves are protected, conserved, and restored for their unique natural character and amenity values (Stephenson 1996). In similar fashion to other mixed-conifer ecosystems, and for similar reasons, forest structure and composition have changed dramatically in giant sequoia groves in the past century (York et al. 2013). Also similar to other mixed-conifer forests, ecological restoration in fire-excluded giant sequoia groves is based primarily on reductions of forest density and fuels. This is accomplished using fire or silvicultural treatments to reestablish stand structure, composition, and function that is more likely to be resilient to future conditions (Stephenson 1999).

Moist mixed-conifer forests are primary foraging, resting, denning, and dispersal habitat for the southern Sierra Nevada population of Pacific fisher (*Pekania pennanti*). Late-seral mixed-conifer and ponderosa pine forests are especially critical to the long-term persistence of fisher in the southern Sierra Nevada because older forest provides critical habitat structures (e.g., large trees and snags, especially pines and oaks with cavities) for resting and denning (Spencer et al. 2016). At the same time, variation in stand structure across the landscape helps fishers meet other habitat requirements, especially foraging, and contributes to long-term resilience of mixed-conifer forest habitat by reducing the potential for severe, large-scale disturbances that eliminate suitable denning and resting habitat. Variable but connected vegetation cover across the landscape can facilitate fisher dispersal across linkage areas, an especially important factor in areas recently affected by wildfire, insect outbreaks, or drought (Spencer et al. 2016). Habitat features suitable to fisher generally benefit other old-forest-associated species, such as the California spotted owl (*Strix occidentalis occidentalis*).

The resilience of coniferous forest ecosystems postfire depends on sufficient tree survival and seed dispersal, both of which are heavily influenced by fire severity patterns.

Large High-Severity Patches

The resilience of coniferous forest ecosystems postfire depends on sufficient tree survival and seed dispersal, both of which are heavily influenced by fire severity patterns. In larger high-severity burned patches, much of the burned area can be far from available seed sources, thereby limiting the likelihood of successful natural regeneration—especially among heavier seeded taxa, such as some pine species (Bohlman and Safford 2014, Bonnet et al. 2005, Crotteau et al. 2013, Welch et al. 2016). High-severity patches would have been rare in the yellow pine mixed-conifer forests during the reference period with most patches being less than 250 ac (100 ha) (Safford and Stevens 2017). Indeed, more than 60 percent of high-severity patches were less than 9 ac (4 ha) (Collins and Stephens 2010, Minnich et al. 2000). Some level of high fire severity and subsequent early-seral stand conditions in mixed-conifer forests are ecologically desirable (USDA FS 2012, 2019a, 2019b). However, uncharacteristically large high-severity patches (especially those exceeding about 100 ac [40 ha]) could result in tree regeneration failure, habitat loss for species associated with late-seral forests, and other undesirable conditions (Eyes et al. 2017, Welch et al. 2016). Published estimates of the natural range of variation (NRV) for mean high-severity patch size were generally (much) less than 4 ha (10 ac) with larger patches rarely exceeding 247 ac (100 ha) (table 4.1) (Safford and Stevens 2017). If patches of this size did occur, they would comprise less than half of the total high-severity area. High-severity patch size values that exceed 200 to 250 ac (80 to 100 ha) and that are frequently more than 10 ac (4 ha) are also outside the desired conditions for forest landscapes, as described in the revised draft Sequoia and Sierra forest plans (USDA FS 2019a, 2019b) and consistent with plan direction in the Giant Sequoia National Monument Plan (USDA FS 2012). Consequently, high-severity patches greater than 200 to 250 ac (80 to 100 ha) are thought to exceed those desired conditions and generally NRV. Because departure categories for desired conditions and NRV are similar, we use them interchangeably throughout this chapter. Properly planned and implemented, reforestation activities can help to restore forest cover, and also promote other desired conditions, such as reduced fuel loads, decreased fuel continuity, increased ecosystem resilience to future wildfires (Coppoletta et al. 2016), greater representation of fire-tolerant/shade-intolerant tree species (Collins and Roller 2013), and increased understory species diversity (Bohlman et al. 2016).

Table 4.1—Desired proportions of high-severity burned patches of varying size classes for the 2015 Rough Fire analysis area on the Giant Sequoia National Monument (Sequoia National Forest) and Sierra National Forest in California, based on supporting documents for the revised draft Sequoia and Sierra forest plans (USDA FS 2019a, 2019b)

High-severity patch size (ac)	Frequency of patches across the forest landscape (proportion of burned area)
Small (≤1 ac)	Frequent (>60 percent)
Medium (2 to 10 ac)	Infrequent (<30 to 35 percent)
Large (11 to 50 ac)	Uncommon (<5 to 10 percent)
Very large (50 to 200 ac)	Rare (<1 percent)

The 2015 Rough Fire

The Rough Fire was ignited by lightning on July 31, 2015, on the Sierra National Forest north of the Kings River in steep, inaccessible terrain (fig. 4.1). The fire burned 151,643 ac (61 638 ha) and included portions of the Sierra National Forest (39 percent), Sequoia National Forest and Giant Sequoia National Monument (54 percent), Kings Canyon National Park (6 percent), and California state and private lands (<1 percent). Vegetation in the Rough Fire was primarily a combination of ponderosa pine forest, oak woodlands, and mixed chaparral below 4,500 ft (1400 m) elevation, and mixed-conifer forest interspersed with montane chaparral at higher elevations. In the Giant Sequoia National Monument, about 30 percent of the area burned in the Rough Fire consisted of mixed-conifer forest. Eight giant sequoia groves totaling approximately 8,900 ac (3600 ha) in the Giant Sequoia National Monument also burned in the Rough Fire. The fire killed many large and old sequoias in the Giant Sequoia National Monument and Kings Canyon National Park; the greatest impacts to sequoias were in the Lockwood portion of the Evans Grove Complex (Reiner and Ewell 2016). Additionally, the Rough Fire burned notable parts of fisher habitat (Core Area Number 3 centered on Sequoia and Kings

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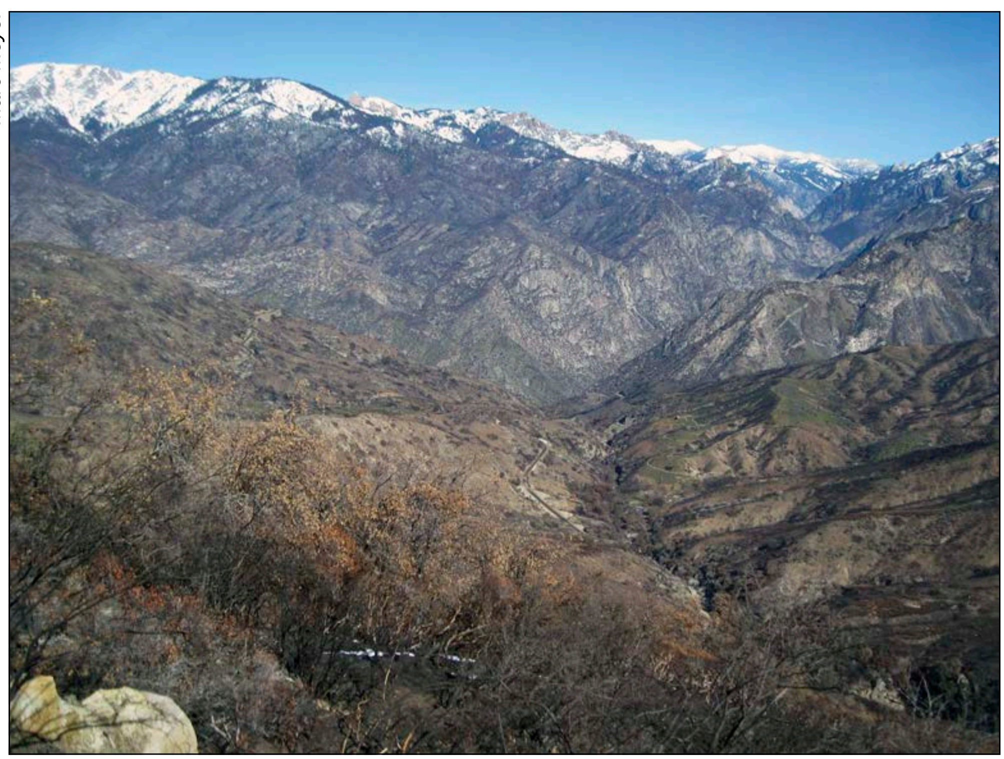

Figure 4.1—Landscape-scale vegetation conditions 1 year after the 2015 Rough Fire, showing a variety of fire effects on mixed-conifer, chaparral, and oak woodland vegetation.

Canyon National Parks and habitat Linkage C in the Kings River Canyon), which were described in the southern Sierra Nevada fisher conservation strategy (Spencer et al. 2016). Land management agencies and stakeholders were concerned with the potential long-term impacts of the Rough Fire to giant sequoia groves, fisher habitat connectivity, watershed health, and other key resources.

In the past few decades, the Rough Fire area has experienced numerous wildfires, including several located within the Rough Fire perimeter (i.e., 1985 Deer, 1988 Garnet, 1988 Obelisk, 1997 Choke, 2001 Highway, 2005 Comb Fires) or adjacent to the fire (i.e., 1989 Balch, 2008 Tehipite, 2010 Sheep Fires). However, most of these wildfires were small, and most of the landscape had not burned for more than a century prior to the Rough Fire (i.e., most of the landscape was moderately to highly departed from the historical fire return interval). Although the previous wildfires locally reduced forest cover, the sizes of stand-replacing patches were relatively small and within NRV (generally less than 24.7 ac (10 ha) and not exceeding 250 ac (100 ha), especially for the 2010 Sheep, 2008 Tehipite, and 2005 Comb Fires, which were primarily managed for resource objectives (Meyer 2015). As an exception, the 1997 Choke Fire in the Monarch Wilderness produced several large high-severity patches, including one that may have exceeded the NRV for maximum patch size (around 200 ac [80 ha]) (Meyer 2015).

Postfire Restoration Framework

Step 1: Identify Priority Resources, Desired Conditions, and Restoration Goals

There are a number of resources within the Rough Fire that managers might choose to evaluate to help inform short- and long-term strategies. Although the Rough Fire covers a large landscape composed of many vegetation types, we focused our analysis on mixed-conifer forests, with particular emphasis on two important resources in the southern Sierra Nevada associated with mixed-conifer forests: giant sequoia groves and fisher habitat, including lower elevation ponderosa pine forests. We reviewed and summarized desired conditions for these key resources based on information provided in land management and resource planning documents (Spencer et al. 2016; USDA FS 2012, 2014) (table 4.2). Based on these sources, we developed two restoration goals for the analysis area: (1) maintain and restore mixed-conifer forest ecosystem integrity, diversity, and resilience, with focus on giant sequoia groves, and (2) maintain sufficient fisher habitat suitability and connectivity.

Table 4.2—Desired conditions for mixed-conifer forests, with a focus on core Pacific fisher habitat and giant sequoia groves in the Rough Fire (2015) analysis area

	Desired conditions	
	Pacific fisher habitat	**Giant sequoia groves**
Vegetation	Old forest structure (large trees and snags, spatial heterogeneity) provides foraging, resting, and denning habitat.	Forest composition is patchy, consisting of a variable mixture of conifer and hardwood trees as well as shrubs. Most forest stands are characterized by low tree densities and fuel loads, with frequent and variable canopy openings especially in drier topographic positions. Seventy percent of mixed-conifer forests located within sequoia groves (50 percent outside groves) are dominated by trees greater than 24 inches in diameter (late seral), with 10 percent in early seral, and the remainder (20 to 40 percent) in mid seral stage.
Fire	Low risk of high-severity fire	Groves are within the natural range of variation for mixed-conifer forests, with fires typically burning at low to moderate severity with some high-severity patches interspersed.
Habitat elements	Large live and dead trees are common and well-distributed across the landscape, especially large pines, black oaks, and trees containing cavities and deformities.	Objects of interest (especially large sequoias) are protected from the undesirable impacts of wildfires and other stressors.
Canopy cover	Exceeds 60 percent in patches, especially in more mesic sites such as canyons and northeast-facing slopes.	Spatial distribution of vegetation is variable and heterogeneous.
Connectivity	Habitat linkage areas maintain connectivity between habitat core areas, including patches of moderate to dense tree canopy cover where conditions permit or shrub cover where tree cover is lacking.	Periodic flushes in oak, pine, and sequoia regeneration replace mortality in older trees.

Step 2: Gather and Review Relevant Spatial Data

For the Rough Fire, the analysis perimeter was expanded beyond the area of the fire to encompass all HUC12 watersheds that were within or adjacent to the fire (fig. 4.2). Ecological condition of vegetation prior to the fire was identified using (1) existing prefire vegetation type (classified into broad potential fire regime types) (see chapter 3), and (2) landscape position to provide an indication of topographically mediated moisture gradients and classified using the Landscape Management Unit (LMU) tool (North et al. 2012a). Different LMUs are arrayed along gradients of moisture availability, evapotranspiration rates (including moisture stress), and associated forest structure (e.g., lower tree densities on ridges and southwest-facing slopes) (Underwood et al. 2010) (app. 2).

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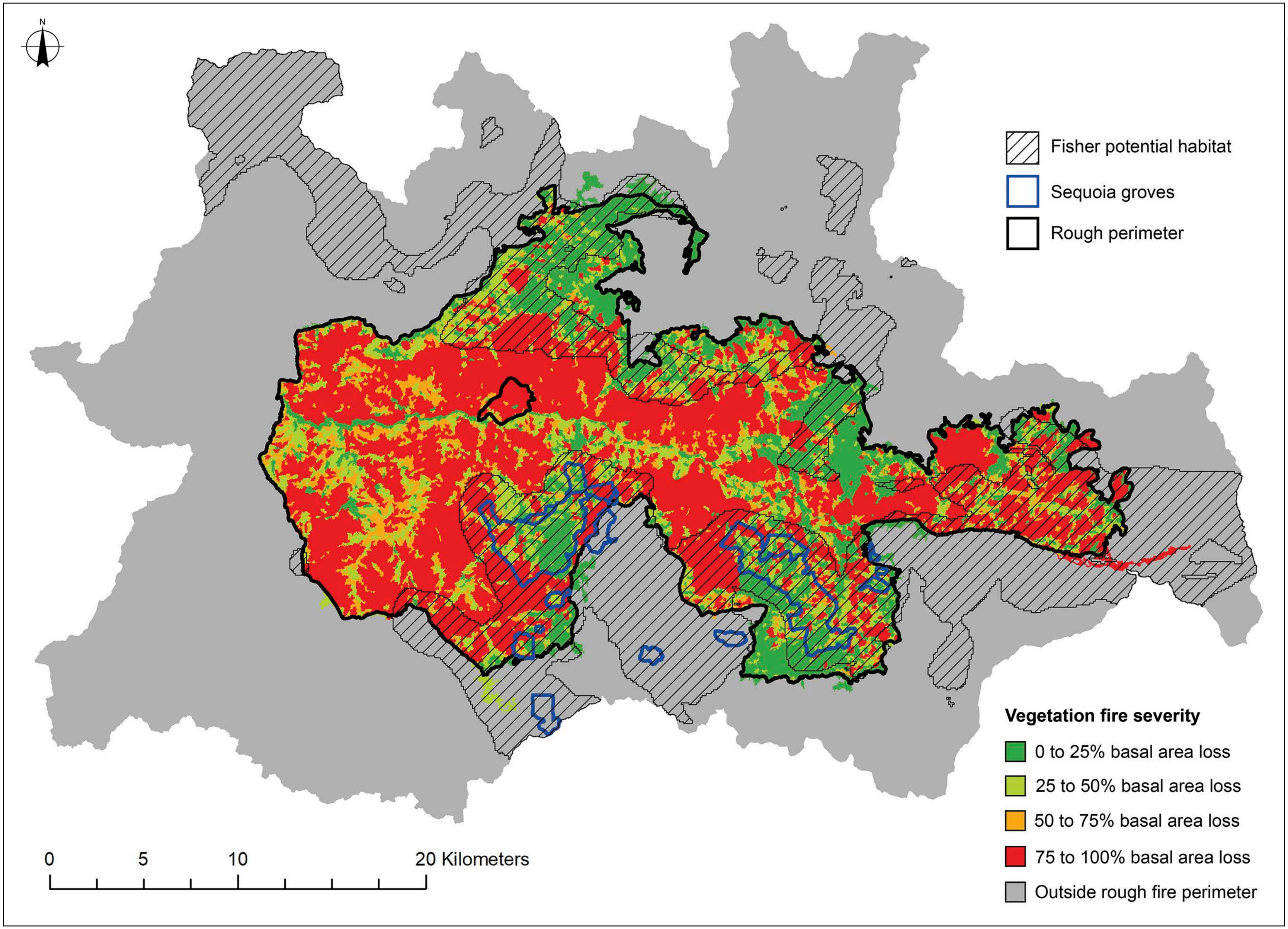

Figure 4.2—Vegetation burn severity after the 2015 Rough Fire, classified by percentage of change in basal area classes ranging from 0 to 100 percent. The analysis area outside of the Rough Fire is highlighted in grey, fisher habitat is shown in hashed polygons, and sequoia groves are displayed in the blue-outlined polygons.

We focused our analysis on mid-elevation conifer forests (mixed conifer, yellow pine) which encompass most of the sequoia and fisher habitat in the analysis area (table 4.3). No other vegetation types were included in the ecological condition assessment for this case study; however, the establish, consider, obtain, and prioritize process (described in chapter 3) could be used to provide similar outputs for other vegetation types to help guide restoration efforts. Canyons and mid-slopes with north-facing aspects were special areas of focus for fisher habitat as these areas (1) experience lower moisture stress and are therefore more likely to be successfully reforested (i.e., higher tree seedling survivorship), and (2) are the LMUs most likely to support dense forest canopies required by fisher for resting and denning. Mid-slopes with southern aspects and on ridges were less important, because these areas experience high moisture stress and often lower tree densities in sites less suitable for fisher or giant sequoia. Canopy cover is also an important predictor of high-quality fisher habitat, especially in patches exceeding 60 percent cover. Data layers do exist regionwide to evaluate canopy cover, but these data layers are highly variable in resolution and have notable limitations. Some available data layers could be used to evaluate canopy cover, including existing prefire vegetation (EVeg, California Habitat Wildlife Relationships density) and LiDAR, which may be available for specific locations of interest (table 4.3) (see box 4A). Additionally, more localized and field-based information and observations (both pre- and postfire) could help validate and supplement spatial data in assessing postfire landscape conditions and trends.

Postfire ecological condition was evaluated to determine the extent to which the Rough Fire effects represented a departure from NRV and desired conditions (as defined in tables 4.1 and 4.2). This was evaluated using fire severity (the four class percentage change in basal area as represented by the Rapid Assessment of Vegetation Condition after Wildfire data) (table 4.3) and further refined using high-severity patch size. Areas dominated by mixed-conifer forest were classed by unchanged to low-moderate fire severity (0 to 50 percent change), moderate-high severity (50 to 75 percent change), and high severity (>75 percent change) (fig. 4.2). We considered high-severity patches dominated by mixed-conifer forest in four patch size classes: (1) patches less than 10 ac (4 ha) in size, (2) patches between 10 ac (4 ha) and less than 100 ac (40 ha), (3) patches between 100 ac and 250 ac (40 and 100 ha), and (4) patches that exceeded 250 ac (100 ha) in size. Classes 3 and 4 were considered to be moderately and extremely departed, respectively, from desired conditions and NRV. Additional analysis could be conducted to ensure that some larger high-severity patches are retained across the landscape to provide habitat for a number of early-seral species. Other methods for evaluating departure from desired conditions in postfire landscapes (app. 3) can help guide development of a postfire restoration strategy.

Additional analysis could be conducted to ensure that some larger high-severity patches are retained across the landscape to provide habitat for a number of early-seral species.

Table 4.3—Primary resources, stressors, and constraints that might be considered in a postfire assessment of the Rough Fire (2015) analysis area, which included the Rough Fire perimeter and hydrologic unit code (HUC) 12 watersheds that were either directly or indirectly affected by the fire[a]

Resources	Spatial data	Explanation
Giant sequoia groves	Giant sequoia management areas (Forest Service)	The sustainability of giant sequoia groves is essential in the Giant Sequoia National Monument.
Fisher habitat	Fisher predicted probability of occurrence >40 percent (CBI model) (Spencer et al. 2011)	Maintenance and restoration of fisher habitat core and linkage areas are critical to the persistence of the fisher population in the southern Sierra Nevada.
Watersheds	Watershed condition assessment	Watershed condition informs where prefire stressors may interact with the effects of the Rough Fire, resulting in undesirable negative impacts to watershed resources.
Mixed-conifer forest vegetation	EVeg (see app. 2)	Mixed-conifer forests provide numerous ecosystem services, including carbon sequestration, soil stabilization, and wildlife habitat.
Early-seral forest vegetation	High-severity fire polygons (RAVG) within forest vegetation (EVeg)	Early-seral forest vegetation provides habitat for plant, animal, and fungi species associated with early-successional environments.
Postfire natural conifer regeneration probability	Post-fire Spatial Conifer Regeneration Prediction Tool (Shive et al. 2018) Field assessment –(Welch et al. 2016)	Natural conifer regeneration is essential for reestablishment and resilience of conifer forest vegetation after fire.
Fire	Vegetation burn severity (RAVG)	Fire severity based on RAVG data displays the magnitude of fire effects on vegetation in four categories that represent percentage of change in basal area.
Climate change at coarse spatial scales	Climatic Water Deficit (CWD) from Basin Characterization Model, current and projected for early 21st century	CWD and climate exposure estimates long-term vulnerability of vegetation to climate change.
Topographically mediated moisture stress	Landscape management units tool	Topographic position and slope gradient can help inform the relative degree of moisture stress to vegetation, the type of treatments available, and reforestation actions (planting density and species selection). Topographically mediated moisture stress may provide an indication of current and near-future moisture stress that is more reliable and precise than climate exposure spatial data.
Mechanical treatments opportunities	North et al. 2012b	Dataset identifies areas on the landscape that are accessible for mechanical treatments.
Soils	Soil survey geographic database	Soil productivity and available water holding capacity may refine priority areas for reforestation.

[a] Many spatial data sources (e.g., forest vegetation, natural conifer regeneration, fire severity) would benefit from field validation using site-specific field data and observations

Box 4A:
Using LiDAR to Inform Postfire Restoration Treatments

The Pacific fisher (*Pekania pennanti*) selects habitat at multiple spatial scales in forest landscapes. At a coarser scale, fishers generally prefer mature and old-forest conditions with dense canopy cover for habitat linkage. At a finer scale, fishers select sites with large trees or snags containing cavities that can serve as suitable resting and denning sites (Zhao et al. 2012) (fig. 4.3). These habitat conditions are also important to a wide variety of forest-dependent wildlife species (Zielinski 2014). Restoration of these conditions are of particular interest in relation to the Rough Fire because these habitat features were substantially affected by the fire. Coarser scale metrics such as vegetation composition and identification of mature forest patches can easily be accomplished using Landsat-derived vegetation maps, which are readily available across the region and are updated at regular intervals (EVeg, app. 2). However, finer scale attributes are often identified through field-based efforts, which can be costly and time consuming and challenging on burned and unburned landscapes. Other remote-sensing tools such as LiDAR can accurately measure finer scale habitat structural conditions and fine tune field-based estimates of forest structure that are needed to plan postfire restoration treatments (Ackers et al. 2015, Kramer et al. 2016). Recent information has suggested that cover of tall trees is more important than overall canopy cover for species dependent on old or mature forest habitat, such as the California spotted owl (*Strix occidentalis*

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Figure 4.3. Fisher resting site in a black oak (red arrow) adjacent to large ponderosa pines.

Continued on next page

occidentalis) (North et al. 2017). These metrics are difficult to obtain or too coarse when derived from Forest Service regional or national datasets.

A small portion of the Rough Fire had available prefire LiDAR data (fig. 4.4). With LiDAR information, it is possible to identify contiguous areas of high-canopy cover (brown areas in fig. 4.4) that did not burn at high severity for evaluating postfire habitat suitability and connectivity. This can be further refined using LiDAR-derived canopy height or structural class information, which can locate clusters of tall trees important for denning fisher and nesting California spotted owls.

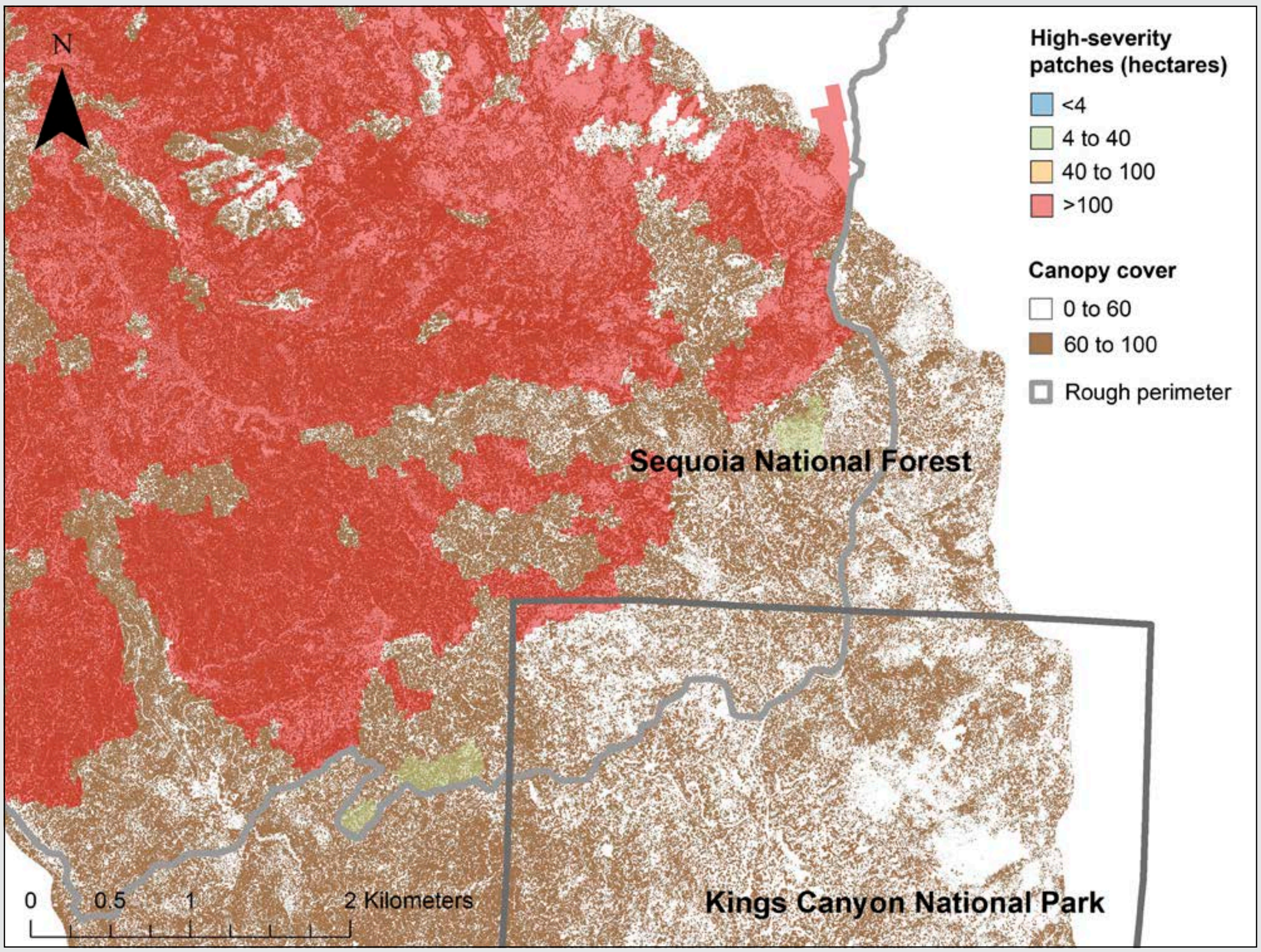

Figure 4.4. LiDAR-based map of canopy cover prior to the 2015 Rough Fire, overlaid with high-severity patches from the Rough Fire that burned on the Sequoia National Forest (Giant Sequoia National Monument) and Kings Canyon National Park.

Step 3: Use the Postfire Flowchart to Identify Restoration Opportunities

Question A: Where did fire improve or maintain ecological conditions and are fire effects within desired conditions or NRV?—
The Rough Fire was evaluated to determine spatial departure from NRV for fire-severity proportion, high-severity patch size, and fire return interval departure (FRID). In the yellow pine and mixed-conifer forest types, the NRV for fire severity is dominated by areas of low and moderate severity with small areas burning at high severity (Safford and Stevens 2017). The Rough Fire was mostly within NRV with respect to low- and moderate-severity fire. Thirty-five percent was estimated to be low-severity fire (31 to 58 percent NRV) and 37 percent was estimated to be moderate-severity fire (15 to 35 percent NRV). However, the estimated percentage of high-severity fire in the Rough Fire was 28 percent, which was notably greater than both NRV (5 to 11 percent) and desired conditions (generally less than 15 percent (Meyer 2015). The Rough Fire contained 526 high-severity patches ranging from 2 to 8,617 ac (1 to 3487 ha). Large high-severity patches exceeding 247 ac (100 ha) (28 total) made up about 70 percent of the area burned at high severity (which exceeds NRV, <50 percent of high-severity burned area) and 5 percent of high-severity patches by frequency (exceeds NRV, <1 percent of high-severity patches) (Safford and Stevens 2017) (fig. 4.5). Some of the largest high-severity burn patches within mixed-conifer forest occurred within suitable fisher habitat and adjacent to the Converse Basin and Evans sequoia groves (fig. 4.6). Based on deviations in NRV for high-severity patch size, 71 percent of mixed-conifer forest (our target vegetation type) in fisher and sequoia habitat was considered to be within NRV after the fire (fig. 4.6). In comparison, 3 percent of this habitat was moderately departed, and 26 percent was considered to be extremely outside of NRV. The two latter areas could be considered further for the feasibility of future management actions to better align postfire conditions with desired vegetation conditions.

The Rough Fire was also evaluated for FRID. Some recent prescribed fires and wildfires occurred within sequoia groves and fisher habitat prior to the Rough Fire. However, the majority of the analysis area is still considered highly departed after the Rough Fire, with substantially fewer fires occurring than would have occurred historically. Although this metric had limited value for further partitioning the landscape as the majority of the landscape was classed as highly departed, it did identify several areas of recent prescribed burning that could be targeted for continued management using prescribed fire.

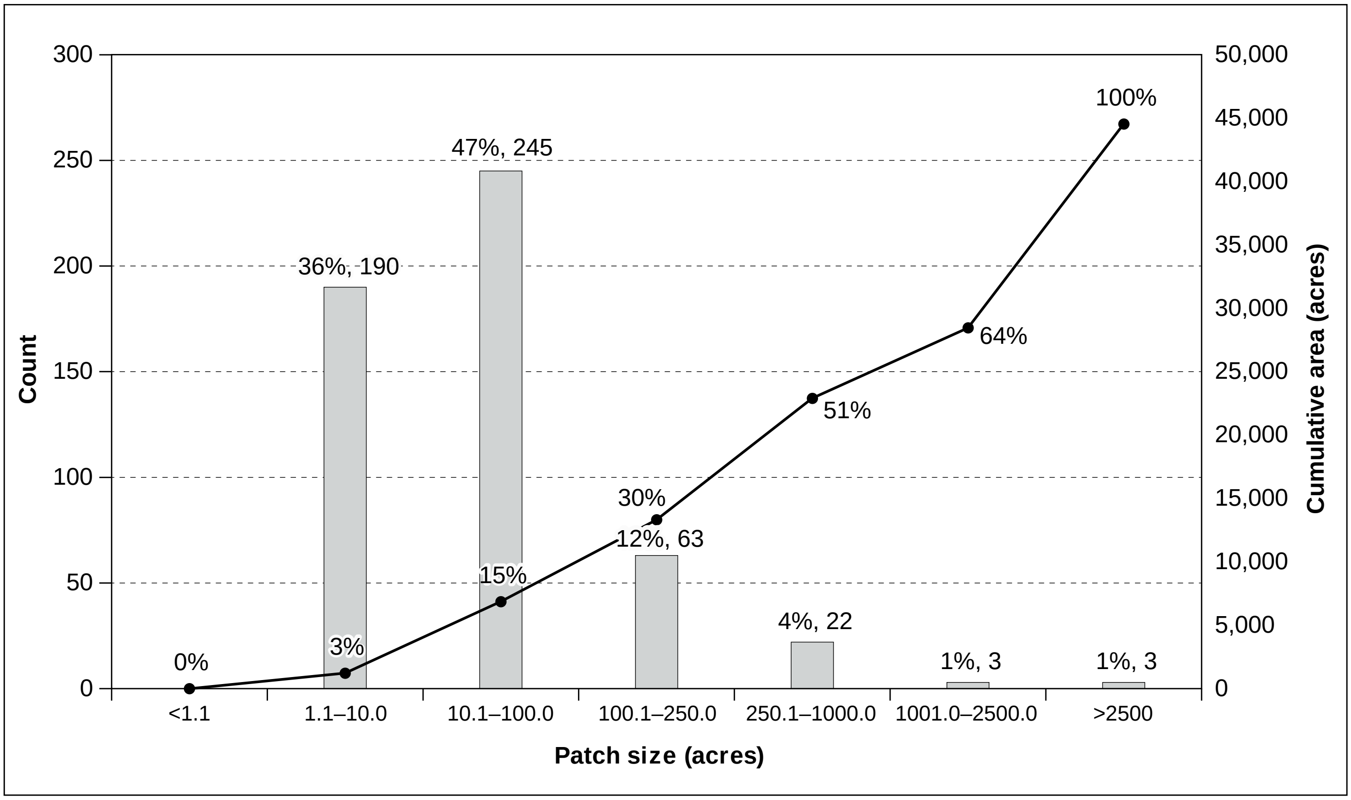

Figure 4.5—Histogram of high-severity patches in mixed-conifer forests of the 2015 Rough Fire, showing the log-transformed patch sizes (acres) to display large patch frequency. Many patches are small to moderate in size, which includes values less than 32 to 40 ha, or 80 to 100 ac. A lower proportion of patches (n = 28) are considered exceptionally large (patches greater than 100 ha or, 247 ac) and are outside the natural range of variation.

Question B: Where do other factors threaten ecological resilience and sustainability?—

Undesirable conditions that could threaten ecological resilience and sustainability in the Rough Fire, particularly in fisher habitat and sequoia groves, include (1) conifer-regeneration failure, (2) widespread and elevated tree mortality resulting from drought or insect outbreaks, and (3) excessive fuel accumulations contributing to increased risk of high-severity reburns and vegetation type conversion. These undesirable outcomes are the result of several interacting stressors, including drought, insect outbreaks, altered fire regimes, and climate change.

Coniferous forests that burned outside NRV, particularly large high-severity patches, may be at elevated risk of conifer-regeneration failure primarily due to the lack of nearby seed sources (Welch et al. 2016). Areas that were outside of NRV (for fire severity and high-severity patch size) identified in the previous step made up 29 percent of the Rough Fire (fig. 4.6). Using the Post-fire Spatial Conifer Regeneration

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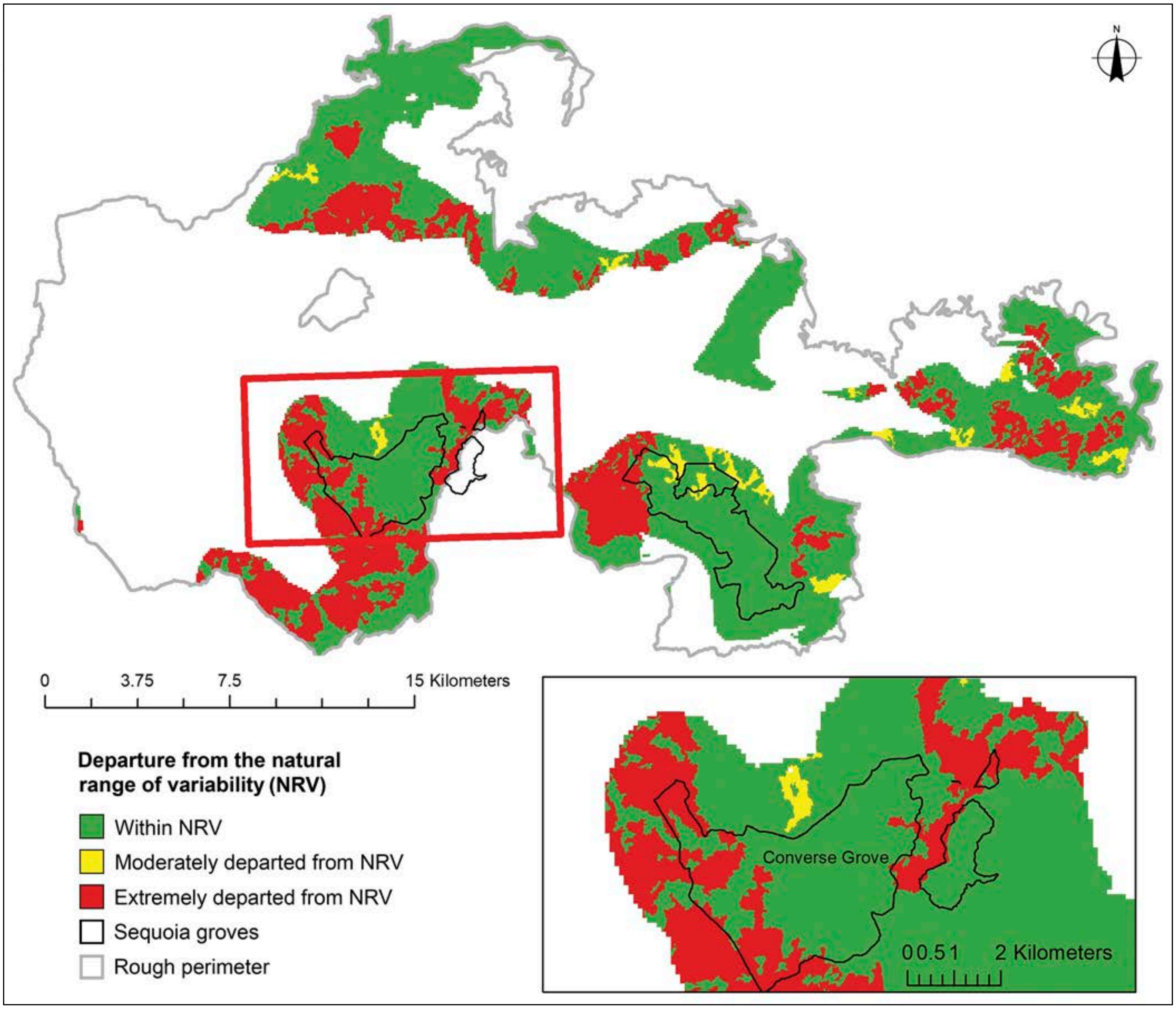

Figure 4.6—Departure from natural range of variation (NRV) within the 2015 Rough Fire in Pacific fisher habitat and giant sequoia groves. This assessment used fire severity class and high-fire severity patch size (see Step 2: Gather and Review Relevant Spatial Data for definition of classes). High fire severity patch size was classified into four groups: (1) patches less than 10 ac (4 ha), (2) patches between 10 ac and less than 100 ac (40 ha), (3) patches between 100 ac and 250 ac (100 ha), and (4) patches that exceeded 100 ha in size. The second two classes were considered to be moderately and extremely departed from NRV and desired conditions (displayed in yellow and red respectively).

Prediction Tool (POSCRPT) developed by Shive et al. (2018), users can identify areas as outside of NRV based on fire severity as a function of their probability of conifer-regeneration failure at 5 years postfire (app. 3). The POSCRPT 40 to 60 percent regeneration probability class supports a median of 67 seedlings per acre (Shive et al. 2018), which is well below the Forest Service Pacific Southwest Region stocking standard. The median seedling density found in the POSCRPT's 60 to 80 percent regeneration probability class is 134 seedlings per acre (333/ha), which is 67 percent of the current stocking rate in the Pacific Southwest Region. That value may be sufficient natural conifer regeneration considering future changes in stand conditions associated with climate change, such as declines in stand densities or shifts in stand dominance from conifers to hardwoods. Within areas that were moderately or extremely departed from NRV, 22 percent of the landscape had less than 60 percent probability of natural regeneration. The remaining 78 percent of the landscape had more than 60 percent probability of natural regeneration (fig. 4.7).

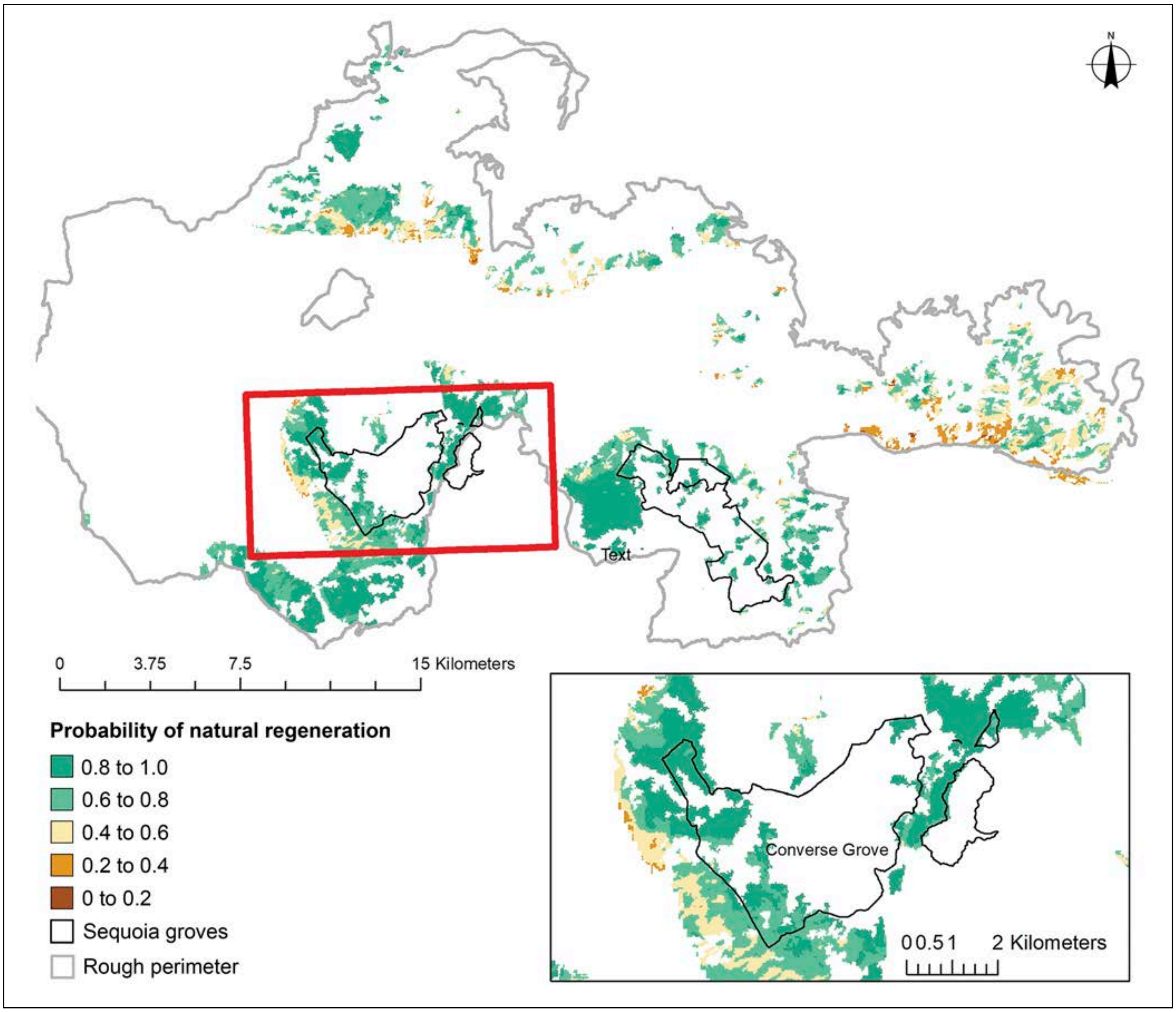

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Figure 4.7—Predictive map of the probability of natural conifer regeneration in mixed-conifer forest in Pacific fisher habitat and giant sequoia groves 5 years postfire in the 2015 Rough Fire using the POSCRPT methodology detailed in appendix 3. Areas in white are not analyzed as they are outside of the mixed-conifer forest in fisher and giant sequoia habitat, are classified as nonconifer vegetation types, or exhibit fire severity patterns within natural range of variation (fig. 4.4). The natural regeneration classes refer to the probability that a single surviving conifer seedling will be found at 5 years postfire in a 60 m^2 (646 ft^2) area. Regeneration probabilities are generally high in the southern part of the fire with some areas of lower probability in the northern and eastern parts of the fire. The inset map in the bottom right displays the probability of conifer regeneration in and around the Converse giant sequoia grove. Lower regeneration probabilities in the southwestern portion outside the Converse grove are generally supported by field observations of dry and shallow soils in this area.

Additional analysis tools may help identify areas where interventions may increase the resistance and resilience of developing and mature forests to stressors (e.g., apps. 3 and 4).

A second factor that might affect the resilience and stability of the Rough Fire landscape is drought. Between 2012 and 2016, the southern and central Sierra Nevada experienced the most extreme multiyear drought in the past 1,000 years (Robeson 2015). Drought conditions in the Sierra Nevada bioregion were most severe in the southern half of the range. The Rough Fire was located at the lower end of the bioregional precipitation gradient and the higher end of the temperature gradient, which in combination resulted in high levels of tree mortality over an extensive portion of the landscape prior to the Rough Fire (Fettig et al. 2019, Restaino et al. 2019, Young et al. 2017). Using the Aerial Detection Survey (app. 2) or remote sensing technology (apps. 6 and 7), managers can identify areas on the landscape that experienced mortality events prior to the fire or that might be susceptible to future mortality events (e.g., dense conifer plantations). Areas that experienced high levels of tree mortality prior to the fire, but subsequently burned within NRV (i.e., at low to moderate levels of fire severity) might be more susceptible to conifer-regeneration failure than otherwise expected. Alternatively, areas that experienced high levels of drought-related mortality and subsequently burned at high severity may contain a high accumulation of fuels (e.g., shrubs, woody debris) and could be susceptible to high-severity reburn or potential vegetation type conversions (Coppoletta et al. 2016).

In addition to altered fire regimes, another important threat to mixed-conifer forest ecosystems is potential shifts in climate. Species distributions and ecosystem function in Western United States ecosystems are driven to a great extent by water availability. To measure susceptibility to future changes in water stress, we classified projected future (2010–2039) climatic water deficit (CWD) into three levels of risk for increased deficit (low, moderate, high) and overlaid the risk classes on the distribution of mixed-conifer forest in the analysis area (see chapter 3 for an example and data sources). In the Rough Fire, mixed-conifer forest at high risk of increased CWD accounted for about 20 percent of the burned landscape and was located throughout many parts of the assessment area.

Mixed-conifer forest, especially fisher habitat and sequoia groves, that is departed from the natural range of variation or at increased risk of interacting stressors may require active management approaches to restore desired conditions or manage for a new desired condition.

Question C: Where are management approaches feasible for the restoration of desired conditions given current and anticipated future conditions?—Mixed-conifer forest, especially fisher habitat and sequoia groves, that is departed from the NRV or at increased risk of interacting stressors may require active management approaches to restore desired conditions or manage for a new desired condition. A consideration of current topographically mediated moisture gradients (based on the LMUs) (North et al. 2012a) or future projections in CWD (see chapter 3) could address feasibility under future climate conditions. Both of these metrics can help to determine where management actions will be most effective for restoring desired conditions and alleviating the impacts of future moisture stress.

Projected future CWD was used to identify mixed-conifer forest sites (especially giant sequoia groves and suitable fisher habitat) that were likely to experience lower or higher levels of moisture stress in the next two decades. Areas of greater future CWD that were also extremely departed from NRV for fire severity may not be feasible sites for traditional management approaches and might require the reevaluation of desired conditions. Of the fisher habitat areas that were extremely departed from NRV following the Rough Fire, 12 percent also had relatively high projected future CWD (CWD classes based on predefined thresholds), suggesting that maintenance of high forest cover in these areas may be difficult to achieve.

Only about 7 percent of fisher and giant sequoia habitat in the analysis area was accessible to mechanical treatments based on topographic and road proximity constraints (North et al. 2012b). Due to these constraints, long-term management actions aimed at maintaining resilient forest cover (e.g., sequoia groves and fisher habitat) on the landscape will require nonmechanical approaches, such as hand thinning, prescribed fire, or wildfires managed for resource objectives.

Restoration opportunity 1: maintain or promote desired conditions—Mixed-conifer stands that burned primarily at low to moderate severity may still be outside NRV or departed from desired conditions with respect to vegetation structure and composition, habitat suitability, or other ecological indicators (fig. 4.2). For instance, mixed-conifer stands in the assessment area that burned at low severity may continue to be characterized by homogenous forest structure and elevated fuels and tree densities susceptible to future severe wildfires, bark beetle outbreaks, drought, and other disturbances or stressors. In such cases, management actions may be needed to restore desired conditions (table 4.4). Alternatively, management actions may help maintain functioning forest ecosystems in the Rough Fire that are currently within their desired conditions. In both cases, fire is an indispensable management tool, capable of doing much of the work to maintain or improve ecological conditions (North 2012, Stephenson 1999, Sugihara et al. 2006). Prescribed fires and wildfires managed for resource objectives have been identified as the primary means to treat large landscapes, particularly in areas where mechanical treatments are limited owing to access (North et al. 2012). In many stands, mechanical thinning followed by prescribed fire may be necessary to more quickly increase forest resilience, especially in areas with high fuel loading (Stephens et al. 2009) or within dense stands of young trees such as conifer plantations (North et al. 2019).

Table 4.4—Postfire flowchart outputs that are the foundation of the restoration portfolio for the 2015 Rough Fire analysis area

	Output
Primary restoration goals	• Maintain or restore mixed-conifer forest ecosystem integrity, diversity, and resilience with a focus on giant sequoia groves • Maintain sufficient habitat suitability and connectivity for Pacific fisher
Most relevant guiding principles from the restoration framework	• Restore key ecological processes • Consider landscape context • Support native biodiversity and habitat connectivity • Sustain diverse ecosystem services • Incorporate adaptation to agents of change
Analysis area	• Rough Fire perimeter and hydrologic unit code 12 watersheds that were either within or adjacent to the fire
Restoration opportunities	• Maintain or promote desired conditions • Take management actions to restore desired conditions • Reevaluate desired conditions considering interacting stressors
Potential restoration actions	• Prescribed fire • Fuel reduction in dense conifer plantations • Evaluate natural regeneration potential in forested areas that burned outside natural range of variation • Monitor restoration actions • Monitor fire effects on monarch (old and large) giant sequoias • Fuels treatments focused on reducing recurring high-severity fire • Fuel reduction treatments to further reduce forest density to within natural range of variation • Reforestation to create future resilient stands in areas that burned outside natural range of variation • Prescribed fire in sequoia groves that were unburned in the Rough Fire • Evaluate and monitor areas with high insect/drought mortality or large stand-replacing patches after fire to determine potential adaptation actions, which may include treatments to promote hardwoods to enhance resilience to future insect outbreaks, droughts, and wildfires • Plant more drought-tolerant genotypes, source seeds from warmer and drier seed zones

Restoration opportunity 2: take management actions to restore desired conditions—

Management actions to restore desired conditions in mixed-conifer forests encompass a wide range of high-priority activities, including managing fuel loads to create desirable conditions for future fires, restoring vegetation composition, implementing watershed restoration actions that are outside of the burned area emergency response process, containing and eliminating invasive plants, enhancing biodiversity through prescribed burning, reducing susceptibility of conifer plantations to insect attack through mechanical thinning, reforestation, and others. Low- and moderate-priority areas may warrant consideration for restoration activities where treatments are feasible and the results will have high impact. For example, fuel breaks for future fire management activities within low- or moderate-priority areas may be accomplished as an addition to salvage harvest operations and associated reforestation activities located in adjacent high-priority areas.

A landscape-scale strategy can be used to plan, prioritize, and schedule fire treatments in the assessment area. Prescribed fire units can be defined and prioritized based on spatial fire behavior modeling, field validation, and expert opinion. The units could have a variety of tactical approaches and objectives. Some examples include (1) application of fire on a short rotation interval to break up the continuity of postfire fuels; (2) maintenance of fire in areas that burned at low and moderate severity within the NRV fire return interval to reestablish natural fire regimes; and (3) reintroduction of fire in unburned giant sequoia groves within the analysis area to promote sequoia health, resilience, and regeneration (table 4.5). Reforestation activities for mixed-conifer forests may include the evaluation of natural regeneration (using direct field assessments and spatial prediction tools) (app. 3), site preparation, planting activities (i.e., artificial regeneration), and release of natural and planted trees (table 4.5). As noted above, additional spatial data layers (e.g., LMU, CWD, soil productivity), tools (apps. 3 and 7), and field data and observations can further refine areas in need of management action (i.e., reforestation activities) to restore desired conditions for forest ecosystems. For example, outputs from POSCRPT (fig. 4.7) can help identify areas for reforestation actions that are unlikely to support sufficient natural conifer regeneration in the foreseeable future.

A landscape-scale strategy can be used to plan, prioritize, and schedule fire treatments in the assessment area.

Restoration opportunity 3: reevaluate desired conditions considering climate change and other stressors—

Some severely burned areas where fire effects are outside NRV for mixed-conifer forests (e.g., large stand-replacing patches or areas reburned at high severity) may be unsuitable for the attainment of desired conditions (fig. 4.8). This is particularly the case in forest stands with high-moisture stress (e.g., high CWD, south-facing slopes at lower elevations) and elevated levels of prefire drought-induced tree mortality. In these areas, management actions may not be feasible for the restoration of current desired conditions, and a new set of desired conditions may be better aligned with likely future conditions (table 4.5). For example, coniferous forest vegetation could transition to a new ecosystem type with minimal management intervention, such as broadleaf woodland or chaparral that support similar, reduced or new ecosystem services (Millar and Stephenson 2015).

Table 4.5—Restoration portfolio for mixed-conifer forests in the 2015 Rough Fire analysis area

Restoration opportunity	Target areas	Management ctions	Timing	Feasibility	Cost of inaction
Maintain or promote desired conditions	High-quality fisher habitat (Spencer et al. 2016) that burned within NRV	Maintain high-quality fisher habitat using prescribed fire consistent with the historical fire return interval; consider prefire mitigation measures (e.g., tree raking) to reduce fuels around large trees used as den sites; mechanically thin dense conifer plantations to reduce susceptibility to insects and drought	Long term (10 + years)	Moderate	High
	High-quality fisher habitat (Spencer et al. 2016) that burned within natural range of variation but in small high-severity patches	Use prescribed fire consistent with the historical fire return interval to reduce fuels loads in a subset of small high-severity patches	Moderate term (3 to 5 years)	Moderate	High
	Sequoia groves and surrounding mixed-conifer forests that burned within natural range of variation where natural regeneration is likely adequate	Monitor areas of postfire vegetation recovery, particularly near monarch (old and large) sequoias where high densities of shade tolerant species may increase fire risk	Short term (1 to 5 years)	High	Moderate
Take management actions to restore desired conditions	Potential high-quality fisher habitat (Spencer et al. 2016) that burned within natural range of variation	Consider fuel treatments to increase the contribution of large trees to canopy cover, possibly using LiDAR to estimate canopy cover and locate large trees	Moderate-term (3-5 years)	High	High
	Potential high-quality fisher habitat that burned outside natural range of variation	Reduce the risk of high-severity fire by implementing fuels treatments that break up continuity in early-seral vegetation types, maintaining adequate canopy cover where feasible	Short term (1 to 3 years)	Moderate	Moderate
	Sequoia groves and surrounding mixed-conifer forest that burned outside natural range of variation and have low probability of natural conifer regeneration	Conduct reforestation activities to provide adequate stocking densities in priority areas based on outputs of analysis tools	Short term (1 to 3 years)	Moderate	Moderate
Reevaluate desired conditions considering interacting stressors	Low-quality fisher habitat (Spencer et al. 2016) and areas outside sequoia groves that burned within or outside natural range of variation	Monitor stands at high risk of type conversion due to climate change and other stressors, encourage hardwood cover in areas of high conifer mortality where warranted	Moderate term (3 to 5 years)	Low	Low

Note: This portfolio is based on the primary management goals, approaches, and opportunities presented in the text and summarized here and spatially represented in figure 4.6. This restoration portfolio has not yet been applied on a national forest to inform project planning.

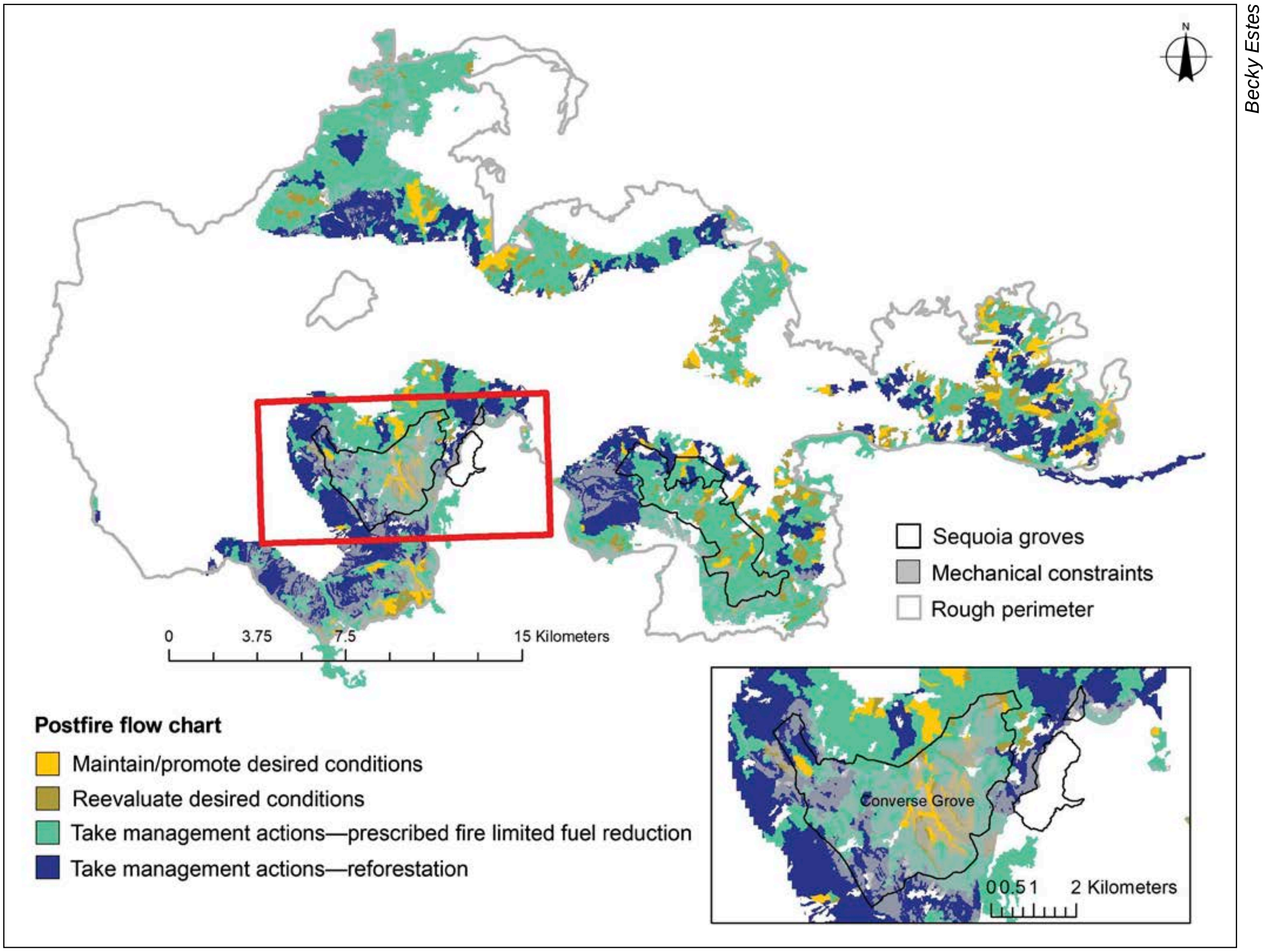

Figure 4.8—Spatial outputs of the postfire flowchart (upper panel) for the 2015 Rough Fire, with a subset of recommended restoration actions in Pacific fisher habitat and giant sequoia management areas. The inset map in the bottom right displays a portion of the analysis area focused in and around the Converse giant sequoia grove in greater detail (denoted by red outlined area in the upper panel). Further refinement of management actions can be determined using additional spatial data not shown here (e.g., mechanical treatments opportunities data for evaluating potential sites for reforestation activities).

Alternatively, management efforts could focus on a subset of more feasible desired conditions for mixed-conifer forests to achieve some long-term restoration goals. In areas of the Rough Fire that burned within NRV, this may include maintaining or establishing many fine-grained and irregularly shaped forest canopy openings (especially in drier topographic positions and low-productivity sites) within approximately 10 percent of the forest landscape to promote early-successional habitat. In areas of the Rough Fire that burned outside NRV, this may also include providing some patches of moderate-to-dense tree or shrub cover to support fisher habitat connectivity in habitat core and linkage areas. Additional desired conditions for other priority resources (e.g., proper watershed and soil function) may also be reconsidered in areas where conditions are significantly departed from NRV and the impacts of interacting stressors are substantial.

Step 4: Develop and Integrate Restoration Opportunities Into Potential Restoration Actions

Based on our review of the postfire flowchart (i.e., restoration opportunities 1, 2 and 3 above), we created a list of restoration opportunities focused primarily on sequoia groves and suitable fisher habitat areas. Based on these opportunities, we generated a list of potential management actions for the analysis area (many also listed in table 4.4):

- Monitor vegetation dynamics (structure, composition, successional trajectories) in priority areas, particularly in mixed-conifer forests that (a) burned within NRV for high-severity patch size (to determine potential future management actions), or (b) burned outside NRV for high-severity patch size with relatively high CWD (to identify areas that are unlikely to support desired conditions for prefire vegetation composition in the future, and determine any adaptive management approaches).
- Implement prescribed fire, hand, or mechanical treatments to further enhance targeted areas that burned within NRV for high-severity patch size.
- Conduct postfire stand inventories to confirm that natural regeneration is present and has a high probability of survivorship in areas that burned outside of NRV.
- Plant and manage artificial regeneration, including small groups of trees strategically planted to seed the surrounding area, or tree islands, in areas that burned in large patches of high-severity fire and have a low probability of natural regeneration success (North et al. 2019).
- Facilitate or accept ecosystem transitions in landscape-desired conditions, such as the conversion of conifer forest to oak woodlands or the management of early-seral forests (including shrublands) for species adapted to early-successional environments.
- Monitor fire effects on monarch (old and large) giant sequoias to evaluate their health and vulnerability to future stressors, especially in more severely burned groves or where fire affected named sequoias.
- Implement prescribed fire in giant sequoia groves that were unburned in the Rough Fire, are located within the analysis area, and are currently departed from their natural fire frequency (i.e., fire deficit).

In concert, these restoration opportunities can achieve landscape-level goals throughout the Rough Fire area. For example, the implementation of prescribed burning in forest stands that burned at low severity and continue to support forest cover will increase the likelihood that such stands are long-lived and do not succumb to future effects of drought, uncharacteristic wildfire, or beetle attack. Such resilient stands will have a high probability of continuing to support current and future management goals for mixed-conifer forests, including fisher habitat and giant sequoia groves.

Step 5: Build a Restoration Portfolio by Prioritizing Actions

The restoration portfolio prioritizes restoration opportunities based on timing, feasibility, opportunity cost, level of integration, and other considerations (table 4.4). The team can focus management in areas with a high potential for success and low risk of interacting stressors based on the restoration portfolio and postfire flowchart. (table 4.5). For example, the team could consider artificial reforestation in priority areas of lowest climate exposure (i.e., sites of lower moisture stress with the highest probability of long-term survivorship) with a focus on giant sequoia management areas and fisher habitat. Additional tools and approaches provided by North et al. (2012b, 2019) and in appendices 3 and 7 can help define zones with specific reforestation objectives based on accessibility of mechanical equipment, topographic features, and the likelihood of natural conifer regeneration and recruitment. Other tools and datasets may be available to further refine the restoration portfolio, prioritize areas where restoration is most likely to be successful, and achieve the postfire restoration goals in the Rough Fire analysis area.

The restoration portfolio prioritizes restoration opportunities based on timing, feasibility, opportunity cost, level of integration, and other considerations.

Conclusions

We assessed the effects of the 2015 Rough Fire on priority resources in the analysis area, including giant sequoia groves, Pacific fisher habitat, and other mixed-conifer forests. Primary stressors on these resources include altered fire regimes, insects and pathogens, and climate change. Our spatial assessment of pre- and postfire ecological conditions in the analysis area was based on vegetation type, landscape management unit, vegetation burn severity (amount and size of high-severity patches), and climatic water deficit.

The postfire flowchart led to the development of three primary management goals and potential restoration opportunities, with a focus on sustaining the integrity and resilience of giant sequoia groves, high-quality fisher habitat, and mixed-conifer forest ecosystems in general. The restoration portfolio identified several potential forest restoration actions, including prescribed burning, reforestation activities, and vegetation and habitat monitoring that can help to achieve long-term restoration goals in the Rough Fire analysis area.

Many areas that burned within the NRV lend themselves to prescribed burning and wildfires managed for resource objectives to promote and maintain desired conditions for terrestrial ecosystems (restoration opportunity 1). High-priority areas for intervention (restoration opportunity 2) include mixed-conifer forest patches that burned outside the NRV for high-severity patch size, particularly in canyon bottoms and northeast-facing slopes that are indicative of relatively low water stress and reduced climate change vulnerability. However, some stands within such uncharacteristically large high-severity patches are subject to high moisture stress (e.g., high CWD, south-facing slopes at lower elevations) and elevated levels of prefire drought-induced tree mortality. Such conditions may warrant a revision of desired conditions toward greater dominance of non-conifer (e.g., hardwood) vegetation.

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Chapter 5: California Chaparral Case Study

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Background

California Chaparral Ecosystems

Chaparral is the dominant vegetation type on dry steep slopes of the national forests in southern California. Chaparral ecosystems are dominated by evergreen fire-adapted shrubs with the ability to recover after fire through fire-stimulated seed germination from a large dormant seed bank or resprouting from unburned root crowns. Despite the resilience of chaparral ecosystems to periodic fire, their integrity is challenged by high frequencies of human-ignited fires, which can occur before resprouting species renew their carbohydrate reserves or regenerating individuals (from seed) reach reproductive size (Syphard et al. 2018). Degradation associated with frequent disturbance is compounded by other stressors, such as nonnative species, prolonged drought, and potential nitrogen deposition (Eliason and Allen 1997, Fenn et al. 2003, Pratt et al. 2014).

Chaparral shrublands provide a suite of ecosystem services not only to the residents of nearby metropolitan areas but also at the regional and even global scale (Underwood et al. 2018). The provisioning of critical services such as groundwater recharge, carbon storage, recreation, and erosion control underscore the importance of maintaining intact chaparral on national forest lands. Economic, social, and ecological values may be at risk in areas that have recently burned and are susceptible to type conversion to nonnative annual grasses, which provide fewer ecosystem services. We developed a restoration portfolio using the 2016 Sand Fire on the Angeles National Forest as a case study to identify and prioritize management actions after fire in chaparral-dominated landscapes to maintain and enhance these ecosystems and their provisioning services. We applied a two-step process to evaluate restoration needs and identify priorities within the Sand Fire: first, priority resources were identified, and then pre- and postfire ecological conditions were determined.

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Sand Fire

The Sand Fire ignited on July 22, 2016, in Los Angeles County east of the Santa Clarita Valley near Soledad Canyon and Sand Canyon. Wind, high temperatures, and steep topography resulted in 20,000 ac (8000 ha) being burned within the first 36 hours. Ten thousand homes were evacuated, 18 structures were lost, and one fatality was reported. The fire was contained on August 3, 2016, after burning 41,432 ac (16 767 ha) on federal, state and private lands (fig. 5.1). The Angeles National Forest comprised 90 percent of the burned area. The northwestern section of the Angeles National Forest has a rich fire history, with five different fires occurring within the 10 years prior to 2016. Most notable are the 2009 Station and 2008 Sayre Fires that overlap with 25 and 2 percent of the Sand Fire burn area, respectively.

Postfire Restoration Framework

Step 1: Identify Priority Resources, Desired Conditions, and Restoration Goals

Our postfire restoration analysis centered on identifying areas where chaparral degradation was most likely and where restoration efforts would maximize key ecosystem service benefits.

Our postfire restoration analysis centered on identifying areas where chaparral degradation was most likely and where restoration efforts would maximize key ecosystem service benefits. High-intensity fire across much of the footprint removed chaparral from steep slopes and created a water repellent soil layer. These conditions can lead to high-velocity runoff events with the ability to mobilize sediment and cause erosion on hillslopes that can affect water quality in the Santa Clara River, Pacoima Creek, and Little Tujunga Creek. Postfire actions to reduce soil hydrophobicity are generally avoided because of the scale at which the actions would need to occur, the lack of clarity surrounding treatment effectiveness, and the transience of the problem (DeBano 2000, Hubbert and Oriol 2005). Therefore, protecting vulnerable aquatic resources and downstream services relies on prioritizing recovery of chaparral stands (table 5.1).

Other resources of concern include bigcone Douglas-fir (*Pseudotsuga macrocarpa* [(Vasey) Mayr]) stands. Bigcone Douglas-fir is endemic to southern California and despite its ability to resprout after fire, recovery is impeded by high-severity fire. Within the Sand Fire, many of the bigcone Douglas-fir stands burned at low to moderate severity, which would likely favor survival and sprouting from epicormic buds in the canopy. Replanting of bigcone Douglas-fir may be a consideration in areas that experienced high levels of actual mortality (not merely top-kill), which were associated with high-severity fire and even in low-moderate-severity patches where trees had been affected by prefire bark beetle infestation and extreme drought.

Nicole Molinari

Figure 5.1—Postfire conditions of chaparral ecosystems in the 2016 Sand Fire.

Table 5.1—Primary resources and stressors considered in a postfire assessment of the Sand Fire (2016)

Resources	Spatial data	Explanation
Chaparral vegetation types	EVeg, fire return interval departure	Chaparral vegetation is the primary vegetation type on the landscape and an important contributor to ecosystem services.
Riparian vegetation types	Eveg	Intact riparian vegetation is important for providing stream conditions, shade, and thermal refugia appropriate for sensitive aquatic species.
Bigcone Douglas-fir vegetation type	EVeg	Dominated by an endemic species of conservation concern.
Sensitive aquatic species	Natural resource manager	Prioritize upland areas where restoration may prevent sloughing or sedimentation into downstream watercourse and affect sensitive riparian species (e.g., arroyo toad [*Anaxyrus californicus*]; Santa Ana sucker [*Catostomus santaanae*]; unarmored three-spined stickleback [*Gasterosteus aculeatus williamsoni*]).
Stressors or Constraints	**Spatial Data**	**Explanation**
Fire	Vegetation burn severity (RAVG), fire return interval departure	Fire severity affects short-term vulnerability of vegetation; fire return interval departure influences chaparral resilience.
Nonnative plants	Herbaceous vegetation layer, FACTS database	Exotic grass invasion can facilitate undesirable type conversion of native shrublands and woodlands to nonnative annual grassland.
Grazing	Grazing allotments	Potential livestock grazing impacts to postfire vegetation recovery.
Climate change	Climatic water deficit, either current or projected for early 21st century	Climatic water deficit and climate exposure estimates long-term vulnerability of vegetation.
Land use designation	Recommended and wilderness areas, special interest areas, wild and scenic rivers	May require formal planning and limit methods available for restoration.
Landscape position	Landscape management units	Slope steepness can inform whether restoration is logistically feasible. Slope and aspect can inform species selection.
Transportation corridors	Roads and trails	Areas within 50 ft (~15 m) of off-highway vehicle roads and trails generally receive greater impacts and may affect restoration actions.

Riparian vegetation may also be a focal resource for postfire management. California bay woodlands, riparian willow scrub, and cottonwood/sycamore riparian woodlands generally burned at low to moderate severity, indicating that these areas are likely to recover without active restoration efforts. However, stretches of riparian habitat that burned at high intensity, as reported for parts of Little Tujunga Creek, may result in increased stream temperature, increased algal and sediment concentrations, and an overall negative impact to aquatic species (Cooper et al. 2015), making them priority areas for restoration.

Land management plans for southern California forests highlight the need to remove nonnative species (which may impede postfire vegetation succession), facilitate recovery after disturbance, and conduct vegetation treatments to improve ecosystem services, such as water quantity and quality. Given these foci, the **desired condition** for chaparral that guided this case study was to **promote or maintain chaparral ecosystem integrity and resilience**. To achieve this desired condition, our two primary restoration goals included maintaining sufficient native shrub cover and reducing the probability of future fire ignitions that would interfere with chaparral ecosystem recovery within the Sand Fire area.

Step 2: Gather and Review Relevant Spatial Data

The Sand Fire boundary was used to evaluate the need for postfire restoration. We selected this geographic extent based on the expectation that fire would have the greatest impact within the fire scar, and therefore restoration actions would be most valuable within the fire perimeter. Within the Sand Fire, the chaparral and serotinous conifer pre-1850 (pre-Euro-American settlement fire regime [PFR]) vegetation type dominated 78 percent of the prefire landscape (table 5.2). Within this PFR type, mixed chaparral, which is co-dominated by several shrub species (e.g., *Arctostaphylos* spp., *Ceanothus* spp.), accounts for 91 percent of chaparral-dominated lands and commonly occurs on northern aspects. Chamise (*Adenostoma fasciculatum* Hook. & Arn.)-dominated chaparral accounts for much of the remaining chaparral PFR vegetation type and occupies south- and west-facing exposures with higher solar radiation. The mixed-chaparral type is typically dominated by species that regenerate from seed after fire (obligate seeders), while chamise can regenerate via seed and resprouts (facultative resprouter). Canyons were largely characterized as supporting mixed evergreen vegetation, and bigcone Douglas-fir commonly occurred on mesic, north-facing slopes.

Table 5.2—Dominant vegetation types in the Sand Fire burn perimeter determined using the pre-Euro-American settlement fire regime (PFR) groups developed by Van de Water and Safford (2011)

PFR type	*Acres*	*Hectares*	*Percent*
Bigcone Douglas-fir	1,310	3 236	3.2
Chaparral, serotinous conifer	32,420	80 077	78.0
Coastal sage scrub	2,781	6 869	6.7
Mixed evergreen	2,133	5 269	5.1
Moist mixed conifer	45	111	0.1
Semidesert chaparral	1,100	2 717	2.6
Other	1,773	4 379	4.3

As is common in chaparral, over 75 percent of the vegetation within the Sand Fire burned at high severity, as measured by the Forest Service Rapid Assessment of Vegetation Condition after Wildfire (RAVG) burn severity data, which are typically generated within a month after fire containment. Low vegetation burn severity comprised 12 percent of the fire scar with a large patch of low severity occurring in the southeastern corner where the fire reburned the previous 2009 Station Fire area.

Major impediments to chaparral recovery in southern California are increases in fire frequency and nonnative annual grasses.

Throughout southern California, modern fire frequencies in chaparral ecosystems are higher or far higher than under pre-1850 conditions (Safford and Van de Water 2014) resulting in potential impediments to recovery (Haidinger and Keeley 1993, Zedler et al. 1983). Prior to the Sand Fire, much of the chaparral ecosystem within the assessment area was burning more frequently than in the past. The natural range of variation (NRV) for fire return interval (FRI) in chaparral was estimated at 30 to 90 years by Van de Water and Safford (2011). Prior to 2016, 81 percent of the area occupied by chaparral in the Sand Fire had experienced FRIs between 18.2 and 36.9 years, which puts them in a moderate departure condition class. Less than 1 percent of chaparral area had experienced even more frequent fire than that, falling into a high departure condition class. The Sand Fire moved the chaparral landscape even further from the NRV (Van de Water and Safford 2011), such that 96 percent of the chaparral area within the Sand Fire is now characterized as moderately departed from historical FRI, and 4 percent is highly departed.

Step 3: Use the Postfire Flowchart to Identify Restoration Opportunities

Question A: Where did fire improve or maintain ecological conditions, and are fire effects within desired conditions or NRV?—

Too-frequent fire is a primary constraint to chaparral recovery (Syphard et al. 2018), and therefore evaluating previous fire within the fire footprint is a necessary first step to understanding recovery potential. Unlike conifer forests (see chapter 4), high-intensity fire represents the historical condition and does not affect chaparral recovery. Ecosystem degradation has been documented in chaparral shrublands after periods of high fire frequency (Haidinger and Keeley 1993, Lippitt et al. 2013, Zedler et al. 1983). Short-interval fire may affect recovery by preventing chaparral shrubs from reaching maturity between fire events. This immaturity risk poses the greatest threat to obligate seeding species that are slow growing and require multiple years to become reproductive, but even resprouting species eventually consume their carbon stores if fires are too frequent.

Time since last fire (TSLF), current fire return interval (CurrentFRI), and condition class (MeanCC_FRI), all found as attributes in the FRID spatial layer, can be used to determine deviations in fire frequency within the assessment area (Safford and Van de Water 2014). Given the excess of recent fires within the Sand Fire perimeter, like much of southern California, TSLF best captures recent deviations from NRV and highlights areas that may have been affected by the 2016 fire event. Current FRI and MeanCC_FRI are more appropriate for capturing fire history across the past century. As such, they will become useful when considering the likelihood for continued disturbances that may disrupt restoration success (see description in question C below).

To identify chaparral stands that are most susceptible to type conversion, we overlaid TSLF on areas of the chaparral and serotinous conifer PFR vegetation type that experienced high-severity fire (as mapped by RAVG) (fig. 5.2).

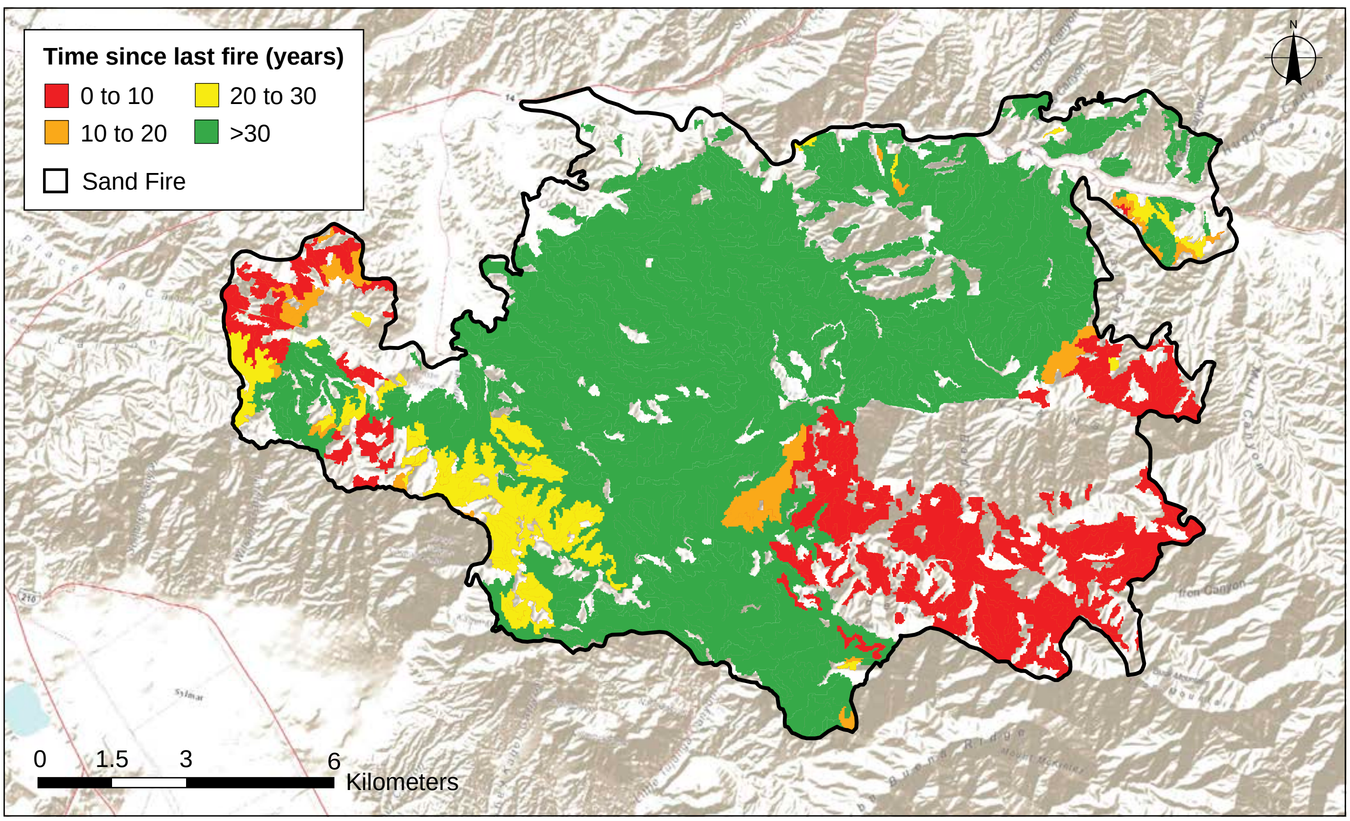

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Figure 5.2—Time since last fire represents the number of years between the Sand Fire and the previous fire occurring within the Sand Fire footprint. The colored parts of the map denote chaparral and serotinous conifer pre-Euro-American settlement type that burned at the highest severity class (75 to 100 percent vegetation loss). Uncolored areas within the map were not dominated by chaparral and serotinous conifers or did not burn at high severity. Chaparral stands that burned within the past 30 years (red, orange, yellow) prior to the Sand Fire may be moving away from desired conditions and toward a degraded state (question C). Chaparral stands that have not experienced fire in the last 30 years (green) were assumed to be resilient and able to recover from the Sand Fire (question B).

The output from this analysis partitioned the landscape into areas that experienced stand-replacing fire in the past 30 years and then reburned in the Sand Fire (fig. 5.2). These chaparral stands may be moving away from desired conditions and toward a degraded state (question C below). Chaparral stands that had not experienced fire in the past 30 years were assumed to be resilient and able to recover from the Sand Fire (question B below). We field validated this output by establishing vegetation surveys within the Sand Fire and placed plots in areas that burned within the past 10 years, areas that burned within NRV, and those that had not experienced fire in more than 90 years (old-growth stands). In general, chaparral plots that burned twice in the past 10 years exhibited signs of degradation that include a reduction in native seedling density and a higher cover of nonnative species than plots that had not experienced fire in more than 30 years.

Question B: Where do other factors threaten long-term ecological resilience and sustainability?—

Chaparral stands that are within NRV for fire frequency have the highest likelihood of recovering passively (due to existing seed banks and resprouting capacity), yet there are other stressors that may impede recovery. A major impediment to chaparral recovery is the presence of nonnative annual grasses, such as bromes (*Bromus* sp.), wild oats (*Avena* sp.), and barleys (*Hordeum* sp.), that can quickly colonize postfire landscapes, limiting available moisture and light to recovering shrub species (Eliason and Allen 1997, Engel 2014), and that cure early in the dry season and promote repeated fire because of continuous fuelbeds. Remote-sensing techniques have used Landsat imagery to estimate the cover of herbaceous annual species, many of which are nonnative annual grasses, across the national forests in southern California from 1984 to 2011 (Park et al. 2018). Extending the nonnative annual grass assessment beyond 2011 will be critical to the continued use of this layer for postfire prioritization. For the Sand Fire, we used the most recent nonnative grass cover data layer (2011) to determine areas with higher risk for type conversion. Areas with higher prefire nonnative grass cover will have a greater likelihood for postfire invasion (fig. 5.3) and therefore could be considered at risk and evaluated for restoration feasibility (question C below). For this analysis, we arbitrarily selected a threshold of 20 percent nonnative cover to divide high (>20 percent) and low (<20 percent) risk; however, the cutoff value would ideally be determined based on the traits of nonnative annual species present in the burned area, previous experience with native species recovery in invaded areas, and likelihood of eradication success. Chaparral stands with minimal presence of nonnative annual grass are likely to be more resilient after the Sand Fire and therefore could be considered for maintenance of desired conditions (restoration opportunity 1). Similarly, high

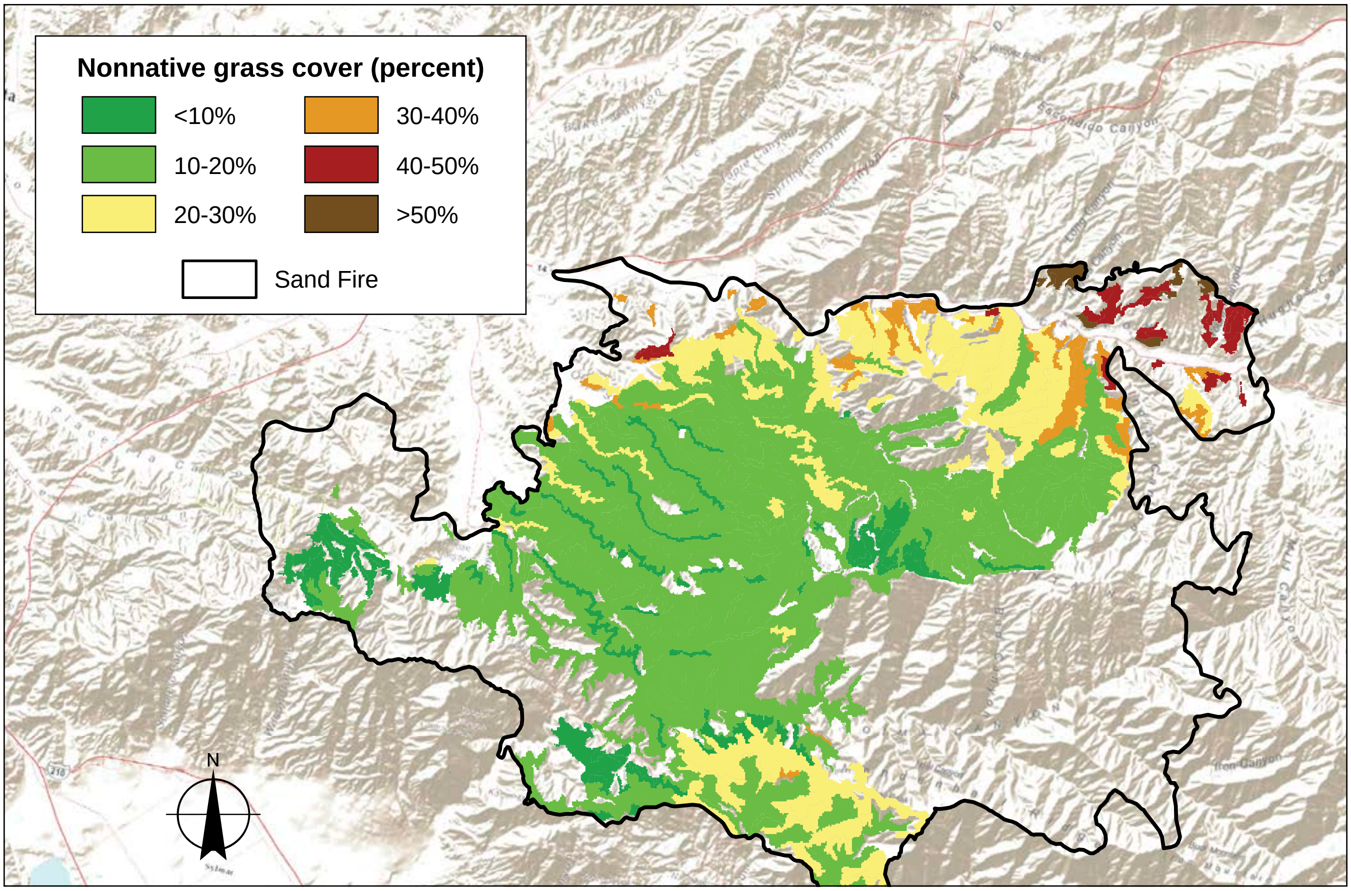

Figure 5.3—The colored areas denote areas that had not experienced fire in the past 30+ years (see fig. 5.2) and based on past fire history are likely to recover on their own, unless additional stressors (e.g., nonnative species, drought) disrupt recovery. This map shows a Landsat-derived overlay of nonnative annual plant cover. Chaparral stands with low nonnative cover (<20 percent) could be considered for maintenance of desired conditions (restoration opportunity 1). Locations with a higher abundance (≥20 percent) of nonnative species may be at-risk to degradation and would ideally be evaluated for feasibility of restoration (question C).

nitrogen deposition can promote nonnative annual grasses, further decreasing the likelihood of native shrub recovery (Allen et al. 2018). Currently, the nitrogen deposition maps are too coarse in scale to make them informative for this analysis; however, more useful fine-resolution data may become available in the future.

Question C: Where are management approaches feasible for the restoration of desired conditions given current and anticipated future conditions?— The feasibility of restoration will be constrained by the context of current and future conditions. Recognition that current climate and disturbance regimes may be different than those under which the prefire vegetation established is an essential consideration when determining the feasibility of restoration. For example, chaparral-dominated lands experiencing more frequent or severe drought today than in the past, or a recent history of frequent human-ignited fires, may be challenging to restore to prefire condition because the climate and disturbance environment have

Understanding how climate and disturbance regimes have changed is critical to determining restoration feasibility.

changed and may no longer be able to support historical species assemblages. The use of current and future climate projections and spatial data showing the historical (past 100 years) frequency of fire can help to determine whether it may be appropriate to realign desired conditions with these new circumstances (restoration opportunity 3 below).

Postfire drought is a key factor influencing the success of shrub establishment. Chaparral stands that experience extreme postfire drought may be more susceptible to die-off of naturally established shrubs (Pratt et al. 2014), and mortality patterns are likely to be similar in restored areas that have been seeded or planted. Thus, feasibility of restoration under these conditions may be limited. Climatic water deficit (CWD), a climate index that incorporates soil characteristics, temperature, and precipitation, can be used to delineate areas on the landscape with the highest exposure to drought. In addition, planning for vegetation resilience may be facilitated by considering a “worst-case” climate scenario. Managers can incorporate projections of future CWD in the short term (2010 to 2039), mid-term (2040 to 2069), or long term (2070 to 2099) under more extreme (e.g., greater climate exposure) scenarios to develop ”no-regrets” solutions (i.e., beneficial even if extreme conditions are not realized) and identify sites with the highest chance of successful restoration. Landscape position (e.g., south- versus north-facing slope from the Landscape Management Unit [LMU] output) may provide additional information on climate exposure. Restoration of chaparral shrubs in drier areas (e.g., south-facing slopes), more drought-prone areas (e.g., high current CWD), or areas that will be more exposed to increased CWD in the future (e.g., high future CWD) may require a more active restoration approach (e.g., long-term watering). Given resource limitations and agency capacity, implementing such approaches may be practically and financially unfeasible. If restoration success is likely to be compromised by drought, managers might consider broadening desired conditions to include native species or vegetation types that are more drought tolerant, for example, coastal sage scrub or native perennial grass species (restoration opportunity 3 below), regardless of prefire species composition. Meanwhile, focusing restoration actions on more mesic areas (e.g., north-facing slopes, areas with low CWD) may increase the probability of successful chaparral restoration (restoration opportunity 2 below). Sites with intermediate climatic exposure may require some mixture of the restoration approaches mentioned above.

Similar to drought, habitual fire may also thwart restoration success and warrant revisiting desired conditions toward species that better tolerate disturbance. The MeanCC_FRI and CurrentFRI attributes within the FRID dataset provide a window into historical fire activity on the landscape. MeanCC_FRI was used to inform locations on the landscape where fire activity over the past 100 years has become severely departed from historical conditions (condition class = -3, burning at a fire frequency of less than 18 years). Approximately 4 percent of chaparral ecosystems within the fire perimeter are now severely departed from pre-1850 fire conditions. These areas might be flagged as having an excessively frequent disturbance regime that may no longer support dense chaparral vegetation (fig. 5.4). This information, coupled with fire ignition data, can guide conversations about locations where fire prevention activities, fire suppression actions, or fuel modifications are most valuable. In instances where fire is impractical to control (e.g., steep terrain, wind corridors) or ignitions are likely (e.g., roadsides, campgrounds), it may be necessary to modify desired conditions to account for the long-term altered fire regime (restoration opportunity 3 below).

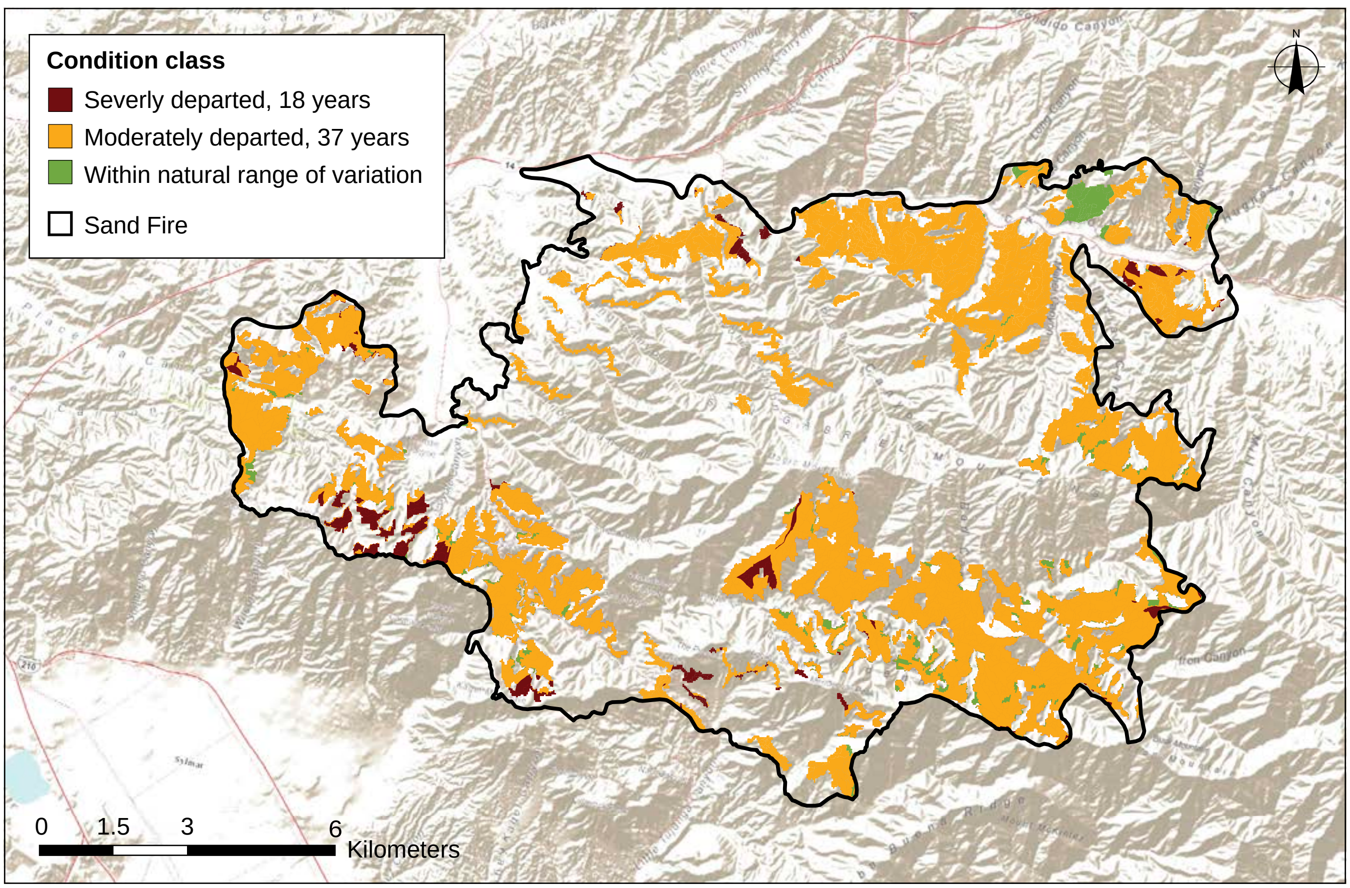

Figure 5.4-Areas identified in Question C as being at risk of degradation due to reburning (time since fire < 30 years) or high nonnative cover (>20 percent). Condition class highlights the fire history of the area and identifies locations where fire return interval is severely departed (in deep red, burning at a fire return interval of less than 18 years). These areas may represent places where successful chaparral restoration is tenuous given the likelihood of continued disturbance. Areas that are moderately (orange) or not departed (green) from the pre-Euro-American settlement fire return interval may be suitable for restoration to pre-fire conditions and evaluated further in restoration opportunity 2.

Restoration opportunity 1: maintain or promote desired conditions—
Given the sensitivity of chaparral to frequent burning, areas that burned within the assessment area may warrant protection from future fire in the near to mid-term (30 years). To achieve this goal, it may be appropriate to maintain fuel breaks in strategic locations (e.g., ridgetops) so that other areas that are ecologically vulnerable or rare on the landscape (e.g., old-growth chaparral, high-biodiversity sites) can be protected (Safford et al. 2018). After fire, information on spatial patterns of ecosystem services can be used to identify locations where resources would be focused to maintain native shrubland with the intent of maximizing ecosystem service values (box 5A). To prevent chaparral degradation, it may be valuable to engage appropriate management staff (e.g., fuels planner, fire prevention, botanist, etc.) in the development of a fire prevention and fuels management strategy aimed at limiting human-caused ignitions and fire spread over the short term to allow chaparral shrubs to reach maturity and reestablish a robust seed bank (seeding species) or increase underground carbon storage (sprouting species), so that regeneration in the future is not impaired.

Developing a fire prevention and fuels management strategy may help ensure that future chaparral regeneration is not impaired.

Preventative measures to reduce the likelihood for nonnative species establishment and hillslope erosion should also be considered. The establishment of fencing or visible barriers can limit trespass from unauthorized users who may increase movement of nonnative species and exacerbate erosion within the fire scar. Containment lines where canopy cover was removed as part of fire suppression can also benefit from the scattering of branches to reduce erosion and create a barrier for trespass. The use of native herbs, grasses, and low-growing vegetation within areas mechanically disturbed during fire activities (e.g., containment lines, fuelbreaks) could inhibit invasion by nonnative species.

Restoration opportunity 2: take management actions to restore desired conditions—
In areas that have been deemed important and ecologically feasible (question c, above) to restore resilient native shrub dominance, additional data layers (e.g., road layer, topography, designated areas) can help inform accessibility and logistical feasibility for restoration. Spatial assessments that incorporate proximity to roads, slope steepness, and special land use designations tailored to the southern California landscape can help to select restoration sites.

Because areas dominated by nonnative species may represent a persistent state, restoration efforts aimed at increasing the abundance of native shrub species may need to consider nonnative species abatement and native species selection for outplanting. If pre-conversion vegetation information (e.g., native species composition, shrub density) is available, it can be used to inform desired conditions. Additionally,

Box 5A:
Mapping the Value of Ecosystem Service Provision in the 2016 Sand Fire

Ecosystem service spatial data was extracted for the Sand Fire with a 2-km (1.2-mi) buffer from a regional dataset that encompasses the four national forests in southern California. The data layers representing prefire conditions include the following:

- Water runoff and groundwater recharge (average for 1981–2010) from the Basin Characterization Model (Flint et al. 2013)
- Mean Enhanced Vegetation Index (ranging from 0 to 1) compiled from Landsat TM imagery as a proxy for carbon storage
- Fire sediment retention calculated from the Sediment Delivery Ratio model of InVEST (Sharp et al. 2014)
- Biodiversity was represented by an index of irreplaceability (Pressey et al. 1994) (ranging from 0 to 100) generated using numerous conservation targets (e.g., sensitive species, natural vegetation types, landscape connectivity, and watershed condition class) each with an associated conservation goal.

The range of values for the Sand Fire are displayed in figure 5.7; however, note that there are likely to be higher values found outside of this study area. The southeast corner of the fire perimeter has the highest values for water runoff (averaging more than 300 mm/year [11.8 inches/year]), along with the San Gabriel Mountains. Groundwater recharge is highest in an east-west swath along the southern edge of the fire boundary. Biodiversity, as defined in this study, is concentrated in a southern area and a northern area around Soledad Canyon. The higher elevation areas of the San Gabriel Mountains and the western side of the fire have relatively high Enhanced Vegetation Index levels, the proxy used for carbon storage, with highest Enhanced Vegetation Index values found along riparian areas. Patterns of sediment erosion retention largely reflect drainage pattern, with less steep areas and stream and river drainages having higher retention than surrounding slopes.

To combine these layers, we used a straightforward approach that resampled data to 30 m (100 ft) where necessary, normalized the values in layers by converting from native mapping units to deciles, and then summed the five individual layers to give an indication of higher and lower values of service provision across the landscape. In this case study, we assume areas with higher values contribute the most to the provisioning of services and therefore would be priorities for

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Emma Underwood.

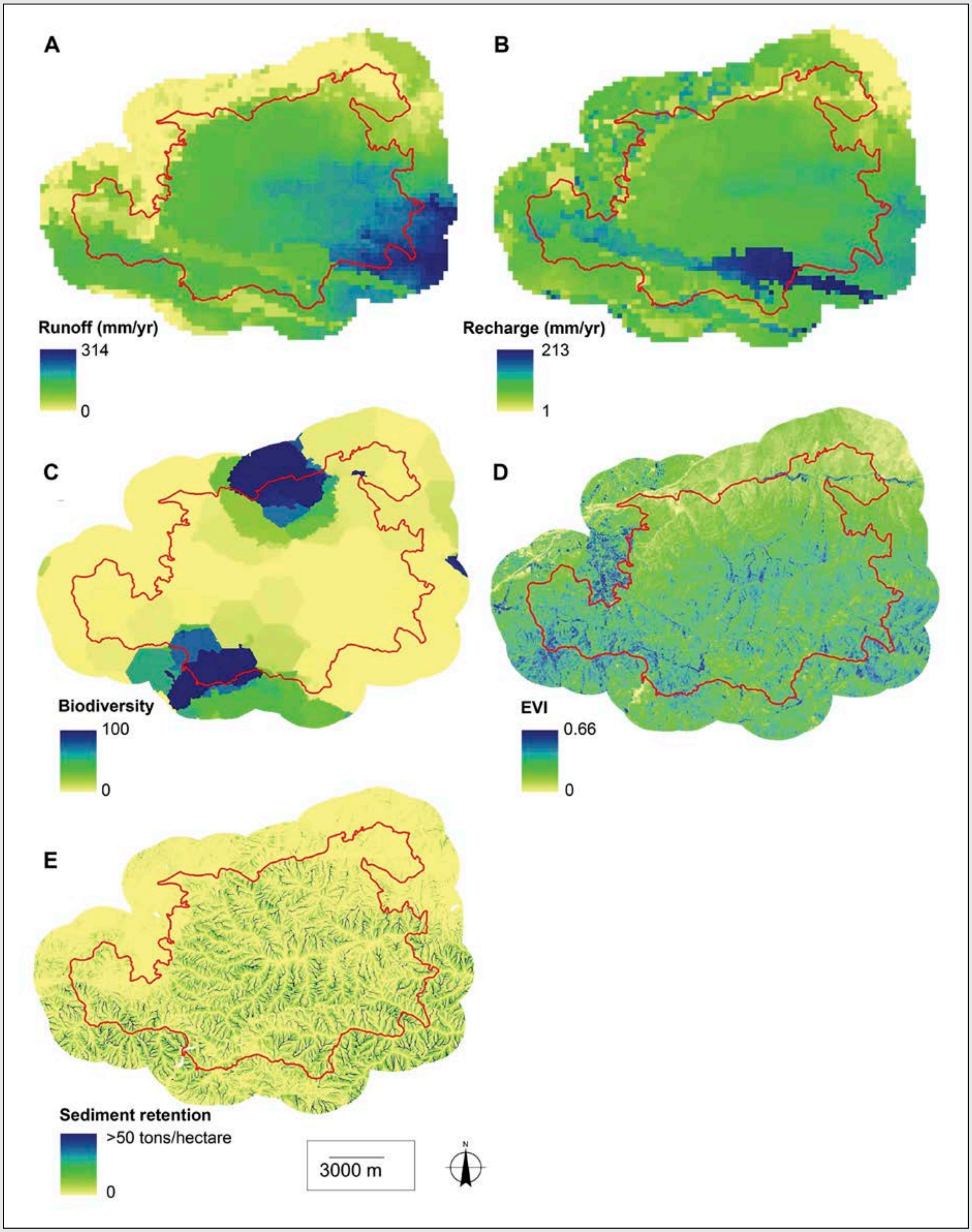

Figure 5.7—Prefire patterns of ecosystem services around the Sand Fire, including 2 km (1.2 mi) buffer shown in their original mapping units; (A) water runoff, (B) groundwater recharge, (C) biodiversity, (D) the Enhanced Vegetation Index from 2014 Landsat imagery as a proxy for carbon storage, and (E) sediment erosion retention index in metric tons/ha.

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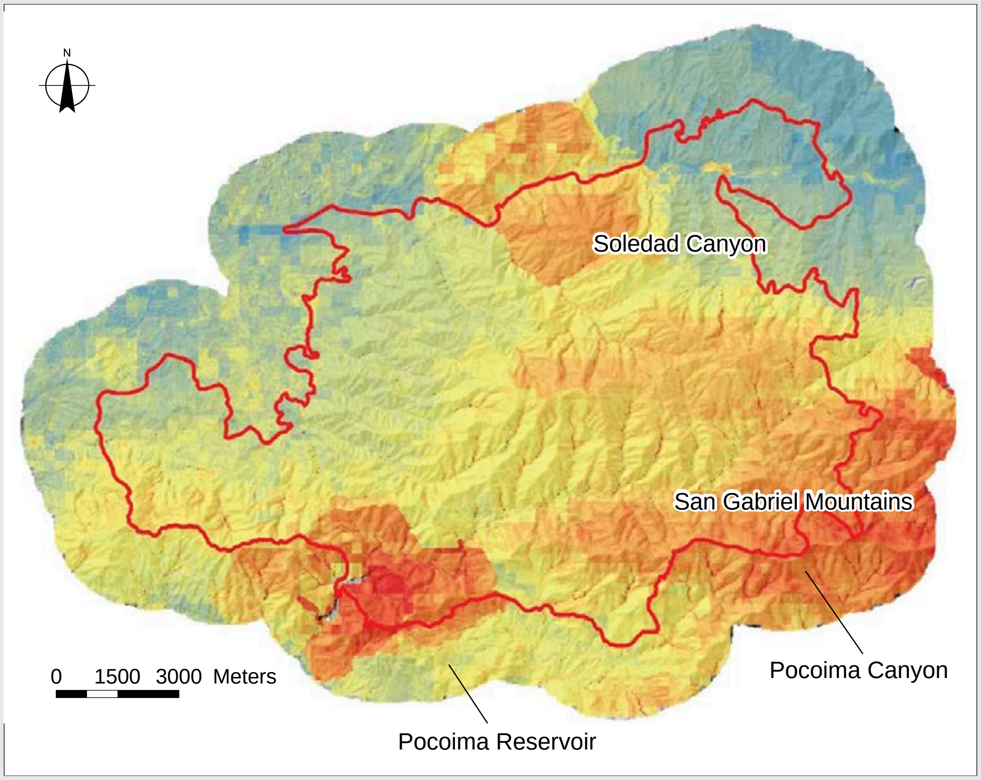

Figure 5.8—Summation of values of five data layers indicating provision of ecosystem services (water runoff, groundwater recharge, sediment erosion retention, carbon storage, and biodiversity) across the Sand Fire (red perimeter); warm to cool colors represent high to low values of ecosystem services.

restoration, i.e., areas in red (fig. 5.8) have highest values for water runoff, groundwater recharge, sediment erosion retention, biodiversity, and carbon storage.

Areas of higher values include the southeastern area, comprising the San Gabriel Mountains, the area to the east of the Pocoima Reservoir, Soledad Canyon, and numerous stream and river drainages in the central area of the burn. Lower value areas are found in the northeastern and western parts of the study area.

This example shows the type of data on the provision of ecosystem services that can be integrated with other information in management decisionmaking. However, the way in which the different ecosystem services data layers are valued and viewed will ultimately depend on goals of resource managers. For example, areas of high value across all services suggests the opportunity for restoration activities to achieve benefits across multiple services. In other cases, the values of a single service might be sufficient for decisionmaking, such as minimizing future sediment erosion. These results can be used in conjunction with other data on burn severity, fire frequency, climatic water deficit, presence of nonnative species, and landscape position to identify potentially successful areas for restoration that will restore not only native vegetation but assist the long-term provision of services in the future.

data layers that inform moisture availability, such as aspect, soils, CWD and landscape position, can help guide which postfire plant functional types (e.g., species that regenerate from seed or resprout) will have highest survivorship (fig. 5.5). Species that recruit via seed postfire may be better suited to xeric south-facing slopes due to their physiological capacity for dealing with drought stress (Jacobsen et al. 2007, Keeley 1998, Meentemeyer et al. 2001). However, the deep roots of resprouting species permit access to persistent water reservoirs, resulting in drought avoidance during times of high drought intensity. Therefore, resprouters may be adapted to withstand high-intensity drought once they are established (Pausas et al. 2016). During restoration, the seedlings of obligate resprouting shrubs, on the other hand, may be more successful on mesic sites due to their drought sensitivity. Resprouters also recover more rapidly after disturbance and are likely to better provide carbon sequestration, soil retention, and wildlife habitat services than seeders.

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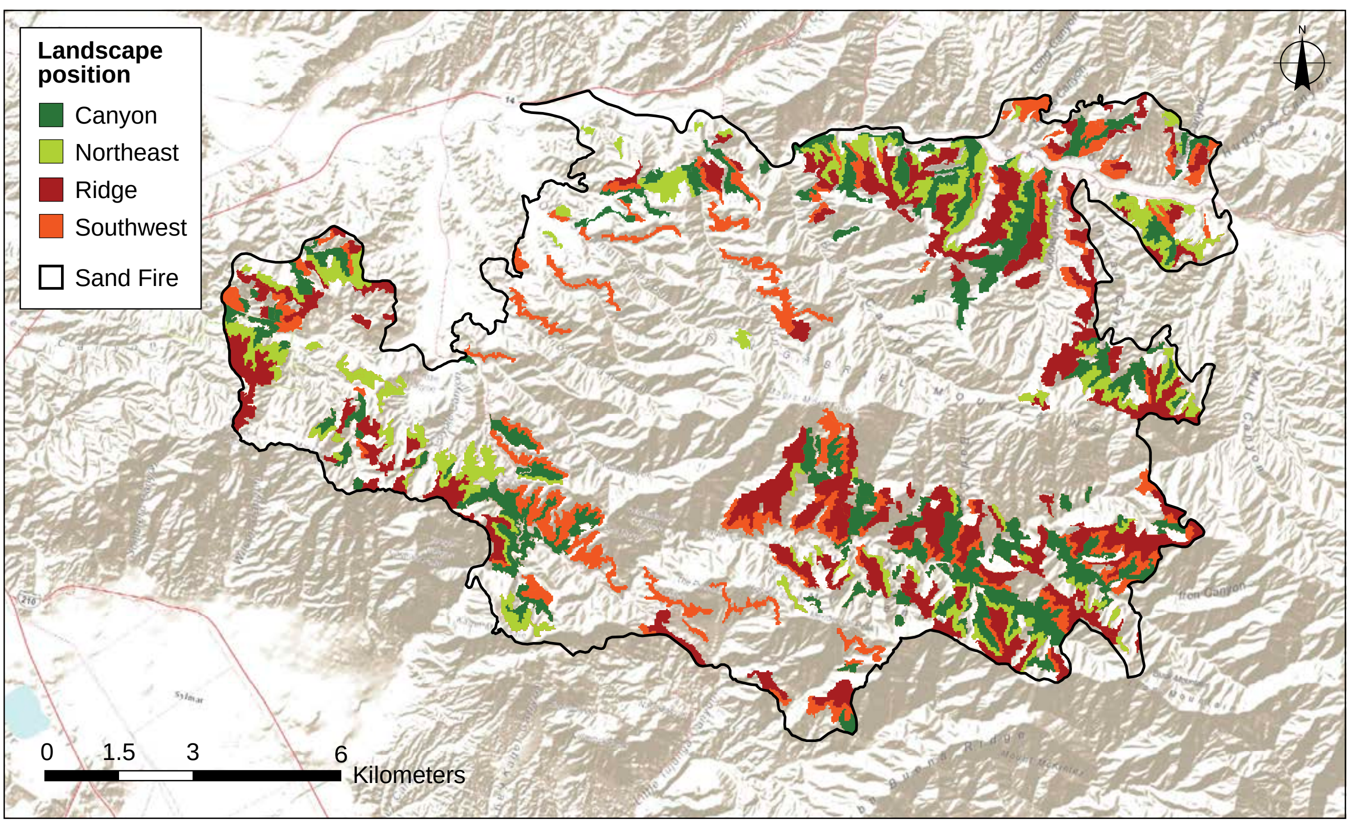

Figure 5.5—Areas identified in question C as being at risk of degradation due to reburning (time since fire <30 years) or high nonnative cover (>20 percent). Landscape position, as determined from the landscape management unit tool, may be important for determining restoration success and selection of species for dry versus mesic conditions.

Restoration opportunity 3: reevaluate desired conditions considering climate change and other stressors—
Extreme drought and a habitually perturbed fire regime may hinder efforts to restore a resilient native shrubland to a prefire state. Given these environmental stressors, managers might redefine goals to maximize the opportunity for resilience in the face of increasing fire and drought. Some options for seeding species include selecting species that have a short time to maturity and therefore are able to reproduce despite short fire intervals. Some coastal sage scrub (e.g., California buckwheat [*Eriogonum fasciculatum* Benth.], common deerweed [*Acmispon glaber* (Vogel) Brouillet], and sage [*Salvia* spp.]), and grassland (e.g., needle grasses [*Stipa* spp.]) species may be good candidates under these conditions.

If extreme drought and a habitually perturbed fire regime hinder efforts to restore a resilient native shrubland to a prefire state, goals may need to be redefined.

Goals may emphasize ecosystem services, such as erosion control and soil stabilization, especially where restoration of historical vegetation seems infeasible (box 5A). For example, within the wildland-urban interface, upland slopes dominated by nonnative annual species may be a high priority for reestablishing deep-rooted, sprouting shrubs that stabilize soil and deter off-trail recreation.

Step 4: Develop and Integrate Restoration Opportunities Into Potential Restoration Actions

A list of potential management actions for the Sand Fire footprint were generated from the postfire flowchart output (full list provided in table 5.3):

- Detect and eradicate high-priority nonnative species with the potential to spread
- Reseed and replant native species
- Restore fire regime by reducing the frequency of fire
- Monitor ecosystem condition and restoration treatment effectiveness over the long term

Many of the management actions listed above will need to be combined to achieve the focal desired condition to **promote or maintain chaparral ecosystem integrity and resilience**. Following fire, areas that show impediments to shrub recovery are often dominated by nonnative annual species. Therefore, weed control would ideally coincide with the replanting of native shrubs to reduce competition for light and soil moisture (Engel 2014, VinZant 2019). Similarly, native shrub recovery will be impeded by continued disturbance, such as fire and recreation (Safford et al. 2018). To this end, postfire restoration discussions and planning require the inclusion of fuel, fire, resource, and recreation personnel.

Table 5.3—Postfire flowchart outputs that serve as the foundation of a restoration portfolio

	Output		
Primary restoration goals	• Promote or maintain sufficient native shrub cover for chaparral ecosystem integrity and resilience • Reduce probability of future human-caused ignitions within the 2016 Sand Fire		
Most relevant guiding principles from the restoration framework	• Sustain ecosystem services • Support regional native biodiversity and habitat connectivity • Restore key ecological processes • Incorporate climate change adaptation		
Analysis area	2016 Sand Fire perimeter		
Restoration objectives	Maintain or promote desired conditions	Take management actions to restore desired conditions	Reevaluate desired conditions considering interacting stressors
Potential restoration actions	• Restore historical (infrequent) fire regime • Manage nonnative plants • Identify areas for unauthorized trespass • Monitor ecological status and trend of passive restoration	• Restore historical (infrequent) fire regime • Manage nonnative plants • Reseed and replant native vegetation • Identify areas for unauthorized trespass • Monitor effectiveness of restoration actions	• Adjust desired conditions to align with current conditions • Manage nonnative plants • Consider planting disturbance/drought tolerant species • Identify areas for unauthorized trespass • Monitor effectiveness of restoration action

Step 5: Build a Restoration Portfolio by Prioritizing Actions

Priority areas for restoration can be refined by integrating ecosystem service data within areas of greatest restoration need and feasibility.

The restoration portfolio was developed for the Sand Fire analysis area (table 5.4). Priority areas for restoration can be further refined by integrating the ecosystem service data (box 5A) within the areas of greatest restoration need that are ecologically feasible to restore (fig. 5.6) or using additional analysis tools (app. 5). The goal of combining this information is to maximize restoration gain such that restoration of native vegetation corresponds with the greatest provision of ecosystem services. For example, chaparral stands where restoration is likely needed and feasible (orange and green areas in fig. 5.4) could be prioritized based on the highest ecosystem service gain (Underwood et al. 2018) (box 5A). In the Sand Fire, these areas include the southeast portion of the fire scar near Pacoima Canyon and the southern extent closest to Pacoima Reservoir (fig. 5.6).

Table 5.4—Restoration portfolio for the Sand Fire analysis area based on the primary management goals, approaches, and objectives presented in table 5.3 (continued)

Restoration objectives	Target areas	Management actions	Timing	Feasibility	Cost of inaction
Maintain or promote desired conditions	Along dozer lines, maintained fuelbreaks and Forest Service routes and permitted road use	Site visits for early detection of nonnative species; contain and, where feasible, eradicate nonnative plants	Short term (1 to 3 years)	Low to moderate[b]	High
	Areas with potential for unauthorized trespass (e.g., dozer lines) that may contribute to erosion or the introduction of nonnative species	Put in visual barriers, vertical mulching, fencing with intertwined shrubs, consider trenches to prevent access. Where appropriate, re-establish native species or pull natural features (e.g., branches, rocks, logs) back onto the area	Short term (1 to 3 years)	Low to moderate[c]	Moderate
	Areas of high resource value or with high ecosystem services	Reduce human-caused ignitions through education, installation of concrete barriers along roads	Mid-term (1 to 10 years)	Low	High
	Public access areas or areas with high recreational use	Monitor for early detection of nonnative species introductions and eradicate	Mid-term (1 to 10 years)	High	High
Take management actions to restore desired conditions	Along dozer lines, maintained fuelbreaks and Forest Service routes and permitted road use	Site visits for early detection of nonnative species; contain and, where feasible, eradicate nonnative plants	Short term (1 to 3 years)	Low to moderate	High
	Areas showing signs of degradation	Reestablish native shrubs and herbs	Short term (1 to 3 years)	Moderate[a]	High
	Areas with potential for unauthorized trespass (e.g., dozer lines) that may contribute to erosion or introduction of nonnative species	Put in visual barriers, vertical mulching, fencing with intertwined shrubs, consider trenches to prevent access. Where appropriate, reestablish native species or pull natural features (e.g., branches, rocks, logs) back onto the area	Short term (1 to 3 years)	Low to moderate[c]	Moderate
	Within areas slated for restoration	Contain and, where feasible, eradicate nonnative plants	Short-term (1 to 3 yr)	Low to moderate	High
	Restored areas	Install long-term vegetation monitoring plots in native plant reseeding and replanting sites; consider deferring grazing operations or off-highway vehicle use	Mid to long term (>5 to 10 years)	High	Moderate
	Restored areas	Consider deferring grazing operations or off-highway vehicle use; install signage to raise appreciation of restoration	Short term (1 to 3 years)	High	High
	Areas of high resource value or with high ecosystem services	Reduce human-caused ignitions through education, installation of concrete barriers along roads	Mid-term (1 to 10 years)	Low	High

Table 5.4—Restoration portfolio for the Sand Fire analysis area based on the primary management goals, approaches, and objectives presented in table 5.3 (continued)

Restoration objectives	Target areas	Management actions	Timing	Feasibility	Cost of inaction
Reevaluate desired conditions considering interacting stressors	Along dozer lines, maintained fuelbreaks and Forest Service routes and permitted road use	Site visits for early detection of nonnative species. Contain and, where feasible, eradicate nonnative plants	Short term (1 to 3 years)	Low to moderate[b]	High
	Areas with potential for unauthorized trespass (e.g., dozer lines) that may contribute to erosion or introduction of nonnative species	Put in visual barriers, vertical mulching, fencing with intertwined shrubs, consider trenches to prevent access. Where appropriate, reestablish native species or pull natural features (e.g., branches, rocks, logs) back onto the area	Short term (1 to 3 years)	Low to moderate[c]	Moderate
	Areas showing signs of degradation	Replant or reseed with native species capable of tolerating stressors (e.g., excessive fire)	Short term (1 to 3 years)	Moderate[a]	High
	Restored areas	Install long-term vegetation monitoring plots in native plant reseeding and replanting sites	Mid to long term (>5 to 10 years)	High	Moderate
	Restored areas	Consider deferring grazing operations or off-highway vehicle use. Install signage to raise appreciation of restoration	Short term (1 to 3 years)	High	High

Note: This restoration portfolio has not yet been applied on a national forest to inform project planning.
[a] These management actions are limited by availability of seed stock, seedlings, and personnel, and, consequently, are constrained to smaller spatial scales (e.g., localized patches within individual sites).
[b] Feasibility increases if action is included as part of BAER effort.
[c] Feasibility increases if action is included as part of suppression repair and rehabilitation.

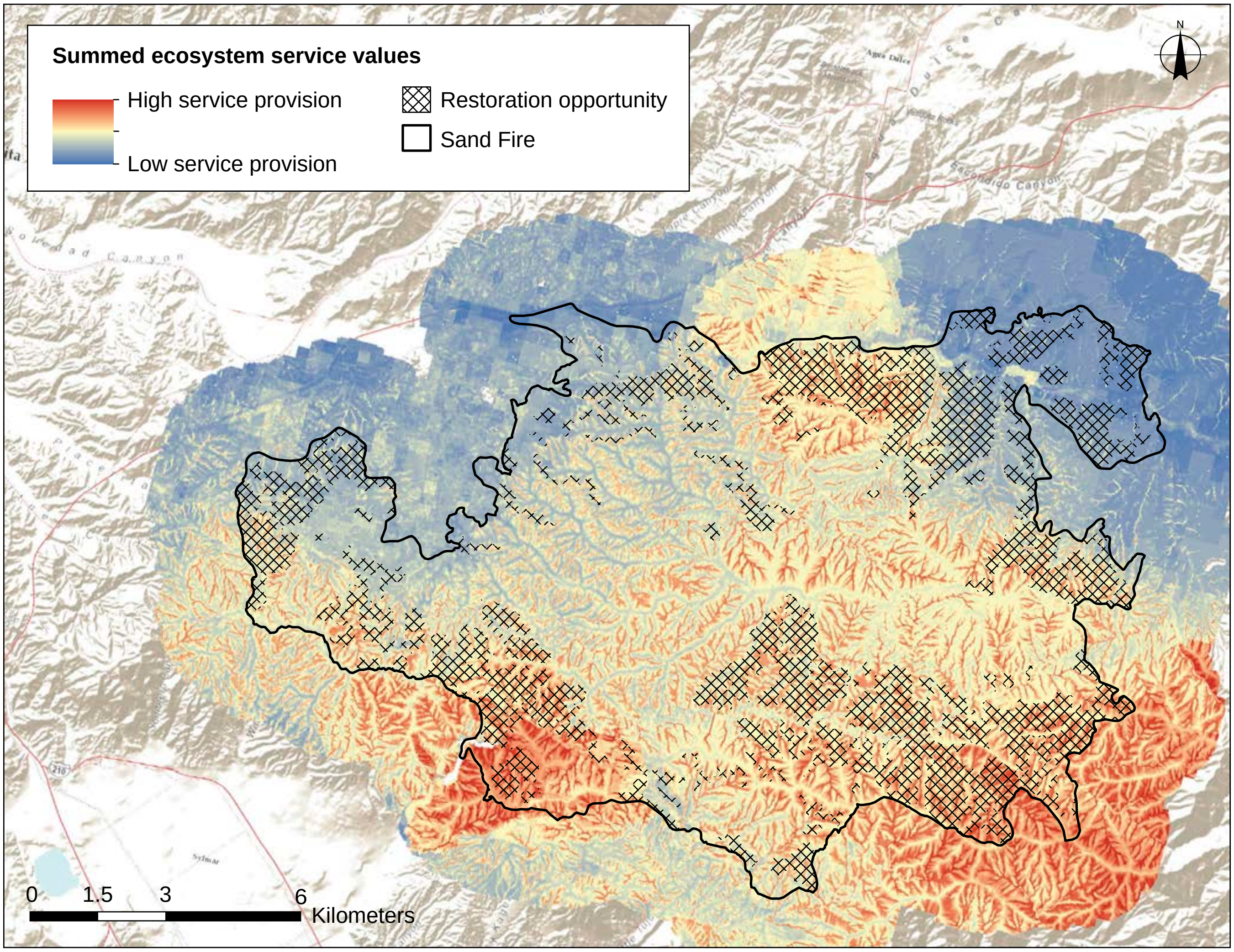

Figure 5.6—Ecosystem service summation overlaid with the restoration areas identified in restoration opportunity 2. The southeast and southwest sections of the fire perimeter show areas where restoration need overlaps with high ecosystem service values and which therefore may represent restoration priorities.

Conclusions

In the Sand Fire analysis area, we conducted a spatial assessment to identify where on the landscape chaparral ecosystems were likely to be resilient and recover passively (i.e., without intervention) (restoration opportunity 1), need active restoration (restoration opportunity 2) or experience novel conditions that may warrant the development of new desired conditions (restoration opportunity 3). Chaparral stands within the Sand Fire were characterized using time since last fire, landscape position, cover of nonnative annual species, fire return interval departure condition class, and fire severity data.

Seventy-five percent of chaparral shrublands within the Sand Fire perimeter had not burned in more than 30 years and are expected to recover without human intervention (restoration opportunity 1). Short-term efforts are important to protect these recently burned landscapes from interacting stressors, such as future fire and invasion from nonnative annual species. Twenty-five percent of chaparral stands affected by the Sand Fire had burned within the previous 10 years. Areas with frequent fire are at risk of failed chaparral regeneration and invasion by nonnative species, which makes them important targets for restoration (restoration opportunity 2). The output from the postfire flowchart could be coupled with ecosystem service values to identify places within the Sand Fire where shrub recovery is most important and most viable for the continued provisioning of valued services. We determined that the area around Pacoima Reservoir and east of Pacoima Canyon supports an abundance of services and therefore may serve as a priority location for ensuring and expediting native shrub recovery through targeted interventions. However, in some areas, restoration success may be thwarted by a history of too-frequent fire (as measured by condition class) or heightened drought conditions (measured by CWD or landscape position). In these areas, desired conditions, and associated management actions, may be reconsidered (restoration opportunity 3) to meet future challenges given current and projected future drought conditions and disturbance regimes.

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Chapter 6: Sagebrush Steppe Case Study

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Background

Sagebrush Steppe Ecosystems

Widespread yet vulnerable, sagebrush (*Artemisia* spp.) steppe ecosystems provide a variety of biological, hydrological, and recreational ecosystem services throughout the Interior West (Homer et al. 2015). One particular service is the provision of essential habitat for the greater sage-grouse (*Centrocercus urophasianus*), which was considered for listing under the Endangered Species Act. That listing was avoided in 2015 by an unprecedented conservation partnership across organizations and state boundaries (Chambers et al. 2017). The once widespread sagebrush steppe ecosystem has been significantly reduced in total area (down to 59 percent of historical extent) and is threatened throughout its range by nonnative invasive plant species (especially cheatgrass [*Bromus tectorum* L.]), altered fire regimes, conifer expansion (i.e., conversion of sagebrush steppe to woodlands or forests), and climate change (Chambers et al. 2014a, 2017). Additional threats to sagebrush include energy development, roads, mining, housing development, recreational activities (e.g., off-highway vehicle use), wild horse (*Equus ferus caballus*) use, and poorly managed livestock grazing (Chambers et al. 2017). These stressors and their interactions have reduced the capacity of sagebrush ecosystems to recover from natural disturbances such as wildfires. The natural fire regime in sagebrush steppe ecosystems is characterized as mixed severity, with low plant survivorship in burned areas interspersed with unburned patches (Baker 2006, Connelly et al. 2000).

Fires in sagebrush steppe ecosystems are spatially complex and strongly influenced by topography and soils, resulting in a wide range of return intervals (Miller and Heyerdahl 2008). Fires promote reproduction and seral-stage diversity among sagebrush species, and inhibit conifer encroachment. However, fires must recur at sufficiently long intervals to allow obligate seeding sagebrush species to mature to reproductive size, because the common sagebrush in our project area (mountain big sagebrush [*A. tridentata* ssp. *vaseyana* Nutt. ssp. vaseyana (Rydb.) Beetle]) does not resprout and often requires 30 to 100 years to recover from fire. Fire return

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The most serious threat to the sagebrush steppe throughout its range is the invasion of cheatgrass.

intervals in these ecosystems prior to Euro-American colonization may have been between 30 and 80 years (Slaton and Stone 2013).

The most serious threat to the sagebrush steppe throughout its range is the invasion of cheatgrass. Owing to its early-season growth, cheatgrass can displace native grasses, forbs, and shrubs by reducing moisture and nutrients in surface soils (Norton et al. 2004). Overgrazing contributes to cheatgrass invasion by reducing the abundance of native perennial grasses, disturbing intact soils and complex biological soil crusts, and dispersing cheatgrass seed. Once established, cheatgrass also dramatically alters fire regimes in sagebrush steppe. This annual grass grows rapidly, particularly following wet years, creating a nonhistorical continuous cover of dry fuels that ignite and spread fire easily (Brooks et al. 2004, Knapp 1998). Fire return intervals in cheatgrass-invaded sagebrush steppe can be as frequent as every 3 to 5 years (Whisenant 1990), effectively eliminating sagebrush and other native species adapted to longer fire return intervals that are characteristic of natural sagebrush steppe ecosystems. After a few cheatgrass-exacerbated fire cycles, the native plant seed bank becomes depleted, greatly reducing reestablishment. The invasion of cheatgrass has contributed to the conversion of millions of hectares of sagebrush steppe to low-diversity, annual grasslands that provide low-quality habitat for native plants, wildlife, and grazing livestock (Balch et al. 2013, Knapp 1996).

Sagebrush recovery after fire is influenced by a variety of factors, including distance to unburned shrubs (to provide a seed source), abundance and viability of seed within the soil seed bank (which may persist up to 3 years), pre- and postfire weather, and postfire disturbances such as grazing (Ziegenhagen and Miller 2009, Newingham and Strand 2018). Other important factors include prefire vegetation composition and structure, fire severity, post-wildfire precipitation, and local soil and hydrology characteristics (Arkle et al. 2014; Chambers et al. 2014a, 2017,; Miller et al. 2015b). Native bunchgrasses are a key determinant in postfire recovery (Chambers et al. 2017), but the arid, coarse volcanic soils of the Crowley Basin typically support limited bunchgrass cover.

Owens River Fire

The Owens River Fire was ignited on September 17, 2016, burning 5,482 ac (2218 ha) on the Mammoth and Mono Lake Ranger Districts of the Inyo National Forest. Approximately two-thirds of the fire burned in sagebrush-dominated vegetation, while the remaining third burned Jeffrey pine (*Pinus jeffreyi* Balf.) forest and other vegetation types (fig. 6.1). The fire burned primarily on national forest lands but included 912 ac (369 ha) of lands under private ownership. The Owens River Fire is bordered by the 1993 Bald Mountain Fire and 2001 McLaughlin Fire to the north

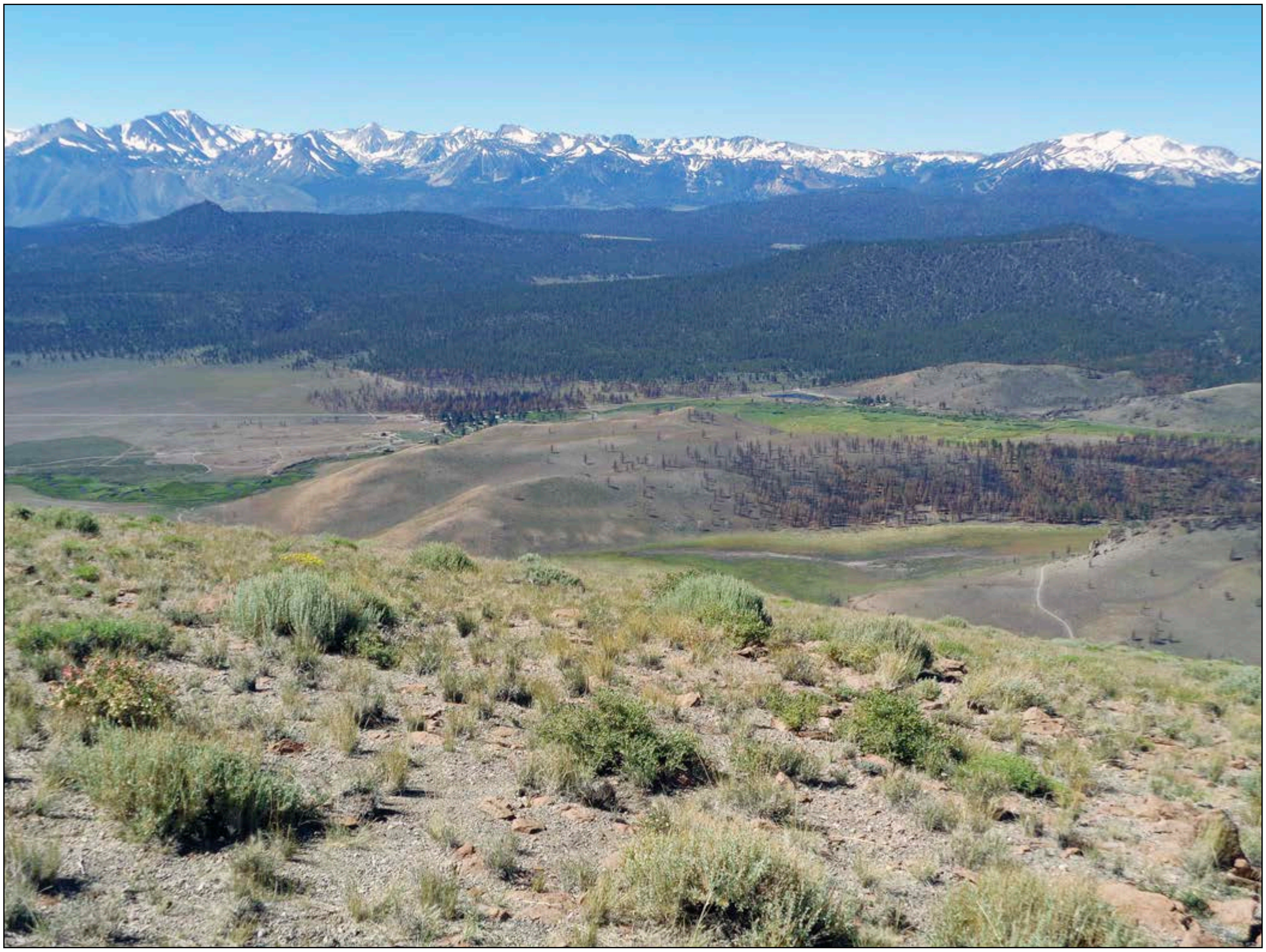


Figure 6.1—Postfire conditions in sagebrush steppe and Jeffrey pine forest after the 2016 Owens River Fire (center background). The foreground displays recovering sagebrush steppe outside the 2016 Owens River Fire perimeter that was burned in a 1993 wildfire, about 24 years prior.

and east, respectively. Both of these earlier fires had been followed by cheatgrass invasion, especially on warm south-facing slopes, creating a substantial seed bank for this invasive annual grass adjacent to the Owens River Fire (based on prefire field observations). There were limited historical fires within the Owens River Fire perimeter, largely due to combined effects of fire suppression, livestock grazing, and earlier shrub reduction efforts in the vicinity (e.g., aerial herbicide application and mechanical removal). The prefire plant community was primarily dominated by relatively tall and dense sagebrush with elevated fuel loads (attributed to dense and old shrubs), especially on the bottom of Long Valley. Mountain big sagebrush is the dominant sagebrush species in the analysis area occurring in varying proportions with bitterbrush (*Purshia tridentata* (Pursh) DC. ssp. *tridentata*), yellow rabbitbrush

(*Chrysothamnus viscidiflorus* (Hook.) Nutt.), rubber rabbitbrush (*Ericameria nauseosa* (Pall. ex Pursh) G.L.Nesom & G.I.Baird)), horsebrush (*Tetradymia canescens* DC.), snowberry (*Symphoricarpos rotundifolius* A. Gray), and native perennial and annual forbs and grasses. Limited conifer encroachment of Jeffrey pine had occurred into the shrublands over the past few decades, especially in the western section of the Owens River Fire.

Postfire Restoration Framework

Step 1: Identifying Priority Resources, Desired Conditions, and Restoration Goals

We considered several resources in the Owens River Fire analysis area but focused primarily on sage-grouse habitat and sagebrush vegetation in our assessment (table 6.1). These primary resources were derived from the 2012 Bi-State Action Plan (Bi-State Technical Advisory Committee Nevada and California 2013), the land management plan for the Inyo National Forest, and specialist input. Sage-grouse habitat was considered a primary resource because this species was considered for federal listing under the Endangered Species Act and is currently a U.S. Forest Service species of conservation concern, and is a species of conservation concern under the new draft land management plan for the Inyo National Forest (USDA-FS 2019). The Inyo National Forest manages approximately 20 percent (213,670 ac [86 469 ha]) of priority sage-grouse habitat identified in the Bi-State Action Plan for Conservation of the Greater Sage-Grouse in eastern California and western Nevada (Bi-State Technical Advisory Committee Nevada and California 2013). The BAER team found that approximately 3,550 ac (1437 ha) of suitable sage-grouse habitat were consumed in the fire..

Our primary restoration goals for the assessment area focused on sustaining and restoring sagebrush steppe ecosystems and sage-grouse habitat.

We reviewed desired conditions for sagebrush steppe based on information provided in the bi-state action plan and land and resource management planning documents relevant to our assessment area (USDA FS 2013a, 2013b). Desired conditions, based upon scientific understanding of historical references, include the following:

- Sagebrush occurs mixed within complex and diverse assemblages of other shrubs, perennial grasses, and forbs.
- At the landscape scale, sagebrush is represented by a range of age classes, including mature shrubs and seedlings.
- Invasive annual grasses (e.g., cheatgrass) are absent or rare, and the introduction and spread of invasive species are minimized.
- Within sagebrush steppe, encroachment by conifer trees such as pinyon pine (*Pinus monophylla* Torr. & Frém.), Utah juniper (*Juniperus utahensis* (Torr.) Little), or Jeffrey pine, is generally rare.

Table 6.1—Primary resources and stressors considered in a postfire assessment of the Owens River Fire (2016)

Resources	Spatial data	Explanation
Sage-grouse habitat[a]	Sage-grouse critical habitat (U.S. Fish and Wildlife Service) and suitable habitat	Maintenance and restoration of sage-grouse habitat is a high-priority goal.
Sagebrush vegetation[a]	EVeg or TEUI (see app. 2)	Sagebrush vegetation is critical to support suitable sage-grouse habitat and regional biodiversity.
Soils	Soil survey data, soil burn severity (see app. 2)	Soil productivity is important to maintain; soil type may influence restoration success.
Watersheds	Subwatershed boundaries	Subwatershed boundaries inform where cumulative impacts of wildfire may result in undesirable negative impacts to watershed resources.
Forest vegetation	EVeg or TEUI (see app. 2)	Forest vegetation (e.g., Jeffrey pine) provides numerous ecosystem services including carbon sequestration and wildlife habitat.
Riparian vegetation	EVeg or TEUI (see app. 2)	Aspen stands and other riparian vegetation are important for biodiversity and wildlife habitat.
At-risk plants	Natural Resource Information System	Nearby occurrences of three at-risk plant species (Mono Lake lupine [*Lupinus duranii* Eastw.], Mono milkvetch Barneby [*Astragalus monoensis* Barneby]. Long Valley milk-vetch [*Astragalus johannis-howellii* Barneby]).
Wildlife and fish habitat (excluding sage-grouse)	Migratory bird habitat, mule deer habitat, freshwater fish habitat	Migratory Bird Treaty Act, recreational hunting, and fishing are important for the local economy.
Rangelands	Grazing allotment	Arid rangelands provide forage for livestock.
Stressors or constraints:		
Fire	Vegetation burn severity (RAVG), FRID, Fire management zones	Fire severity affects short-term vulnerability of vegetation; Fire return interval departure influences sagebrush resilience; Fire management zones show potential strategic treatment areas to contain fire spread
Topographically mediated moisture stress[b]	Landscape management units	Topographic position and steepness can inform relative degree of vegetation moisture stress and restoration treatment access
Invasive plants	Cheatgrass distribution data (spatial interpolation) on the INF; FACTS database	Cheatgrass invasion could facilitate undesirable type conversion of native shrublands to nonnative annual grassland
Conifer encroachment	EVeg or TEUI, especially at the intersection of sagebrush and Jeffrey pine vegetation	Jeffrey pine or pinyon pine encroachment into sagebrush may result in sage-grouse habitat loss or reduced ecosystem resilience to stressors
Grazing	Grazing allotments, wild horse territories	Potential livestock and wild horse grazing impacts to postfire vegetation recovery
Climate change	Climatic Water Deficit (CWD) – either current or projected for early 21st century Climate-smart restoration tool (https://climaterestorationtool.org/csrt)	CWD and climate exposure estimates long-term vulnerability of vegetation; restoration tool provides climate-informed seed zone recommendations for sagebrush and other species
Off-highway vehicles (OHV)	Roads and trails	Areas within 50 ft (15 m) of OHV roads and trails generally receive greater impacts and may affect restoration actions

Many spatial data sources (e.g., sagebrush vegetation, soil and vegetation burn severity, invasive plants) would benefit from field validation using site-specific field data and observations.
[a] Primary resources that are the focus of this case study.
[b] Topographically mediated moisture stress may provide an indication of current and future climate exposure in the absence of more reliable and precise climate exposure spatial data.

- Sagebrush ecosystems provide suitable habitat and connectivity for wildlife species such as greater sage-grouse.
- Biological soil crusts frequently occur within the interstitial spaces among shrubs and perennial grasses.

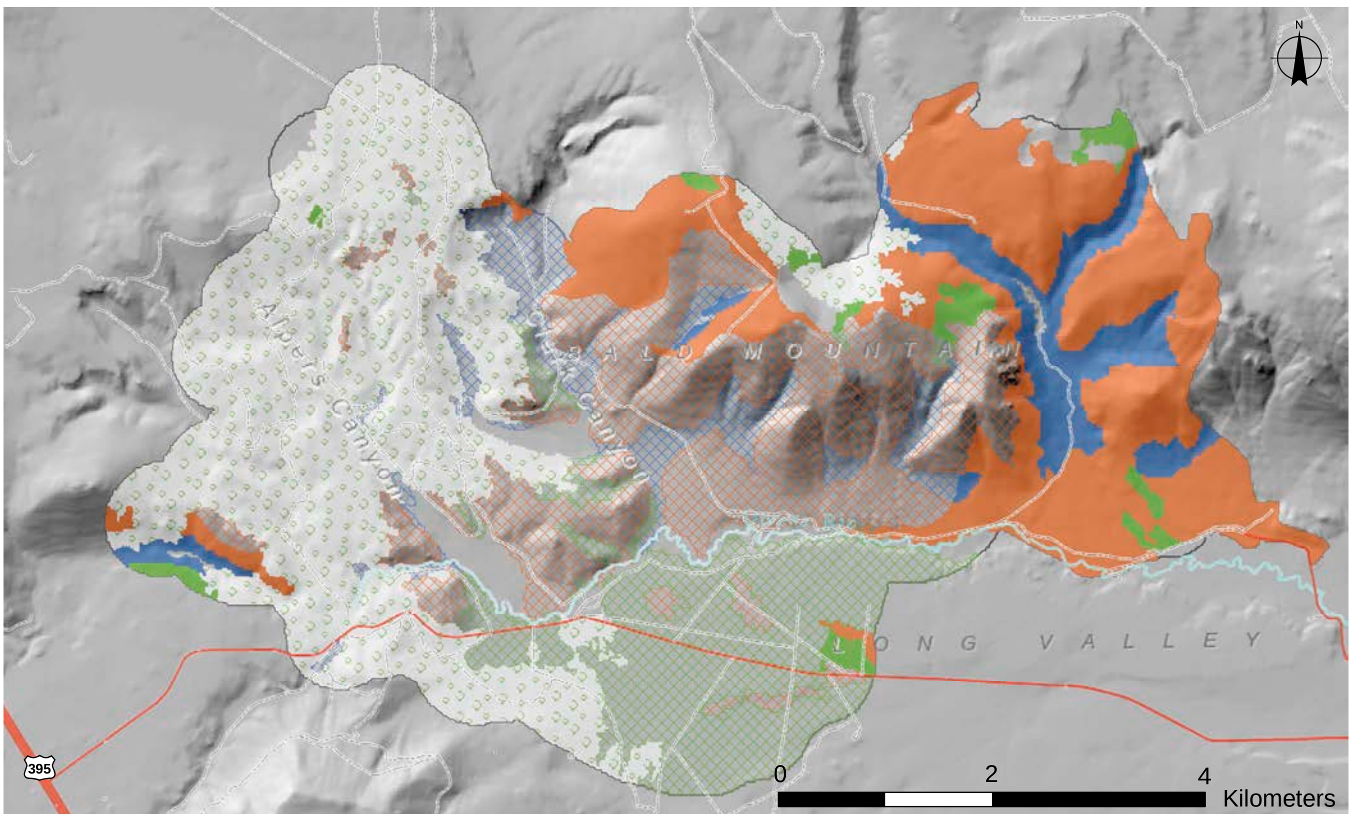
Our primary restoration goals for the assessment area focused on sustaining and restoring sagebrush steppe ecosystems and sage-grouse habitat, based on land management and resource planning sources (table 6.2). The Owens River fire affected several additional resources of concern, including mule deer (*Odocoileus hemionus*) habitat, at-risk plant habitat, active grazing allotments, timber stands, and riparian areas linked to recreational fisheries.

Table 6.2—Postfire flowchart outputs that serve as the foundation of a restoration portfolio

	Output		
Primary restoration goals	• Promote or maintain sagebrush ecosystem integrity and resilience • Maintain and enhance sage-grouse habitat quality and connectivity		
Most relevant guiding principles from the restoration framework	• Restore key ecological processes • Consider landscape context • Support native biodiversity and habitat connectivity • Sustain diverse ecosystem services • Incorporate climate change adaptation		
Analysis area	• Owens River Fire and adjacent recent fire perimeters, including a 500 m (1640 ft) buffer from the Owens River Fire perimeter		
Restoration opportunities	Maintain or promote desired conditions	Take management actions to restore desired conditions	Reevaluate desired conditions considering interacting stressors
Potential restoration actions	• Create fuel breaks where appropriate (Miller et al. 2014b) • Prevent invasion of nonnative plants where feasible • Suppress fires in burned areas for >35 years • Monitor ecological status and trend of passive restoration efforts • Maintain soil biotic crusts where feasible	• Reseed and replant native plants • Remove encroaching conifers • Defer livestock grazing • Install extra signage and barriers to discourage off-highway vehicle use outside of designated roads and routes • Eradicate and contain nonnative plants where feasible • Monitor effectiveness of management actions	• Monitor ecological status and trend • Contain nonnative plants where feasible • Consider adjusting desired conditions to align with current, novel conditions
Additional actions for secondary resources	• At-risk plant species: flag, avoid, and monitor at-risk plant populations • Forest vegetation: consider reforestation using climate-smart approaches • Mule deer habitat: promote forage and hiding cover in suitable habitat		

Step 2: Gather and Review Relevant Spatial Data

Our analysis area included the Owens River Fire, with a 500 -m (0.31-mi) buffer around its perimeter, and the perimeters of the adjacent Bald Mountain and McLaughlin Fires (fig. 6.2). This analysis area captures the influence of previously burned and unburned areas directly surrounding the Owens River Fire, especially because these areas may serve as sources of nonnative plant propagules. The 500-m buffer represented a distance that would capture most neighboring nonnative invasive plant occurrences with the potential to disperse inside the fire perimeter (wind- or animal-facilitated seed dispersal), based on published estimates of dispersal distance in sagebrush ecosystems (Monty et al. 2013, Nielson et al. 2011).



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Big sagebrush priority resources within the 2016 Owens River Fire analysis area

- Higher moisture—canyon bottoms, unburned
- Higher moisture—canyon bottoms, burned
- Mid moisture—northeast slopes, burned
- Lower moisture—steep and/or southwest slopes and ridges, unburned
- Lower moisture—steep and/or southwest slopes and ridges, burned
- Mid moisture—gentle northeast slopes, unburned
- Forest area

Figure 6.2—Spatial assessment identifying mesic sites prioritized for sagebrush restoration in the Owens River Fire on the Inyo National Forest.

We evaluated prefire ecological condition using (1) prefire vegetation type (using pre-Euro-American settlement fire regime classes) and (2) landscape position as an indicator of topographically mediated moisture gradients (based on landscape management units [LMUs]) (app. 1). These topographically mediated moisture gradients are related to sagebrush ecosystem resilience and risk of cheatgrass invasion, with higher resilience and lower invasibility associated with cooler and moister sites on the landscape (Chambers et al. 2014a, Condon et al. 2011). We also reviewed but did not include additional prefire data sources in our initial analysis, including sage-grouse habitat data (suitable habitat, habitat connectivity) and soil survey data that provided moisture gradient information at finer spatial scales (table 6.1).

Next, we evaluated postfire ecological condition using spatially explicit datasets most relevant to sagebrush ecosystems. To do this, we initially examined a combination of vegetation burn severity and fire return interval departure (FRID) data. Although vegetation burn severity and FRID data can be informative for evaluating the general condition of terrestrial ecosystems, these spatial data may have methodological issues when applied to sagebrush ecosystems (i.e., vegetation burn severity) or have received little attention in the published literature focused on sagebrush steppe (i.e., FRID). Consequently, their utility in assessing the ecological condition of sagebrush ecosystems is uncertain. We used Rapid Assessment Of Vegetation Condition after Wildfire (RAVG) data to evaluate vegetation burn severity. Vegetation burn severity is an indicator of aboveground biomass consumption (Keeley 2009) that may be correlated with shrub and perennial grass mortality in arid, shrub-dominated ecosystems (Miller et al. 2013). Vegetation burn severity also may inform ecosystem resilience to disturbance and resistance to invasive plants in sagebrush and other Great Basin ecosystems (Miller et al. 2013, 2015a), with high-severity burned patches often considered a priority for restoration (Chambers et al. 2014b). In sagebrush vegetation, the use of delta Normalized Burn Ratio (dNBR) or relativized delta Normalized Burn Ratio (RdNBR) values may provide more resolved information on vegetation change than the broadly defined fire severity classes (i.e., unchanged, low, moderate, high). Regional Forest Service data based on the RdNBR developed by Miller and Thode (2007) were not available during our initial analysis, and rapid assessment data are more sensitive to postfire resprouting (including species such as rabbitbrush and bitterbrush). However, we found that vegetation burn severity was less informative for the Owens River Fire area because more than 85 percent of sagebrush vegetation burned at high severity), a pattern observed in published studies of burned sagebrush ecosystems (Miller and Thode 2007, Slaton and Stone 2013). Although we found soil burn severity to be slightly more informative than vegetation burn severity in assessing fire effects to sagebrush ecosystems in the Owens River

Fire, we assumed the stratification of topographic position and slope was sufficient for assessing the risk for postfire runoff and erosion in the analysis area. We examined FRID data, but only about 5 percent of the Owens River Fire burned in previously recorded wildfires, suggesting limited impacts of a surplus fire frequency (i.e., too-frequent fire that may favor cheatgrass invasion) in the analysis area. Because neither fire severity nor FRID data were particularly discriminating in our analysis, we predominantly used prefire data (i.e., prefire vegetation type, landscape position) for our final spatial assessment of the Owens River Fire.

We considered sagebrush vegetation situated in more sheltered topographic positions as indicative of relatively lower moisture stress, including valley bottoms and gentle slopes (<30 percent) on northeastern facing aspects (mesic sites). Ridgetops, steeper slopes (>30 percent), and southwestern facing aspects were indicative of areas of higher moisture stress (xeric sites) that ranked as lowest priority in our assessment. We chose to prioritize areas with a higher probability of success to improve restoration achievement in high-value areas, based on several factors such as overall landscape condition (fair), resource availability (low), and specialist input.

Twelve patches totaling 533 ac (216 ha, or 10 percent of the area burned) of sagebrush were located in lower topographic positions with high moisture availability (fig. 6.2). Of this area, 473 ac (191 ha) were also located within suitable sage-grouse habitat, and 41 ac (17 ha) were previously burned in the 1993 Bald Mountain Fire or 2001 McLaughlin Fire. Sage-grouse habitat burned in the Owens River Fire did not include any significant habitat corridors or patches of sagebrush connectivity in the region (Bi-State Technical Advisory Committee Nevada and California 2013).

Step 3. Use the Postfire Flowchart to Identify Restoration Opportunities

Question A: Where did fire improve or maintain ecological conditions and are fire effects within desired conditions or NRV?—

We first examined whether the Owens River Fire burned within the natural range of variation (NRV) for fire severity and frequency. The comparison of fire severity patterns with historical reference conditions suggests that the analysis area is burning at the higher end of the range of severity historically experienced by these ecosystems (i.e., primarily mixed vegetation burn severity); although lack of reference data for historical high-severity patch sizes (e.g., mean, maximum) and their effects of sagebrush recovery suggests that our NRV evaluation of fire severity is inconclusive. Nevertheless, mapping of larger high-severity burned sagebrush patches (patches with interior regions that extend about 200 m from the perimeter can be used to represent areas lacking sufficient propagules for ecosystem recovery) may locate areas where fire effects did not maintain desired conditions for sagebrush ecosystem resilience (box 6A). Although historical fire return interval estimates for big sagebrush are highly variable (decades to centuries) (Slaton and Stone 2013, Van de Water and Safford 2011), FRID data (with estimates on the low end of the range) indicated that nearly all prefire vegetation in the analysis area was burning less frequently than historically prior to the Owens River Fire: 55 percent was in condition class 3 (high departure from NRV; mostly nontargeted Jeffrey pine forest), about 44 percent was in condition class 2 (moderate departure from NRV; mostly sagebrush), 0.4 percent was in condition class 1 (sagebrush burning within NRV). After the Owens River Fire, most of these areas dominated by sagebrush were burning within NRV (condition class 1), suggesting that, in the absence of interacting stressors (e.g., cheatgrass and altered fire regimes) (see question B below), the Owens River Fire could possibly

Box 6A:
Assessing High-Severity Burned Sagebrush Areas for Replanting Needs

Mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana* Nutt.) can take at least 30 years to recover after fire (see chapter 6 "Background"). Along with receiving adequate precipitation, distance to live sagebrush has been identified as one of the most important factors in determining sagebrush recovery after fire (Ziegenhagen and Miller 2009). Most sagebrush species do not resprout after fire, and there are low densities of viable seeds in the soil (Young and Evans 1989) making seed dissemination from adult plants critical for postfire recruitment. Sagebrush seeds are typically only dispersed within 9 to 12 m of the parent plant (Blaisdell 1953, Johnson and Payne 1968, Mueggler 1956). Biological constraints on sagebrush dispersal imply that interiors of large burned areas will be among the slowest to recover after fire.

We undertook a simple Geographic Information System exercise to delineate the interiors of high-severity burn patches that will be most in need of replanting sagebrush. We (1) chose a vegetation dataset with the best available delineations of sagebrush vegetation types for the project area, (2) intersected the project vegetation dataset with a vegetation burn severity dataset to identify high burn severity areas (75 to 100 percent basal area loss) in sagebrush, and (3) created an interior buffer (200 m inside severely burned sagebrush patches that had a higher probability of natural recovery and may be excluded from restoration actions) and clipped data to create the final selection of high burn severity areas in the interiors of sagebrush patches. We tested the use of a smaller buffer, but ended up with more area in the interior areas than was potentially treatable; likewise, a larger buffer resulted in excluding areas in the interior that were in need of restoration. Our final selection (fig. 6.3) provided a reasonable number of potential candidates for interior areas in need of restoration, which field staff could further refine once they had performed site visits.

Continued on next page

improve ecological conditions by restoring the fire frequency and structural class diversity considered within the NRV for sagebrush ecosystems. However, although we answered a tentative "yes" to the question of whether fire improved ecological conditions and was within NRV, we needed to consider additional interacting stressors in our next step (question B) according to the postfire flowchart.

Question B: Where do other factors threaten long-term ecological resilience and sustainability?—

There are several stressors that might interfere with long-term ecological resilience and sustainability of sagebrush ecosystems in the analysis area, including (1) non-native annual grasses (i.e., cheatgrass, with its subsequent effects on fire frequency and ecological succession), (2) inappropriate past or present livestock grazing, (3) off-highway vehicle (OHV) use, (4) conifer encroachment, and (5) climate change. To address potential impacts of these stressors, we examined spatial data of invasive

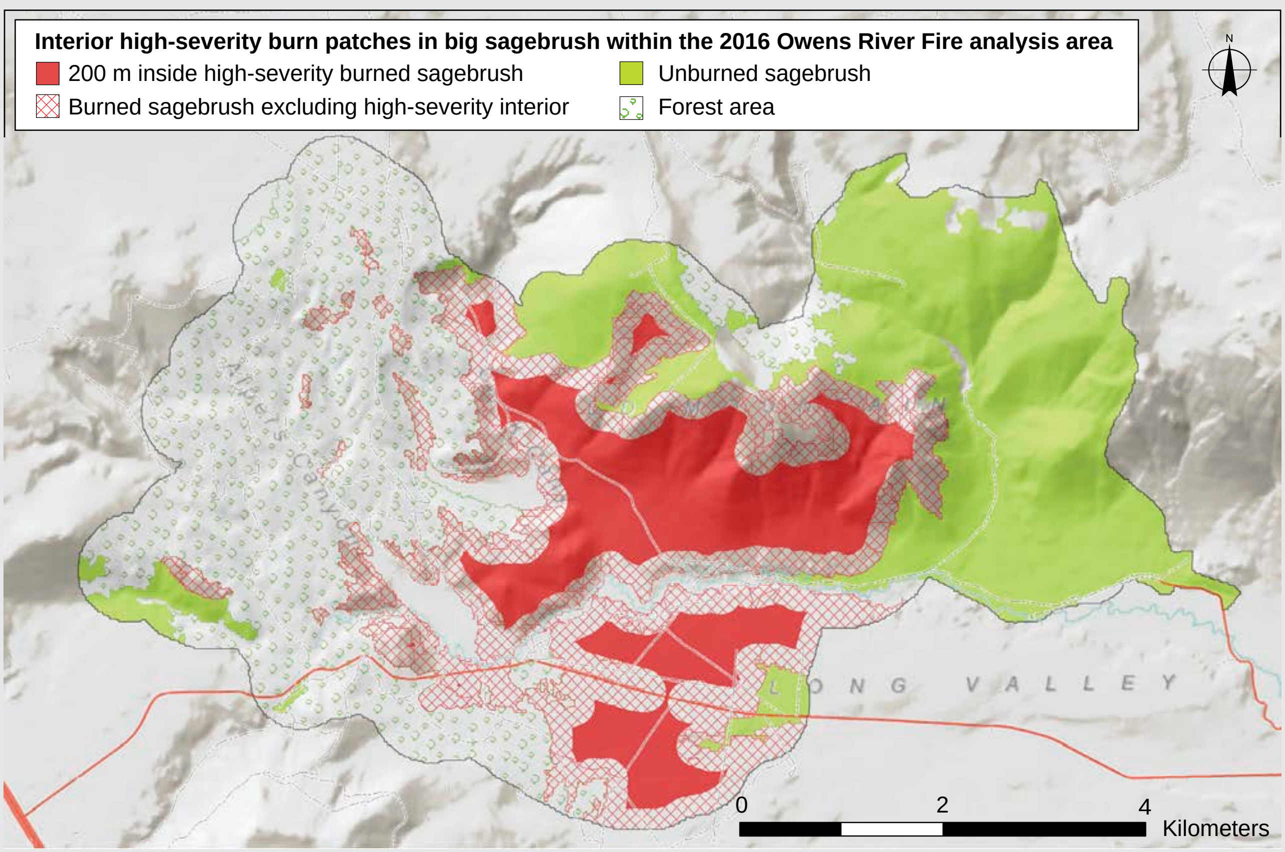

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Figure 6.3—Map of burned and unburned sagebrush patches, with areas highlighted in red located 200 m (656 ft) inside the perimeter of severely burned sagebrush. These areas may be in greatest need of sagebrush replanting efforts, given slow sagebrush recovery in burn patch interiors.

plants, livestock grazing allotments, OHV road access, and climate exposure (table 6.1), especially in relation to mesic sagebrush sites identified in step 3. First, we observed several prefire cheatgrass occurrences totaling about 6 ac (2.4 ha) in the Owens River Fire analysis area, with additional occurrences about 750 m from the fire perimeter. Because of limitations in accurate mapping of cheatgrass extent, we assumed the mapped occurrences were most likely an underestimate of true extent (see box 6B). Second, rangeland allotment data showed that the analysis area was covered by four grazing allotments, suggesting potential impacts of livestock grazing in sagebrush ecosystems, but with no clear indication of where inappropriate grazing levels may have occurred. No wild horse territories occurred in or near the analysis area based on spatial data and recent field observation. Third, 3 of 12 (25 percent) mesic sagebrush sites (145 ac [59 ha] total) were bisected by national Forest Service system roads totaling 1.9 mi (3.1 km) in length. The BAER team identified an additional impact as a result of firefighting activities (15.2 mi [24.4 km] of dozer line, 1.4 mi [2.2 km] of hand line, and four drop points within the analysis area) that required invasive plant species response efforts. Fourth, potential for conifer encroachment into sagebrush, primarily by Jeffrey pine, was identified in western Long Valley (especially the southwestern section of Owens River Fire) based on prefire vegetation data and recent prefire field accounts from the area (for conifer encroachment mapping techniques see box 6B). Vegetation burn severity data indicated that most of these encroached areas burned at high severity, suggesting that they had little or no potential for conifer encroachment in the near future. However, unburned and some burned sagebrush located immediately outside the southern edge of the Owens River Fire had also experienced conifer encroachment that warrants management action (restoration opportunity 2). Lastly, climatic water deficit (CWD) data suggested moderate increases (15 to 20 percent) in projected CWD in the analysis area over the next two decades, especially in Clark and Alpers Canyons where recent mapping of shrubland patch mortality confirmed that these areas had undergone loss of sagebrush and bitterbrush cover during several years of drought preceding the fire.

Collectively, this information indicated that potential stressors could interfere with long-term ecological resilience and sustainability in sagebrush ecosystems throughout the analysis area. This was especially apparent in mesic sagebrush sites bisected by roads and adjacent to nonnative invasive plant occurrences. These areas led us to question C in the postfire flowchart. Additionally, despite potential widespread impacts of stressors, we recognized that other mesic sagebrush sites in the Owens River Fire were less affected by nonnative invasive plants and OHV access. We categorized these areas as relatively unaffected by localized stressors, where the management goal would be focused on maintaining or promoting desired conditions (restoration opportunity 1).

Box 6B:
Remote-Sensing Tools for Arid Shrubland and Woodland Burn Restoration Planning and Monitoring

The scale and complexity of spatial patterns within burn perimeters are usually great enough that remote-sensing technologies are required to assess conditions efficiently and adequately. Managers have access to a variety of imagery sources, acquired from sensors on satellites or aircraft, which measure electromagnetic radiation reflected from the vegetation canopy and ground surface (fig. 6.4). Temporal, spatial, and spectral resolution vary across sources, as does cost, though some technologies, such as the Landsat archive and newly emerging synthetic aperture radar are currently available for free. Three examples are given below demonstrating the range of products available, including derived products, such as change-detection algorithms based on imagery. These products are also described in "Appendix 2: Data Sources for Data Gathering and Analysis."

Detecting cheatgrass infestation and native shrub cover change—

F3 is an algorithm that combines ground-based and remote sensing data to create maps of ecosystem metrics (Huang et al. 2018). The U.S. Forest Service Pacific Southwest Region Remote Sensing Lab used this approach in the Owens River Fire, leveraging the distinct phenological signal of invasive annual grass as compared to perennial vegetation. Optical data from the RapidEye satellite constellation plus Synthetic Aperture Radar (SAR) were used to map invasive annual grasses and native shrubs. The optical dataset detects the

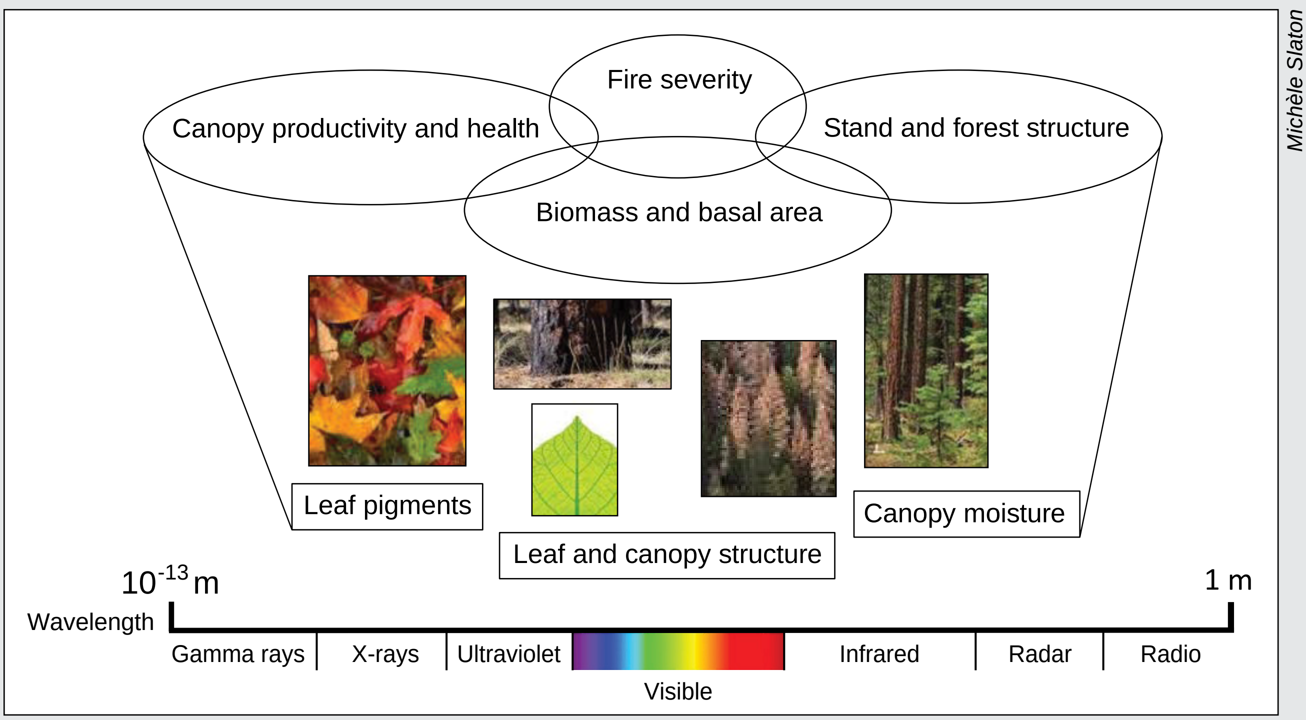

Figure 6.4—A conceptual diagram illustrating the leaf to ecosystem attributes derived from remote-sensing analyses of the electromagnetic spectrum. Mapping tools and applications used in vegetation monitoring are based on these biophysical principles.

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unique phenology, while the addition of radar data discriminates shrub versus grass canopy structure. The resulting map (fig. 6.5) depicts gain and loss of shrub cover in the study area over the decade preceding the Owens River Fire. Gains were due in part to regrowth after previous fires (fig. 6.6), and losses were due largely to drought-induced shrub mortality.

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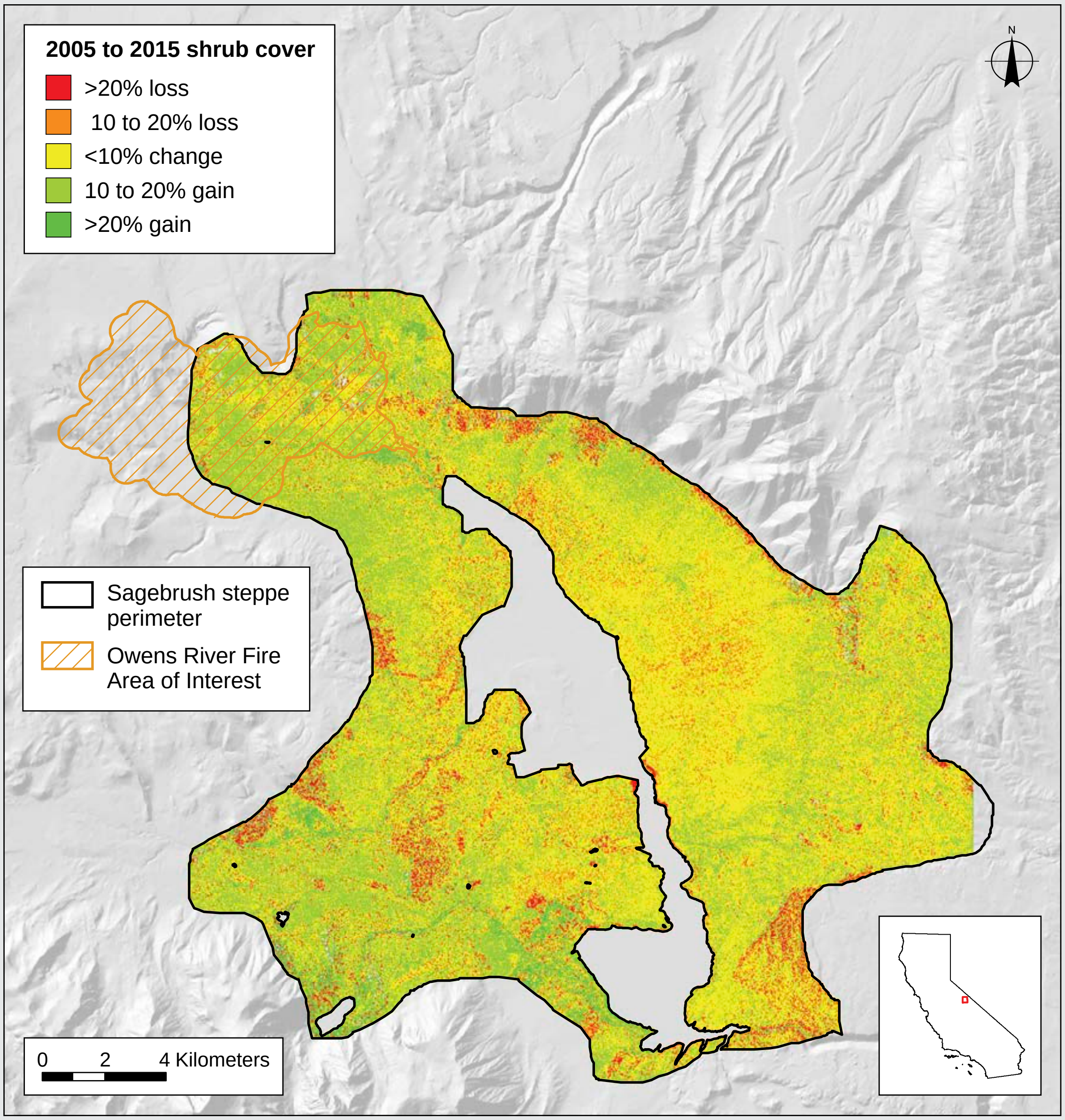

Figure 6.5—Map of changes in native shrub cover 2005–2015, based on remote-sensing and field training data used in F3 model. Changes in cover prior to the Owens River Fire were mostly caused by drought or regrowth after previous fires or rangeland management projects. This prefire trend information can help prioritize areas where restoration may be most successful within the Owens Fire area of interest (AOI), Inyo National Forest.

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Mapping conifer encroachment—

Light detection and ranging (LiDAR) uses laser light to provide an accurate, high-resolution, 3-D image of an area (McGaughey 2014). In the Owens River Fire, prefire LiDAR (fig. 6.7) detected encroaching trees into sagebrush (fig. 6.8), providing both a visual and a quantitative measure for planning efforts for potential management action.

Mortality induced by causes other than fire—

The Ecosystem Disturbance and Recovery Tracker (eDaRT) is an automated anomaly detection algorithm that compares vegetation to a recent historical baseline (Koltunov et al. 2020). eDaRT uses all available Landsat imagery (30 m or 100 ft) to map disturbances, including canopy mortality. Outputs for the Owens River Fire area (fig. 6.9) showed that significant prefire shrub mortality had occurred in the 2009–2016 drought (fig. 6.10).

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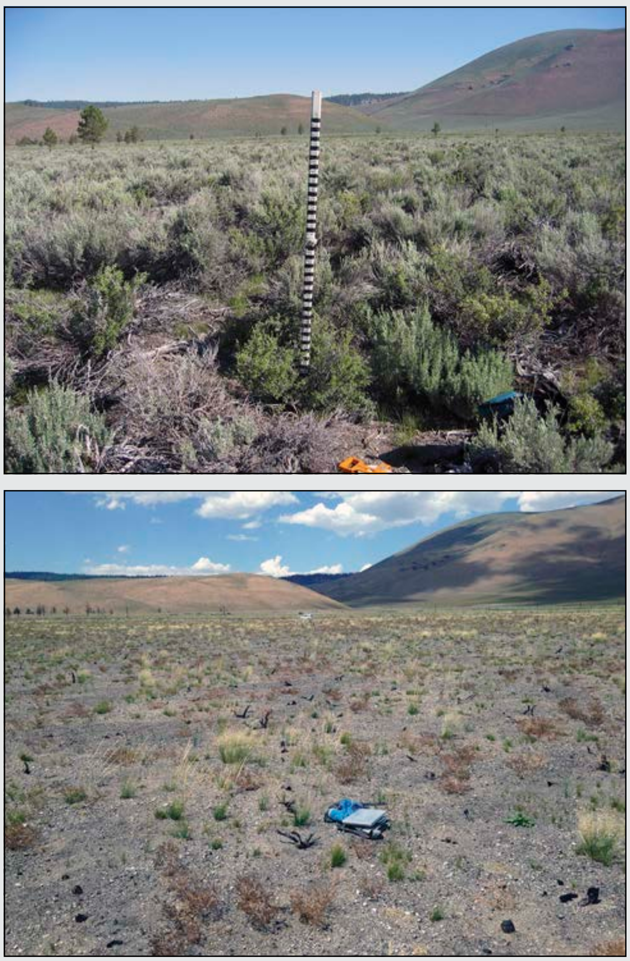

Figure 6.6—Vegetation regrowth 3 years after the 2002 McLaughlin Fire within the footprint of the Owens Fire. Dominant shrubs are resprouting bitterbrush (*Purshia tridentata*), and rabbitbrush (*Chrysothamnus viscidiflorus*), with native perennial grasses and nonnative grass (*Bromus tectorum*) in the interspaces.

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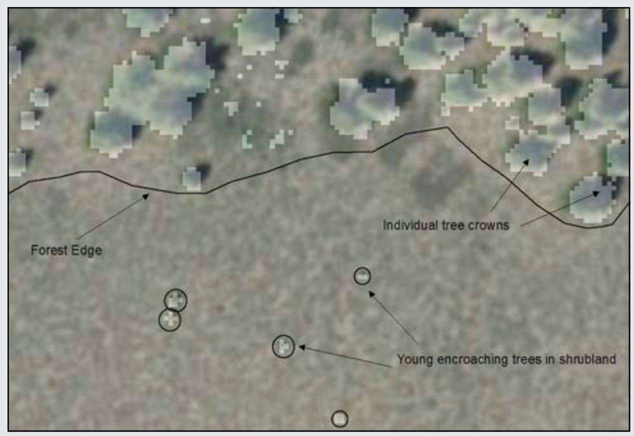

Figure 6.7—LiDAR-derived map of conifer encroachment in the sagebrush-forest ecotone of the Owens River Fire area (Inyo National Forest).

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Figure 6.8—Jeffrey pine (*Pinus jeffreyi*) encroachment in sagebrush steppe within a section of the Owens River Fire area that had no previously recorded burn history.

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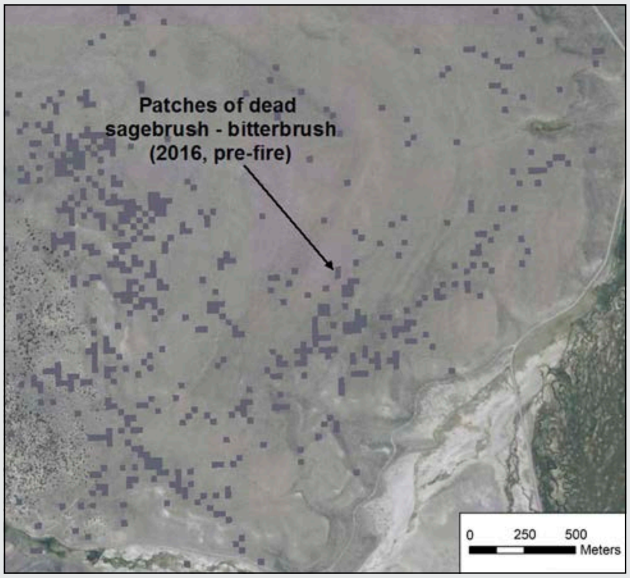

Figure 6.9—Map of shrub mortality patches identified using the Ecosystem Disturbance and Recovery Tracker in the Owens River Fire area.

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Figure 6.10—Localized patch of sagebrush mortality near the Owens River Fire area, likely owing to drought conditions.

Question C: Where are management approaches feasible for the restoration of desired conditions given current and anticipated future conditions?—
We reexamined the spatial data for the mesic sites of sagebrush identified in the sections above (addressing questions A and B) for essential structural features (e.g., shrub cover), indicators of ecosystem integrity, and extent of departure from NRV. As noted above, vegetation burn severity data indicated a loss of shrub cover in all four sagebrush patches and subsequent impacts to sage-grouse habitat. Soil burn severity data reported by the BAER team indicated that two of these larger patches were burned at high soil burn severity, suggesting loss of soil productivity, nutrient availability, biological soil crusts, and hydrologic function (e.g., soil water infiltration and runoff) and greater susceptibility to cheatgrass invasion. Collectively, these patterns suggest that postfire conditions for sagebrush ecosystems in our analysis area have substantially departed from our desired conditions, and restoration activities may be required to achieve landscape desired conditions for sagebrush steppe; field visits to the site would be necessary to confirm these patterns of departure from desired conditions. There are several feasible management actions (e.g., sagebrush restoration) that could be developed to address this departure of current postfire conditions from desired conditions and NRV (outlined below).

Restoration opportunity 1: maintain or promote desired conditions—

In mesic sagebrush sites, management opportunities could include passive restoration, nonnative invasive plant management, and status and trend monitoring. Facilitating postfire succession of native species in the analysis area, combined with small, strategically placed fuel breaks in areas neighboring the Owens River Fire (addressed in restoration opportunity 2), may enhance the long-term resilience of arid shrubland ecosystems to wildfire, particularly through limiting future wildfire spread into the Owens River Fire perimeter during the critical period of postfire recovery. Control of nonnative invasive plant species on the valley bottom would facilitate the growth of native early-seral plant species (e.g., buckwheats [*Eriogonum* spp.], cryptantha [*Cryptantha* spp.], gilia [*Gilia* spp.] skeletonweed [*Stephanomeria* Nutt.], goosefoot [*Chenopodium* spp.]) that provide native ground cover and summer forage for sage-grouse.

Long-term monitoring would greatly complement passive restoration and nonnative plant treatments in the Owens River Fire area (Pyke et al. 2018). For example, five long-term ecological monitoring plots were burned in the Owens River Fire, offering an opportunity to track postfire vegetation trajectories and evaluate the effectiveness of passive restoration approaches. Remote-sensing techniques (box 6B) also greatly contribute to monitoring efforts in the analysis area.

Restoration opportunity 2: take management actions to restore desired conditions—

In four of the burned mesic sites and one unburned site with conifer encroachment into sagebrush (step 3, questions B and C), management actions could be selected to restore desired conditions, diminish the impact of stressors, and reduce departure from NRV. We compiled a potential list of restoration actions for sagebrush and pinyon-juniper ecosystems (e.g., evaluation of ecological site conditions, species selection for revegetation) based on local expert input and published resources (Chambers et al. 2014a; Finch et al. 2016; Miller et al. 2014a, 2015b; Pyke et al. 2014, 2015) (table 6.2).

Restoration opportunity 3: reevaluate desired conditions considering climate change and other stressors—

Restoration of some sites in the Owens River Fire may no longer be feasible owing to the dominance (biomass or cover) of cheatgrass or other nonnative invasive species observed in the field by forest staff in 2018. This may occur in areas of cheatgrass occurrence that burned too frequently (e.g., negative FRID condition class), or areas exposed to additional site-specific stressors (e.g., inappropriate livestock grazing) or widespread stressors (e.g., climate change) that inhibit or preclude native plant recovery. In these cases, conversion to nonnative annual grassland may be likely, with concomitant losses of ecosystem services. It may be important to monitor these areas for long-term vegetation change and nonnative species containment, or to apply adaptive management approaches for managing these potentially novel or hybrid ecosystems (e.g., by revegetating areas with unique combinations of species that tolerate high disturbance). Finally, emerging evidence elsewhere in the Great Basin indicates that despite the presence of cheatgrass, maximizing the cover of perennial grasses and forbs promotes elements of ecosystem resilience and integrity (Chambers et al. 2017). Although this is not the ideal invasion-free landscape that may be desired, such mixed-vegetation conditions do provide benefits to wildlife, range, and other resources and suggest a reevaluation of desired conditions in light of interacting stressors. Additional native forbs and shrubs, including early-seral species, could be particularly beneficial as perennial grass cover may have been historically limited in the Crowley Basin. In some limited cases, seeding or planting of sagebrush and other native shrub species may be feasible in localized, targeted areas (e.g., high-value habitat corridors, experimental sites) to achieve long-term native vegetation recovery (Ott et al. 2019).

Step 4: Develop and Integrate Restoration Opportunities Into Potential Restoration Actions

Based on our review of the postfire flowchart (i.e., restoration opportunities 1, 2, and 3 described above), we proposed a list of restoration opportunities (table 6.2), including some related to other valued resources not specifically addressed earlier. Based on these opportunities, we generated a list of potential management actions for the Owens River Fire analysis area:

- Reseed and plant greenhouse-stock sagebrush, bitterbrush, and other native species obtained from local seed sources (Gucker and Shaw 2019, Miller et al. 2014a) focusing on creating or expanding sagebrush islands within the fire perimeter or within fire suppression activity areas
- Remove encroaching conifers (e.g., Jeffrey pine) in sagebrush within burned and unburned patches adjacent to the southern fire perimeter
- Defer livestock grazing for at least the first 2 years postfire or longer if desirable forage species have not recovered
- Install signage or barriers to discourage illegal off-road vehicle use in the burned area
- Eradicate or contain the spread of nonnative invasive plants where feasible
- Apply strategic fuel breaks to neighboring unburned areas to limit future wildfire spread (and nonnative plant invasions)

- Implement slope or road rehabilitation measures to stabilize soils and encourage native plant regeneration
- Monitor restoration treatment effectiveness

Most of these management actions (most also listed in table 6.2) can be combined and integrated to maximize treatment effectiveness and efficiency. For example, native plant revegetation efforts could be combined with nonnative plant and grazing management, and off-road vehicle closures to ensure greater success of restoration efforts (i.e., in areas targeted for revegetation efforts, install signage or barriers to discourage off-road vehicle use, eradicate or control nonnative plants, and work with grazing permittees to redirect livestock grazing to other areas). Consolidation of high-priority restoration areas may be enhanced using additional spatial tools and site-specific evaluation and analysis (see box 6B). For example, three of the mesic sagebrush patches in or adjacent to Clark Canyon are characterized by (1) sufficient road access (provides increased accessibility for revegetation activities), (2) close proximity or connectivity with cheatgrass occurrences (i.e., higher potential for invasion), (3) availability of suitable habitat for sage-grouse, (4) relatively lower moisture stress (i.e., topographic positions of higher moisture availability and lower current CWD), and (5) patches of high soil burn severity that would influence recovery (Figs. 6.2 and 6.3); sage-grouse habitat, CWD, and soil burn severity not displayed). These areas of recovering sagebrush could be targeted for a combination of native plant reseeding, deferred grazing, prohibitive off-road vehicle signage, nonnative plant control, road stabilization, and effectiveness monitoring efforts.

Consolidation of high-priority restoration areas may be enhanced by using additional spatial tools and site-specific evaluation and analysis.

Step 5: Build a Restoration Portfolio by Prioritizing Actions

For sagebrush steppe ecosystems, postfire revegetation efforts will be constrained by local greenhouse and seed stock availability (e.g., native plant seeds and seedlings), which requires precise application in the priority mesic sagebrush patches. However, even small patches of recovering sagebrush vegetation may facilitate more rapid and desirable successional transitions (Chambers et al. 2017, Finch et al. 2016), underscoring the importance of identifying priority treatment areas. Another primary constraint for the Owens River Fire area is accessibility, especially road access, which is further limited by private property inholdings and limited river crossings. Mesic sagebrush patches in Clark and Alpers Canyons (fig. 6.2) are accessible and operable for the types of management actions identified in table 6.3. The prioritization of management actions (fig. 6.11) will depend on the integration of these and other factors, such as availability of resources.

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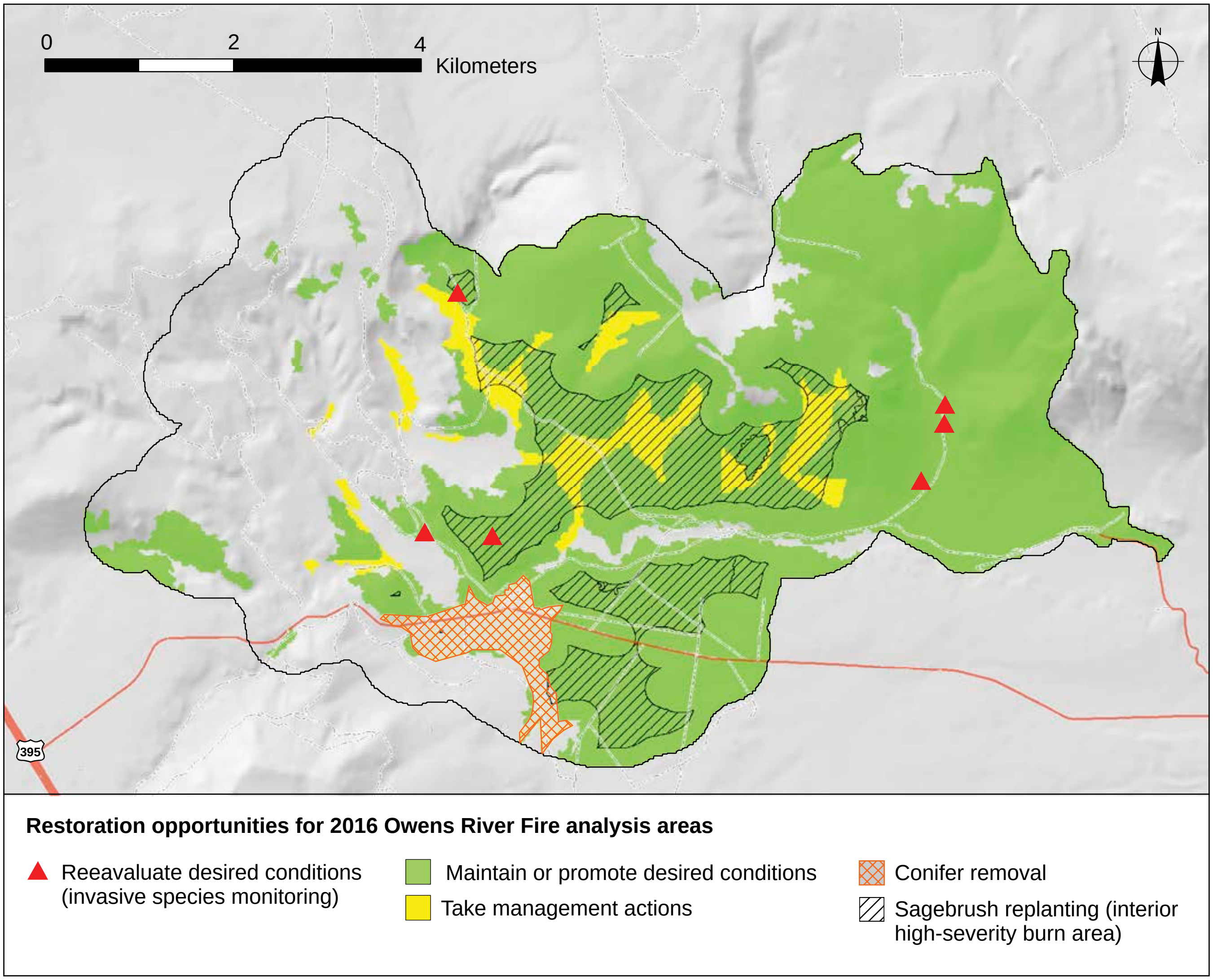

Figure 6.11—Restoration opportunities for sagebrush vegetation in the Owens River Fire analysis area. Areas selected to take management actions and identified for potential sagebrush replanting (i.e., overlap between yellow and cross-hatching polygons) could be prioritized for sagebrush replanting efforts and complementary restoration actions (e.g., redirect grazing outside of priority restoration areas).

Finally, we developed a restoration portfolio based on these integration and prioritization steps (table 6.3). The management actions we identified provide the basis of an ecological restoration portfolio for the Owens River Fire that includes areas where the fire improved ecological conditions, as well as areas where the fire degraded priority resources. By employing a suite of actions designed to address the full range of restoration opportunities created by the fire, this restoration portfolio maximizes the potential for achieving the postfire restoration goals in the Owens River Fire analysis area.

Table 6.3—Restoration portfolio for the Owens River Fire analysis area based on the primary management goals, approaches, and opportunities presented in table 6.2.

Restoration opportunity	Target areas	Management actions	Timing	Feasibility	Cost of inaction
Maintain or promote desired conditions	Burned sagebrush patches, especially in areas of management activities	Contain and, where feasible, eradicate nonnative plants	Short term (1 to 3 years)	Low to Moderate	High
	Burned sagebrush patches, especially in areas of management activities	Create appropriate fuel breaks (Miller et al. 2014b) around burned areas to facilitate fire suppression until sagebrush ecosystem can benefit from subsequent fire (>35 years)	Mid-term (3 to 10 years)	Moderate	Moderate
	Sagebrush vegetation in Clark Canyon and Alpers Canyon	Install long-term vegetation monitoring plots in native plant reseeding and replanting sites and areas of conifer removal to evaluate treatment effectiveness	Mid to long term (>5 to 10 years)	High	Moderate
Take management actions to restore desired conditions	Sagebrush vegetation in Clark Canyon	Reseed native grasses and forbs and replant native shrubs (likely limited to localized patches due to limited availability of seed stock, seedlings, and personnel)	Short term (1 to 3 years)	Moderate	High
	Unburned sagebrush located outside of the north edge of the Owens River Fire	Hand thin Jeffrey pine from unburned sagebrush stands	Short term (1 to 3 years)	High	Moderate
	Burned sagebrush patches	Work with grazing permittees to redirect livestock grazing outside of target burned areas	Short term (1 to 3 years)	Moderate	High
	Burned area especially in Clark Canyon	Install signage or barriers to discourage illegal off-road vehicle use	Short term (1 to 3 years)	Moderate	High
Reevaluate desired conditions considering interacting stressors	Nonnative plant distribution	Conduct long-term monitoring of nonnative plants using remote sensing and field surveys	Mid to long term (>5 to 10 years)	High	Moderate

Note: This restoration portfolio has not yet been applied on a national forest to inform project planning.

Conclusions

We assessed the pre- and postfire ecological condition of the Owens River Fire analysis area based on vegetation type and landscape management unit, but also included vegetation burn severity and FRID condition class. Most of the target ecosystem (i.e., sagebrush) burned at stand-replacing severity in a landscape that is not departed from the historical fire return interval or is burning slightly less frequently than NRV (i.e., low to moderate FRID). These conditions suggested that maintaining or promoting desired conditions (restoration opportunity 1) was appropriate for much of the analysis area. However, some unburned and burned areas located along or immediately outside the southern edge of the Owens River Fire had experienced conifer encroachment that warranted intervention and some areas of severely burned sagebrush in Clark Canyon were targeted for native plant reseeding and replanting efforts (restoration opportunity 2). Finally, some areas that were heavily invaded by nonnative species suggest a reconsideration of desired conditions (restoration opportunity 3) that would reflect a mix of native and nonnative species in the future. The restoration portfolio included seven important restoration management actions for restoration and maintenance of sagebrush steppe in the Owens River Fire analysis area. Most of these actions were considered feasible, integrative, and critical to supporting the primary management goals, especially in target areas located within and adjacent to the Owens River Fire perimeter.

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Chapter 7: Key Lessons and Caveats

Jonathan W. Long, Hugh D. Safford, and Marc D. Meyer[1]

This report originated from a workshop on long-term postfire ecological restoration held in late 2015 at Yosemite National Park, and a second workshop held at the Natural Areas Conference at the University of California-Davis in late 2016. Workshop attendees included ecologists from the U.S. Forest Service Pacific Southwest Region Ecology Program; scientists from the U.S. Forest Service Pacific Southwest Research Station; and national forest specialists from a variety of fields, including silviculture, soils, and hydrology. In this concluding section, the editors highlight some of the key lessons learned from the process of developing this framework document, which represent important topics for thoughtful consideration and further research.

Using recent, predisturbance measures based on EVeg as a reference may bias restoration toward prefire conditions that were already departed significantly from pre-Euro-American conditions.

- **Nonfire disturbances**. Since the first workshop, considerable interest has developed in addressing the topic of nonfire disturbances, particularly widespread bark beetle mortality associated with the extended California drought from 2012 to 2016. New research studies have identified some of the short-term effects of that mortality and possible implications for future fire behavior, but the science on long-term ramifications with and without interventions remains limited.
- **Evaluation of departure**. We found tensions in the process of evaluating departure from reference or desired conditions. The original assessment guidance focused on pre-disturbance vegetative conditions, which were typically based on available and relatively accurate data, such as EVeg. Using recent, predisturbance measures based on EVeg as a reference may bias restoration toward prefire conditions that were already departed significantly from pre-Euro-American conditions. This is especially the case for forest structural and compositional changes related to fire exclusion, including possible reductions in early-successional and other nonconiferous, forest-dominated communities. An approach founded in restoration would ideally focus on departure from reference conditions, such as those described in NRV or historical range of variation assessments. Spatial representations of reference conditions could be represented by biophysical settings in LANDFIRE (although such data may be inaccurate when applied to small areas), Forest Service vegetation maps from the 1930s, soils-vegetation maps from the 1940s and 1950s, or other site-specific historical data.

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- **Interpretation of desired conditions**. The case studies revealed challenges in evaluating departure and developing restoration portfolios based upon desired conditions. Desired conditions may come from aging planning documents that are overdue for revision and do not represent the current state of knowledge (although several plan revisions are currently underway). They may define desired conditions too broadly to assess whether disturbances have resulted in significant departures or to quantitatively direct interventions. Teams charged with making postdisturbance recommendations may attempt to better quantify desired conditions based upon current understandings of NRV as well as projected changes in climate.
- **Future conditions**. It may be important to shift from the natural or historical range of variation as a target to future natural variation by considering how changes in climate may affect ecological site potentials. Although an area may be vulnerable to high levels of moisture stress that could compromise vegetation recovery, can we distinguish whether an intervention would be futile, or whether intervention might significantly increase the chance of recovery? The science regarding future ecological conditions is currently coarse and potentially unreliable, making it difficult to translate into specific management strategies. Furthermore, socially-driven changes in conditions add to that uncertainty (see box 1A). However, science will advance in ways that make it more feasible to determine the conditions under which interventions may be successful, and to enhance those odds.
- **Assessment boundaries.** One case study used watersheds as the boundary for its assessment, while the shrublands the shrublands case studies used fire perimeters as the boundaries of their assessments. It is important to consider whether watersheds, potential operational delineations, fire perimeters, or a terrestrial vegetation unit may be the most appropriate units for restoration planning. As one example, the mixed-conifer case study described desired conditions as "Seventy percent of mixed-conifer forests located within sequoia groves (50 percent outside groves) are dominated by trees greater than 24 inches in diameter (late seral), with 10 percent in early seral, and the remainder (20 to 40 percent) in mid seral stage." Such specific goals require considering the appropriate scale for evaluating departure, and addressing questions such as how far beyond a fire perimeter would such criteria be applied, and how would they be translated to stands within the perimeter?
- **Evaluation criteria.** Criteria used in evaluation may appear somewhat arbitrary or tentative, especially when translated into discrete categories or thresholds (e.g., 40- to 100-ha high-severity burn patches). Conceptually, it

would be more appropriate to evaluate conditions relative to the frequency of patches of various sizes as a distribution relative to a reference time and space. However, managers often need to consider relatively fixed thresholds within a treatment area in order to make pragmatic choices. Regardless, an adaptive management framework is critical for evaluating the outcomes from any postdisturbance interventions over long periods and for better understanding these criteria. To support such a framework, it is important for the assessment to identify information gaps and suggest monitoring priorities to address them.

- **Short- versus long-term view**. The case studies illustrated that in many cases, the data that are immediately available in the wake of a disturbance do not provide the level of detail needed to effectively evaluate ecological departure. For example, short-term assessment relies on indicators that are easily measured after the fire (such as change in vegetation cover and size of high-severity patches), while longer term indicators (such as areas supporting natural regeneration) may be difficult to obtain without sufficient time, resources, and field verification. Consequently, the specific analysis methods used in the evaluation could lead to different views of priorities (see app. 3).
- **Time to develop a restoration strategy**. Although participants in the workshops initially suggested that providing specific guidance about how to implement the framework would yield a more useful product, there remains debate about that approach. For example, some participants suggested that providing guidance regarding how much time to allocate for an assessment (e.g., 30 days) could help managers to plan and execute the framework. On the other hand, such an abbreviated schedule may not fit other contexts, including slower moving disturbances such as bark beetle mortality.
- **Linkage to project planning**. Managers interested in applying the restoration framework in this document to a specific landscape will want to understand how to link products of the restoration framework (e.g., restoration portfolio) with project planning and monitoring. We anticipate future engagement with national forests to further develop an intuitive, practical, and science-based approach. We also anticipate a companion report that will focus more on strategies and tactics for postfire restoration in California forests.
- **Administrative challenges of multiple wildfires**. One of the reviewers of this report noted that national forest staff face a growing challenge in planning because large disturbances (including large wildfires as well as large

Moving from postfire triage to preparations for the next disturbance is important.

beetle outbreaks) are becoming so frequent as well as spatially overlapping (fig. 7.1). As a result, managers may get locked into rapid triage from one fire to the next, with less opportunity to consider long-term, cumulative effects. This trend illustrates the importance of thinking not only in broad landscape terms about restoration needs and opportunities after disturbances, but also how to prepare for the next disturbance. Even where fires may result in some undesirable conditions, they may create opportunities to disrupt the potential impacts of future large disturbances.

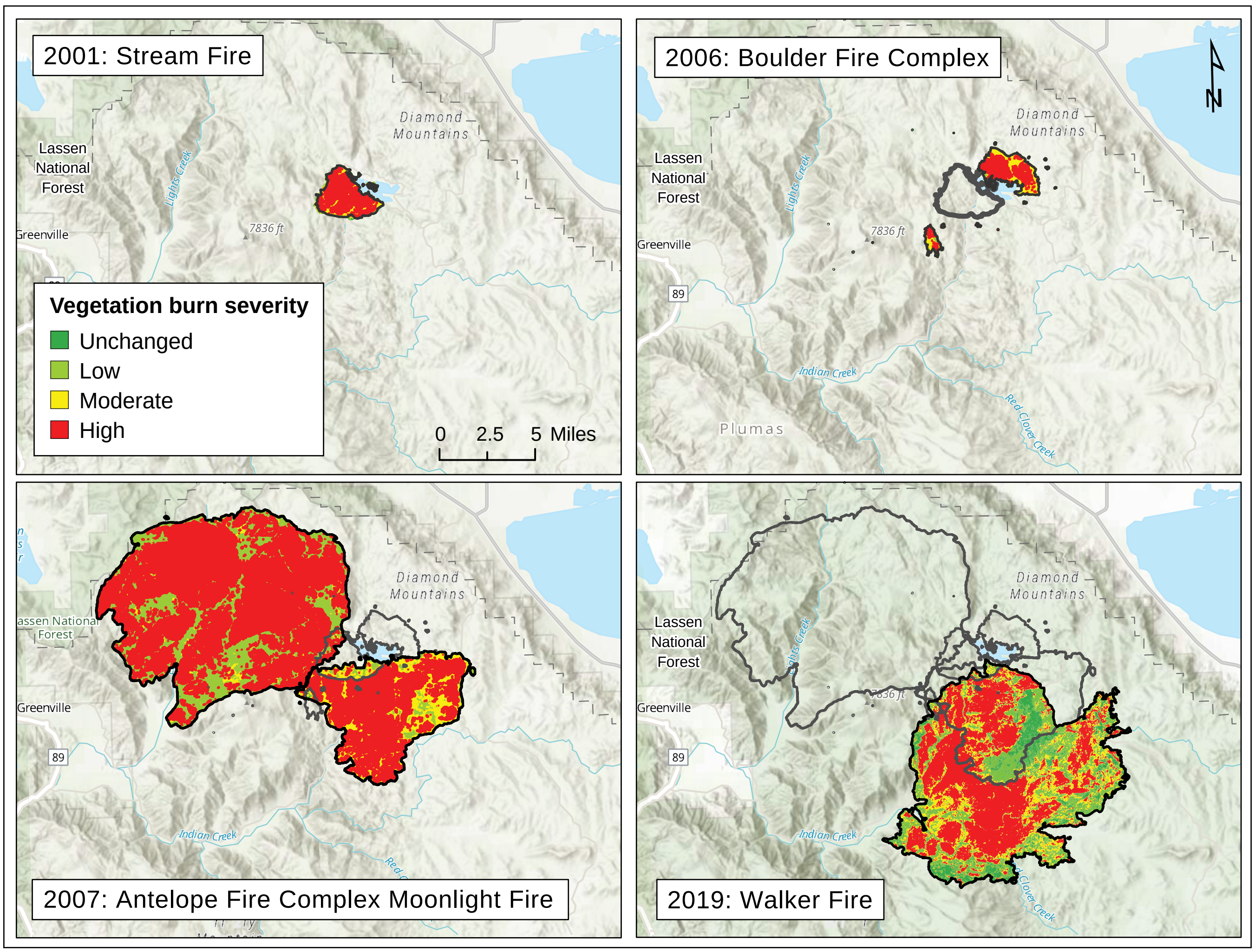

Figure 7.1—Overlapping wildfires between 2001 and 2019 in the Mount Hough Ranger District, Plumas National Forest. Credit: Ryan Tompkins, University of California Cooperative Extension.

- **Need for science and adaptive management**. Managers are clearly concerned that uncharacteristically large and severe fires, the spread of invasive species, and climate change may be shifting conditions into novel and less desirable configurations. We need more science to understand the extent and contexts of these changes, and whether interventions are effective in preventing such shifts. Decisions about whether to invest in interventions need to be informed by data on effectiveness, rather than assuming that interventions are either destined to fail or critical to the success of overarching restoration goals. Adaptive management will be needed in these contexts to facilitate learning and improve postfire planning and restoration.

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Appendix 1: Legislation, Regulations, Policy, and Direction Pertaining to Ecological Restoration

The practice of ecological restoration on National Forest System lands is guided by fundamental legislation, policy, and national and regional direction. Legislation mandates broadly that the national forests be managed for sustainability and multiple objectives, whereas U.S. Forest Service policy and direction focus more specifically on restoration planning and practice.

A number of federal statutes govern the restoration and maintenance of the ecological resilience of National Forest System lands and resources so as to realize sustainable multiple-use management and to provide a range of ecosystem services. Collectively, these statutes highlight the importance of maintaining forested areas to support the national welfare. These include (but are not limited to) the following legislation, listed in chronological order:

- **Organic Administration Act of 1897 (16 USC 475, 551).** The Organic Act defines the purpose of national forests, and directs that ''[n]o national forest shall be established, except to improve and protect the forest within the boundaries, or for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States.'' The act directs the secretary of agriculture to ''make such rules and regulations . . . to preserve the (national) forests from destruction.''
- **Multiple-Use Sustained-Yield Act of 1960 (16 USC 528–531).** This act states that national forests are to be administered for outdoor recreation, range, timber, watershed, and wildlife and fish purposes. The act directs the secretary of agriculture to manage renewable surface resources of national forests for "multiple use" and "sustained yield." Multiple use refers to the management of the diverse renewable resources of national forests in a balanced combination that will best meet the needs of the American people, providing for periodic adjustments in use to conform to changing needs and conditions, and "harmonious and coordinated management" of the resources without impairment of the land's productivity. Sustained yield refers to achieving and maintaining in perpetuity a regular output of renewable resources without impairing the productivity of the land.
- **Forest and Rangeland Renewable Resources Planning Act (FRRRPA) of 1974**, as amended by the **National Forest Management Act (NFMA) of 1976 (16 U.S.C. 1600–1614, 472a).** The FRRRPA and NFMA state that the development and administration of National Forest System renewable resources are to be in accordance with the concepts for multiple use

and sustained yield of products and services as defined in the Multiple-Use Sustained-Yield Act of 1960. The FRRRPA and NFMA establish that all forested lands in the National Forest System shall be maintained in appropriate forest cover with species of trees, degree of stocking, rate of growth, and stand conditions designed to secure the maximum benefits of multiple-use, sustained-yield management in accordance with land management plans. The FRRRPA and NFMA set the requirements for land and resource management plans for units of the National Forest System, including requiring guidelines to provide for diversity of plant and animal communities based on the suitability and capability of the specific land area in order to meet overall multiple-use objectives. The NFMA also requires that national forest lands "shall be (periodically) examined… as to stocking rate, growth rate in relation to potential and other pertinent measures. Any lands not certified as satisfactory shall be returned to the backlog and scheduled for prompt treatment. The level and types of treatment shall be those which secure the most effective mix of multiple-use benefits."

- **Healthy Forests Restoration Act (HFRA) of 2003 (16 U.S.C. 6501–6591).** The HFRA provides processes for developing and implementing hazardous fuel reduction projects on certain types of ''at-risk'' National Forest System and Bureau of Land Management lands, and also provides other authorities and direction to help reduce hazardous fuels and protect, restore, and enhance healthy forest and rangeland ecosystems.

Postfire restoration is often limited by funding constraints. In some cases, "fire cost recovery settlement funds" may be available where settlements or litigation for environmental damages caused by wildfires have resulted in receipts to the federal government. Disbursement of these funds is regulated by Public Law 85-464 of 1958 (16 USC 579c). Section 7 of Public Law 85-464 states that such monies will be "made available until expended to cover the cost to the United States of any improvement, protection, or rehabilitation work on lands under the administration of the Forest Service rendered necessary by the action which led to the forfeiture, judgment, compromise, or settlement." In a Forest Service correspondence dated March 20, 2014 (file code 6520/3900), the Pacific Southwest Region regional forester directed that national forests develop business plans and processes to expeditiously use such fire settlement funds. Attachment A of the correspondence notes that neither fire resource damage assessments, nor settlement agreements, judicial decisions, nor any other documents issued in relation to Forest Service fire cost-recovery litigation direct how the Forest Service uses these funds or how the Forest Service prioritizes restoration activities funded by them.

Forest Service policy focuses more directly on ecological/ecosystem restoration and management practices that promote long-term sustainability and resilience to climate change. The following regulations and policy documents are especially pertinent:

1. **The USDA Forest Service Planning Rule of 2012 (36 CFR 219)** implements requirements under the NFMA for National Forest System Resource Planning and is designed to ensure that plans provide for the sustainability of ecosystems and resources; meet the need for forest restoration and conservation, watershed protection, and species diversity and conservation; and assist the agency in providing a sustainable flow of benefits, services, and uses of National Forest System lands. The planning rule establishes requirements to guide development, amendment, or revision of land management plans to maintain and restore ecosystems while providing for ecosystem services and multiple uses. The planning rule emphasizes restoration of natural resources to make National Forest System lands more resilient to climate change, protect water resources, and improve forest health. Plans are required to take into account the interdependence of ecosystems, impacts from and to the broader landscape, system drivers and stressors, including climate change, and opportunities to restore fire-adapted ecosystems for landscape-scale restoration.
2. **Forest Service Manual 1020 (Forest Service Mission)** sets out objectives and guiding principles to realize the agency's mission. The mission of the Forest Service is to "sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations." FSM 1020.2 (Objectives) states the following Forest Service objectives:
    - Advocates a conservation ethic in promoting the health, productivity, diversity, and beauty of forests and associated lands
    - Protects, restores, and manages the national forests and grasslands so they best demonstrate the sustainable multiple-use management concept
    - Develops and provides scientific and technical knowledge aimed at improving the capability to protect, restore, manage, and use forests and rangelands
    - FSM 1021 lists guiding principles. The first two are as follows:
        - We use an ecological approach to the multiple-use management of the national forests and grasslands.
        - We use the best scientific knowledge in making decisions and select the most appropriate technologies in the management of resources.

3. **Forest Service Manual 2020 (Forest Service Ecosystem Restoration Policy)** provides "broad guidance for restoring ecosystems on National Forest System lands so that they are self-sustaining and, if subject to disturbances or environmental change, have the ability to reorganize and renew themselves." The objective of the policy (FSM 2020.2) is as follows:
    - Ecosystems (are) ecologically or functionally restored, so that over the long term they are resilient and can be managed for multiple use and provide ecosystem services.

FSM 2020.3 directs the Forest Service to "emphasize ecosystem restoration across the National Forest System and within its multiple use mandate." Further, Forest Service land and resource management plans, project plans, and other activities may include goals or objectives for restoration. In developing restoration goals and objectives, the Forest Service can consider a suite of factors, including the following:

- Public values and desires
- The natural range of variation (NRV)
- Ecological integrity
- Current and likely future ecological capabilities
- A range of climate and other environmental change projections
- The best available science information

The January 2006 Ecosystem Restoration: A Framework for Restoring National Forests and Grasslands (USDA 2006) provided several additional recommendations for the planning and implementation of restoration projects, including the following:

- Consider the effects of restoration at local and landscape levels
- Give priority to restoring ecosystem processes, such as natural fire regimes
- Establish objectives for the long term
- Recognize that ecosystems are dynamic and avoid "static endpoint" thinking
- Use multiple sources of relevant information, such as historical records, scientific studies, practical experience, and indigenous knowledge
- Deal with uncertainty by using adaptive approaches to restoration
- Design and implement monitoring as part of restoration and use this information to learn and adapt

The Forest Service Pacific Southwest Region (Region 5) has also emitted specific direction related to ecological restoration. The Region 5 Ecological Restoration Leadership Intent (USDA Forest Service 2015) sets ecological restoration as “the central driver of wildland and forest stewardship in the Pacific Southwest Region, across all program areas and activities.” The document sets out 15 goals, including the following (paraphrased):

- Collaboratively accelerate restoration pace and scale
- Increase forest resilience through treatments and wildfire
- Restore degraded meadows
- Decrease occurrence of uncharacteristically severe forest fires and their impacts
- Expand fire prevention efforts in southern California in order to conserve chaparral and coastal sage scrub
- Ensure a grounding of restoration efforts in concern for biodiversity and ecological processes both before and after disturbances such as fire
- Reforest after wildfire where appropriate and implement suitable stand maintenance activities that meet project goals and site conditions
- Ensure sustainability of forests, resources, and carbon as climates change
- Expand watershed improvement programs
- Improve habitat connectivity
- Decrease invasive species impacts

In summary, ecological/ecosystem restoration has been identified as a major policy and management priority on National Forest System lands. The Pacific Southwest Region postfire restoration strategy adheres to and tiers to congressional legislation, as well as Forest Service policy and direction. In providing suggested guidance for planning and implementation of restoration activities in burned ecosystems, the strategy fills an important Forest Service need.

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Appendix 2: Data Sources for Data Gathering and Analysis

Table A2-1—Summary of data variables or tools and their sources, locations, and descriptions useful in developing a postfire restoration portfolio (continued)

Variable/tool	Source	Data location	Scale	Description
Climate metrics	Basin Characterization Model (BCM), U.S. Geological Survey (USGS)	California Landscape Conservation Cooperative, Climate Commons (CA Climate Commons); http://climate.calcommons.org/dataset/2014-CA-BCM	270 m	The next four climate metrics were derived from Parameter-elevation Regressions on Independent Slopes Model (PRISM) data using a BCM). Grids represent historical (1900 to 2010) and future climates modeled based on two General Circulation Models: the National Oceanic and Atmospheric Administration Geophysical Fluid Dynamics Laboratory (GFDL) model and National Center for Atmospheric Research Parallel Climate Model (PCM) from 2010 to 2100 in 30-year means, providing monthly blocks of variables. Raster file.
Potential evapotranspiration (PET)	BCM, USGS	CA Climate Commons; http://climate.calcommons.org/dataset/2014-CA-BCM	270 m	PET is the total amount of water that can evaporate from the ground surface or be transpired by plants summed annually. Raster file.
Actual evapotranspiration (AET)	BCM, USGS	CA Climate Commons; http://climate.calcommons.org/dataset/2014-CA-BCM	270 m	AET is the amount of water that evaporates from the surface and is transpired by plants if the total amount of water is not limited, summed annually. AET measures when conditions (energy + water) for plants are favorable to support photosynthesis. Raster file.
Climatic water deficit (CWD)	BCM, USGS	CA Climate Commons; http://climate.calcommons.org/dataset/2014-CA-BCM	270 m	CWD is annual evaporative demand that exceeds available water, summed annually. It is calculated based on potential evapotranspiration minus actual evapotranspiration. CWD measures when plants have insufficient water to support photosynthesis. Raster file.
Water balance (WB)	BCM, USGS	CA Climate Commons; http://climate.calcommons.org/dataset/2014-CA-BCM	270 m	Combinations of AET/CWD. Raster file.
Future climate metrics	CalAdapt	https://cal-adapt.org/	Varies	Projected future temperature, precipitation, snowpack, drought, wildfire, sea level rise, and streamflow for user-defined areas.
Historic climate metrics	Climate Engine	https://app.climateengine.org/climateEngine	Varies	Historical climate data using a number of geospatial climate tools (such as gridMET, PRISM, TerraClimate) for user defined areas.
Digital elevation models (DEMs)	LANDFIRE	Landfire.gov -> tools -> download data or download toolbar to identify area of interest and then download data	30 m	1 arc second (30 m) national elevation dataset DEM was projected from Geographic to Albers and clipped out to the LANDFIRE boundary. Raster file.

Table A2-1—Summary of data variables or tools and their sources, locations, and descriptions useful in developing a postfire restoration portfolio (continued)

Variable/tool	Source	Data location	Scale	Description
Landscape management unit tool	General Technical Report PSW-GTR-237, University of California–Davis	Tool website: http://ice.ucdavis.edu/project/landscape_management_unit_lmu_tool (Best to download with Internet Explorer)	10 or 30 m	A Geographic Information System (GIS) tool developed to parse a landscape into basic topographic categories. The landscape management unit (LMU) tool has two versions: version 1 bins the landscape into three slope positions crossed with three aspects (Underwood et al. 2010); version 2 addresses management needs by condensing topographic categories present in version 1, while adding a category based on mechanical operation limitations that usually occur around >30 percent slopes. The second version also allows the user to modify topographic categories. Raster file.
Vegetation layer, EVeg	Remote Sensing Lab, U.S. Forest Service, Pacific Southwest Region (R5)	https://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5347192 https://enterprisecontentnew-usfs.hub.arcgis.com/	30 m	The R5 CALVEG classification system conforms to the upper levels of the National Vegetation Classification Standard (USNVC) hierarchy as it currently exists (http://usnvc.org/data-standard/natural-vegetation-classification/). The USNVC sets guidelines for all federal agencies involved in this work. Lowest (floristic) levels of this hierarchy are currently being developed and have not yet been finalized for their applicability to California. Vector file.
Presettlement fire regime (PFR)	Research Paper PSW-RP-266, Safford & Van de Water 2014	https://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=STELPRDB5327836	Min map unit 5 ac	Crosswalk from the current vegetation type to its probable historical fire regime (by "historical," we refer to the three or four centuries before Euro-American settlement). Each PFR is named for the dominant existing vegetation type supported by that PFR. Vector file.
Biophysical Settings (BpS)	LANDFIRE	http://www.landfire.gov/NationalProductDescriptions20.php	30 m	The BpS layer represents the vegetation that may have been dominant on the landscape prior to Euro-American settlement and is based on the current biophysical environment and an approximation of the historical disturbance regime. Each BpS map unit is matched with a nonspatial model of vegetation succession. LANDFIRE uses BpS models to depict reference conditions of vegetation across landscapes. The actual time period for this data set is a composite of both the historical context provided by the fire regime and vegetation dynamics models and the more recent field and geospatial data used to create it. Although the spatial resolution is 30 m, analysis of LANDFIRE data is most appropriate at sub-regional, regional, and national scales due to potential inaccuracies at smaller spatial scales. Raster file.

Table A2-1—Summary of data variables or tools and their sources, locations, and descriptions useful in developing a postfire restoration portfolio (continued)

Variable/tool	Source	Data location	Scale	Description
Vegetation fire severity	Rapid Assessment of Vegetation Condition after Wildfire (RAVG)	http://www.fs.fed.us/postfirevegcondition/whatis.shtml	30 m	The RAVG products produced at the Remote Sensing Applications Center (RSAC) include the following for each wildfire processed: Map and GIS products showing location of basal area or canopy cover loss within fire perimeter. Summary table of vegetation affected by the fire, separated into four or seven classes of basal area loss. RAVG uses the relativized normalized burn ratio (RdNBR) and can be calibrated using field data. Raster file.
Vegetation fire severity	Remote Sensing Lab, U.S. Forest Service, Pacific Southwest Region	https://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=STELPRDB5327833	30 m	Maps derived from RdNBR for immediate and 1-year postfire images calibrated to basal area (BA) change of trees or canopy loss. This data product is preferred in the Pacific Southwest Region because it is based on extensive field validation (Miller and Thode 2007), but it is not produced until one year after the fire through 2018. Vector file.
Vegetation fire severity	Monitoring Trends in Burn Severity (MTBS)	http://www.mtbs.gov/	30 m	MTBS uses the differenced normalized burn ratio (dNBR), which is correlated to the amount of prefire chlorophyll. This analysis is typically done 1 year postfire on all fires greater than 500 ac. Raster file.
Burned area reflectance classification (BARC)	U.S. Remote Sensing Applications Center, Salt Lake City, Utah	http://www.fs.fed.us/eng/rsac/baer/. Work with the Burned Area Emergency Response (BAER) team to determine if they have already requested the data. If not put in a request to the Remote Sensing Applications Center for data.	30 m	Satellite-derived data layer of postfire vegetation condition. The BARC has four classes: high, moderate, low, and unburned. This product is used as an input to the soil burn severity map produced by the BAER teams. Raster file.
Soil burn severity (SBS)	Remote Sensing Applications Center, Salt Lake City, Utah; Local BAER team	http://www.fs.fed.us/eng/rsac/baer/. If data is not yet available, work with the BAER team as they will be reclassifying and field verifying this layer.	30 m	BAER team reclassifies and field verifies the BARC data to map soil severity. Raster and vector files.
Soil survey geographic database	U.S. Natural Resources Conservation Service	https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm	10 m	Soil survey data provides soil physical, chemical, and health properties; erosion factors; and qualities and features. Raster and vector files.

Table A2-1—Summary of data variables or tools and their sources, locations, and descriptions useful in developing a postfire restoration portfolio (continued)

Variable/tool	Source	Data location	Scale	Description
Fire return interval departure (FRID)	U.S. Forest Service, Pacific Southwest Region	http://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=STELPRDB5327836 (internal) Pacific Southwest Region Ecology Program, Hugh Safford	Min map unit 5 ac	This polygon layer consists of information compiled about fire return intervals for major vegetation types on the national forests in California and adjacent land jurisdictions. Comparisons are made between pre-Euro-American settlement and contemporary fire return intervals (FRIs). Current departures from the pre-Euro-American settlement FRIs are calculated based on mean, median, minimum, and maximum FRI values. Vector file.
U.S. Forest Service, Pacific Southwest Region rapid assessment of postfire condition data	U.S. Forest Service, Pacific Southwest Region	ftp://fsweb.rsac.fs.fed.us/RAVG/California/ (internal to the U.S. Forest Service)	Min map unit 5 ac	This dataset looks at the potential for natural revegetation by combining RAVG, prefire vegetation, and land suitability data. Vector file.
Ecosystem Disturbance and Recovery Tracker (eDaRT)	Remote Sensing Lab, U.S. Forest Service, Pacific Southwest Region	Contact: Michèle Slaton, ecologist; Pacific Southwest Region, Remote Sensing Lab: michele.slaton@usda.gov	30 m	Time series algorithm using all available Landsat images to detect forest disturbance of all types, 1980s to present.
F3 (forest structure metrics)	Remote Sensing Lab, U.S. Forest Service, Pacific Southwest Region	Contact: Shengli Huang, senior remote sensing scientist; U.S. Forest Service, Pacific Southwest Region Remote Sensing Lab, shenglihuang@usda.gov	Typically 30 m, but project-dependent, up to 10 m	Imputation algorithm uses plot-based and remote sensing data to generate landscape-scale grids of vegetation structure and composition metrics, including recent historic, current, and predicted conditions under various management scenarios. F3 is a model that integrates Forest Inventory and Analysis (FIA) plot data, Forest Vegetation Simulator (FVS), and the FastEmap (field and satellite for ecosystem mapping) tool.
Nitrogen deposition	Center for Conservation Biology, University of California–Riverside	http://ccb.ucr.edu/biocommaps.html	4 km for high-deposition areas; 36 km for low-deposition areas	Raw nitrogen deposition data from 2002. Raster file.

Table A2-1—Summary of data variables or tools and their sources, locations, and descriptions useful in developing a postfire restoration portfolio (continued)

Variable/tool	Source	Data location	Scale	Description
Insect and disease detection survey data	U.S. Forest Service, Forest Health Technology Enterprise Team	http://foresthealth.fs.usda.gov/portal/Flex/IDS	Size of mapped polygon	Aerial detection surveys are collected by aerial observers from the U.S. Forest Service and other cooperating state and federal agencies. Areas of damage are captured as polygons on hardcopy 1:100,000 scale maps or through a Digital Aerial Sketch-mapping System (D-ASM). Polygons are coded to identify the damage agent, damage type, and other attributes. Reporting the number of dead trees or dead trees per acre is required for areas with mortality. Areas with mortality are summarized on this map by 12-digit or 6th-level USGS subwatersheds. Vector file.
Terrestrial ecological unit inventory (TEUI)	U.S. Forest Service, Pacific Southwest Region	TEUI maps are available from individual national forest GIS coordinators (i.e., there is not a national spatial data clearing house for the TEUI program).	Min map unit of 1,000 ac (land type associations [LTAs]) and 10 ac (land types [LTs])	LTAs are mapped for most national forests in the Pacific Southwest Region. LTs are mapped, but not field validated, at the intensity required in the terrestrial ecosystem unit inventory guide (Winthers et al. 2005) for the Lake Tahoe Basin Management Unit; the Inyo, Eldorado, and Mendocino National Forests; and the Monterey District of the Los Padres National Forest.
Mechanical treatments opportunities	U.S. Forest Service, Pacific Southwest Region	https://www.fs.usda.gov/detail/r5/landmanagement/gis/?cid=STELPRDB5327833	30 m	This dataset represents four scenarios (A-D) of mechanical treatment opportunities in Sierra Nevada National Forests based on a hierarchy of biological (i.e., nonproductive forest), legal (i.e., wilderness), operational (i.e., equipment access), and administrative (i.e., at-risk species and riparian areas) constraints, under forest plan standards and guidelines. Scenario descriptions and analysis are provided in North et al. (2015).

Note: Some of the data sources mentioned in the table are only available through the Forest Service network, while others require establishing an account with the California Landscape Conservation Cooperative, Climate Commons. It is important to recognize that at the time of publication these were the best available data. However, spatial data evolve rapidly, allowing for the release of updated information on a regular basis. URLs, data locations, and contacts may change or terminate over time.

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Appendix 3: Postfire Conifer Regeneration Prediction Tools

Hugh D. Safford

Two tools have recently been developed to aid in the identification of areas in yellow pine, dry mixed-conifer, and moist mixed-conifer forest that are unlikely to support sufficient conifer regeneration to meet management goals. Both tools are focused on predicting seedling densities 5 years after fire, because the National Forest Management Act and Forest Service regulations (e.g., USDA FS (1992) require that productive forest be restocked within 5 years after a major stand-altering event, such as major tree harvest or a stand-replacing fire. Five years is also a forestry rule-of-thumb threshold beyond which burned areas require major extra investment in site preparation to plant, and planting in such locations is therefore rarely undertaken. We recommend that the tools be used sequentially. First, the Postfire Spatial Conifer Regeneration Prediction Tool (POSCRTPT) (Shive et al. 2018) is used to identify locations where probability of conifer seedling presence 5 years after fire is low enough to warrant concern. Next, the Welch et al. (2016) field assessment tool is used to field check locations identified by the spatial prediction and determine whether seedling densities 5 years after fire are likely to meet seedling stocking guidelines or not. Using these tools, sites where seedling regeneration is likely to be adequate or inadequate can be quickly identified and sites for reforestation efforts can be prioritized.

Conifer Regeneration Prediction at the Landscape Scale Using Spatial Data

Shive et al. (2018) used an extensive Forest Service postfire inventory dataset from California to develop POSCRPT for forecasting postfire forest regeneration. POSCRPT predicts spatial variation in seed availability by using a kernel-based estimator of annual seed production based on live basal area (either as measured postfire, or from prefire basal area adjusted by burn severity). After scaling by 30-year mean annual precipitation, POSCRPT generates a map of predicted seedling densities that can be binned into higher accuracy seedling-presence probability classes (the probability of observing at least one living seedling in a 60-m^2 (646-ft^2) area 5 years after fire).

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POSCRPT is a distinct improvement over current Forest Service practice in the Pacific Southwest Region, which bases reforestation considerations on basal area mortality maps produced through the Monitoring Trends in Burn Severity (MTBS) program. Areas with >50 percent basal area mortality as mapped by MTBS are declared "deforested" and reforestation need is assessed using this baseline. However, basal area mortality maps are not predictions of postfire seedling recruitment and do not include considerations of climate, burn patch size, or distance to nearest living seed tree (among other things), all of which are major drivers of tree regeneration. POSCRPT incorporates these factors and directly models conifer regeneration. It is also worth noting that Welch et al. (2016) showed that natural seedling recruitment in areas with basal area mortality <75 percent was nearly always sufficient to meet stocking guidelines, which means that even under current practice the area of land considered for reforestation could be reduced substantially.

There is very high spatial variation in seedling density in the postfire environment (see Shive et al. 2018: table 3). For example, plots falling in the seedling probability class 0.6 to 0.8 showed a median density of 333 seedlings/ha (134 seedlings/ac), a mean density of 3,665 seedlings/ha (1,478 seedling/ac), and a range from 0 to 380,166 seedlings/ha (153,311 seedlings/ac). Current Pacific Southwest Region stocking guidelines for mixed-conifer forest (dry or moist) recommend targeting a median of at least 200 seedlings/ac, but this value is based on production forestry assumptions and ignores forest-density sustainability issues under warming climates and increasing fire risk (Welch et al. 2016). We suggest that the users of the spatial regeneration tool focus on areas with <0.6 probability of seedling presence after fire, as these are the areas where median densities (stocking rate) are predicted to fall well below stocking guidelines.

Employment of the spatial prediction tool requires some background in using Python coding and *R* statistical analysis. Applications of the tool are currently being carried out by the Pacific Southwest Region Ecology Program, and first implementations of the tool were made in the fall of 2018. An example is provided in the mixed-conifer forest case study for the Rough Fire (chapter 4). Recent updates to the tool include the ability to incorporate postfire weather and masting, but fine-scale dynamics, such as competition and microclimates, cannot be modeled.

Conifer Regeneration Prediction in the Field

Welch et al. (2016) used the same dataset as Shive et al. (2018) to develop a set of statistical models of conifer regeneration density in yellow pine and mixed-conifer forests (dry and moist) 5 years after fire. The models were used to build a simple-to-use graphical tool that permits identification in the field of locations that are likely to be above or below a predetermined stocking threshold (fig. A3.1), based on a series of easily measured variables (slope, aspect, live basal area in the stand, distance to nearest living seed tree). Independently assessed classification accuracy of the method was about 75 percent, which is very high for a field tool.

Welch et al. (2016) published a suggested field protocol for using the tool. The text is reproduced below.

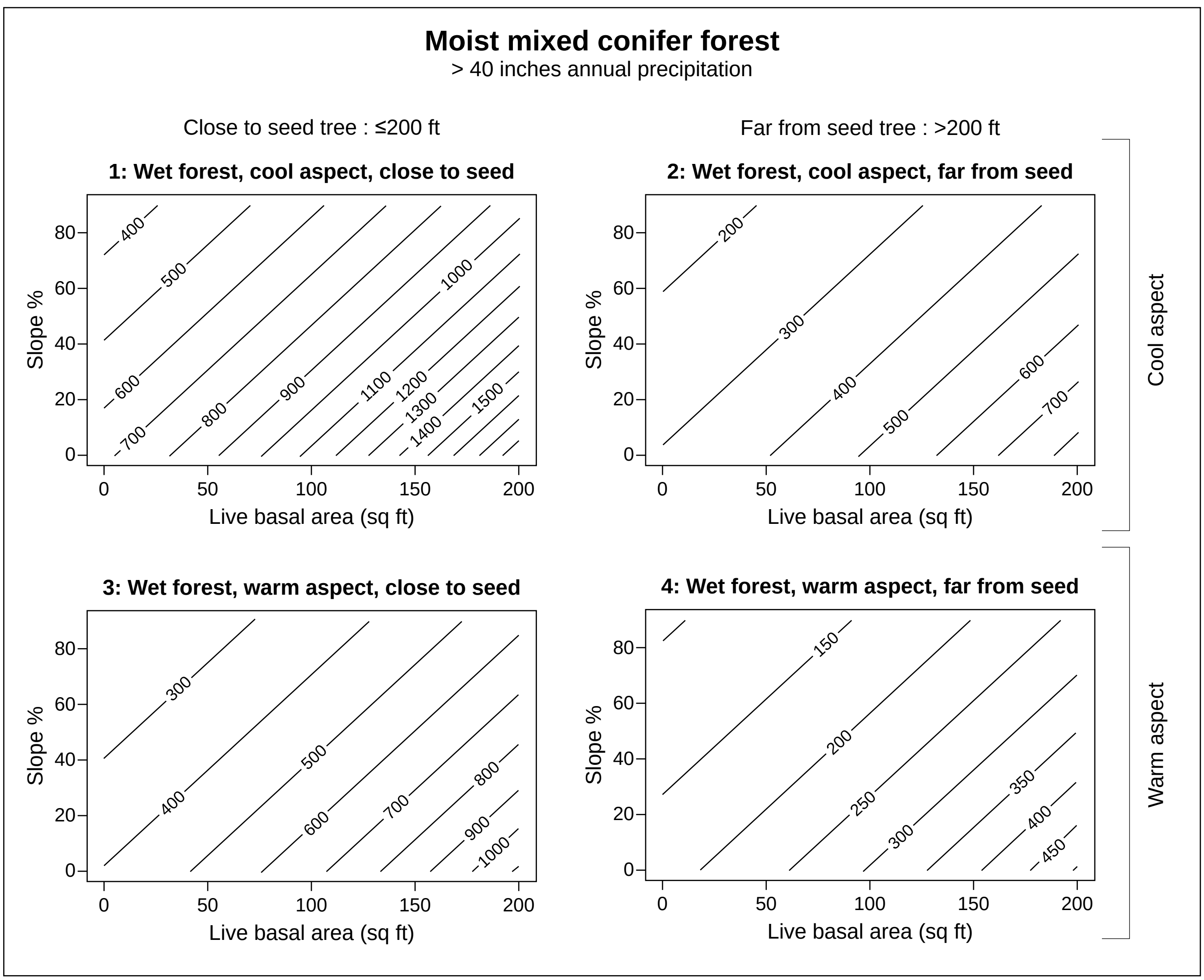

Figure A3.1—Seedling density isolines from the Welch et al. (2016) predictive method, in U.S. units to facilitate Forest Service field use.

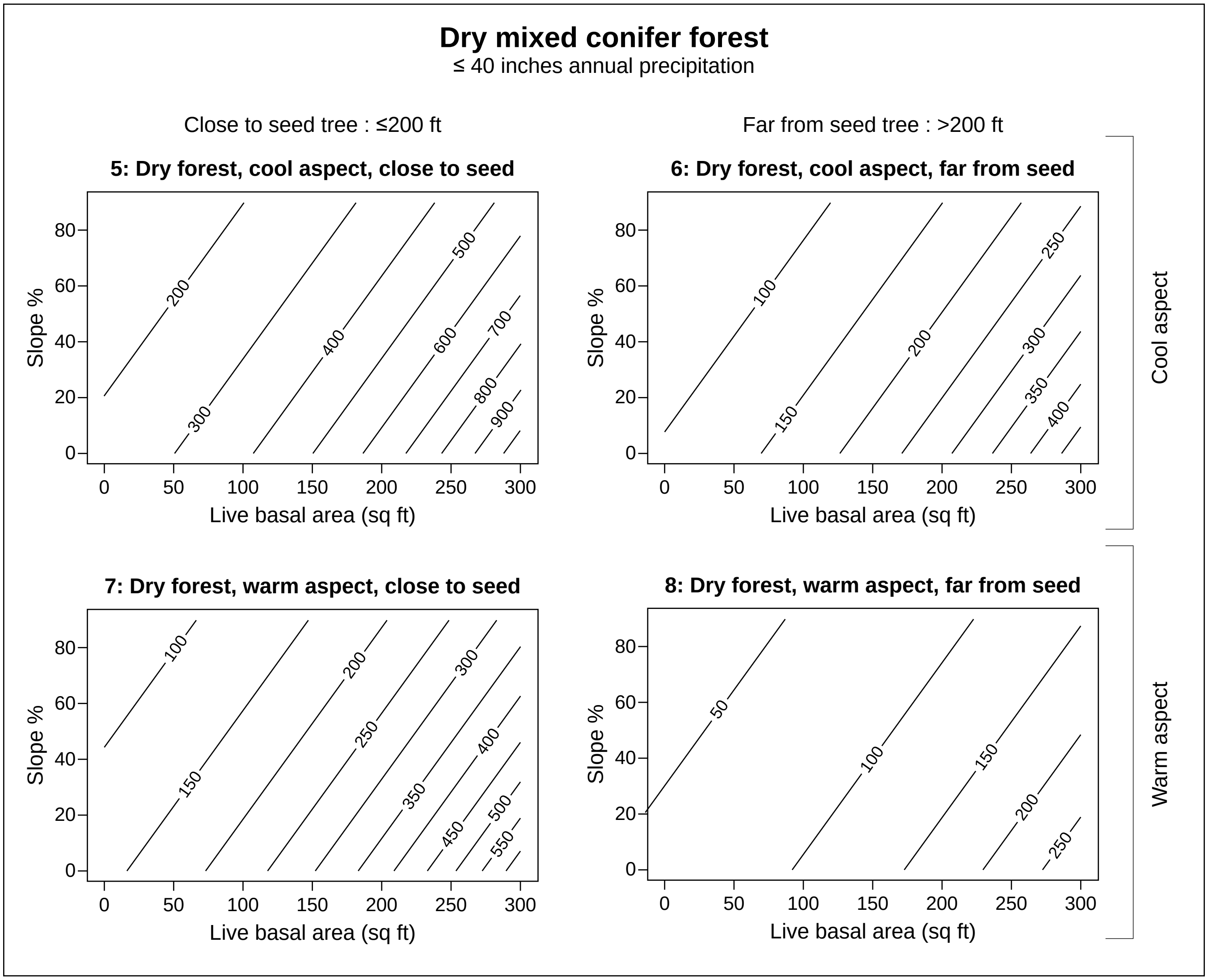

Figure A3.1 (continued)—Seedling density isolines from the Welch et al. (2016) predictive method, in English units to facilitate Forest Service field use.

Suggested Protocol for Field Assessment of Predicted Seedling Densities 5 to 6 Years After Fire

Typically, a preliminary assessment of postfire reforestation need will be made based on remotely sensed imagery (of fire severity, for example) or aerial photography or field reconnaissance, using variables such as fire severity, aspect, and distance to remnant forest edge. Polygons are then drawn on maps with preliminary hypotheses of probable reforestation need. Ideally, this preliminary estimate is made using the POSCRPT spatial prediction tool described in Shive et al. (2018) and already in use on Pacific Southwest Region fires. Figure A3.1 provides information to be used in subsequent field verification of the preliminary polygons for dry and moist mixed-conifer forests (dry mixed-conifer forests includes yellow pine dominated forests) that have burned at high severity (≥75 percent loss of prefire basal area). Field sampling protocols will vary according to need, ease of access, and size of the areas to be assessed, but in general, we recommend that a protocol be adopted that visits at least 1 percent of the area in question. Each 60-m^2 (646-ft^2) plot is equivalent to 0.6 percent of a hectare and 1.5 percent of an acre, so we recommend sampling a minimum of two plots per hectare or one plot per acre.

Follow these steps:

1. Develop a paper or electronic datasheet for the data to be collected.
2. Determine whether the area to be visited is within dry or moist mixed-conifer forest. Use local knowledge of precipitation and vegetation patterns, or climate datasets like PRISM, or maps of potential natural vegetation (local maps or the LANDFIRE biophysical setting data, for example). Remember that north slopes in areas with <1000 mm precipitation may support moist mixed-conifer forests (dominated by shade-tolerant conifers like firs and Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco]), and some south and west slopes or thin soils in areas with >1000 mm (39.4 inches) precipitation may support dry mixed-conifer forests (dominated by pines and oaks).
3. Visit a set of previously selected Global Positioning System (GPS) locations, which were ideally selected through a stratified random process laid over a spatial grid in a Geographic Information System (GIS). GIS data can be used to assign the appropriate forest type, aspect class, and distance from forest edge to the plot locations before they are visited; however, all of these determinations are important to verify in the field as all of these variables have major influence on predicted seedling densities. In the case of the distance to forest edge value, there are often living trees within high-severity patches, and the distance to nearest seed tree is therefore typically less than the distance to the forest edge.
4. Perform the following at each site in the field:
    a. Verify the forest type
    b. Determine the aspect class (warm: south and west; cool: north and east)
    c. Use a rangefinder to measure the distance to the nearest living seed tree
    d. Measure the slope inclination with a clinometer (percentage of slope)
    e. Use a basal area gauge or prism to estimate the live basal area in the surrounding stand
5. Determine whether there are any seedlings within a circular area of 60 m^2 (646 ft^2) around the GPS point; 60 m^2 has a radius of 4.37 m (14.3 ft), which corresponds to 5.7 paces for a standard human (a pace = 76.2 cm or 30 inches).

6. Using forest type, distance class to nearest living seed tree, and aspect class, choose the appropriate subgraphic in figure A3.1.
7. Using percentage of slope (y-axis) and live basal area (x-axis), locate the appropriate x, y coordinate for the plot being visited.
   a. If there is at least one seedling in the sample plot, enter the predicted seedling density (the value at the x, y coordinate). This is a prediction of the seedling density that one would sample at this site 5 to 7 years after fire given the site variables.
   b. If there are no seedlings in the plot, enter the following in the predicted seedling density field:
      i. The predicted density from figure A3.1, if the plot is <30 m (98 ft) from the nearest living seed tree.
      ii. Half of the predicted density from figure A3.1, if the plot is 30 to 60 m (98 ft) from the nearest living seed tree.
      iii. Enter "0" if the plot is >60 m from the nearest living seed tree.

After collecting the field data, enter the data into a spreadsheet or database and calculate predicted median seedling densities. Compare the median seedling density against your desired stocking rate to determine if the area is a candidate for reforestation. This comparison can also serve to prioritize areas.

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Appendix 4: Burn Severity Spatial Analyses

Jens T. Stevens, Jamie M. Lydersen, and Brandon M. Collins[1]

Background

Stand-replacing fire, which refers to conditions where most of the forest overstory is killed by fire, is an important outcome of individual fires and fire regimes overall. The shape and size of stand-replacing patches is of particular importance when forecasting, and managing for, postfire forest succession. Tree mortality is often contiguously clustered into patches of stand-replacing fire, which can be mapped based on algorithms comparing pre- and postfire satellite imagery. This process has been well-studied and generally relies on calculating the differenced normalized burn ratio (dNBR) or a relativized version thereof (RdNBR) from LANDSAT imagery, identifying thresholds of (R)dNBR associated with particular levels of basal area mortality or canopy cover loss based on field plot calibrations, and classifying the resultant (R)dNBR raster layers into several fire severity classes (Miller and Thode 2007). The dNBR tends to correlate better with fire intensity because it is highly sensitive to prefire biomass, whereas the relativized measure (accomplished by dividing dNBR by the prefire image) generates more reliable measures of fire severity that do not vary because of prefire biomass (Safford et al. 2008). Severity class thresholds may vary depending on region, timing of postfire image acquisition, or vegetation type. Robust thresholds for low, moderate, and high severity have been developed for use in conifer-dominated vegetation in California. The high-severity category, reflecting stand-replacing fire, is especially accurately demarcated (Lydersen et al. 2016, Miller et al. 2009). The (R)dNBR reflects the change in green vegetation; so for species such as oaks and shrubs that may resprout after fire, it does not directly capture mortality. Imagery collected 1 year postfire (so-called extended assessments), rather than immediately postfire, may better reflect mortality, both for shrubs and oaks, which tend to resprout quickly if they are not completely dead, and conifers, which may green-up or continue to die from fire injuries for months to years postfire (Lydersen et al. 2016). However, in mixed stands, the resprouting of broadleaf trees and shrubs can reduce the severity signal captured by extended assessments relative to initial assessments. As a result, the extended assessments are best used in forest strongly dominated by nonsprouting conifers. Because stand-replacing fire connotes

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such ecological significance, it is most appropriate to use RdNBR thresholds for the highest severity class that capture near-complete tree mortality, e.g. >90 or 95 percent. Using such thresholds means that the vast majority of area classified as high severity that is away from patch edges will have nearly 100 percent mortality (Miller and Quayle 2015).

Not all areas within mapped high-severity patches are ecologically equivalent, and there are a number of methods available to account for the ecological differences within these patches, depending on the spatial attributes of patches such as the distance from the patch edge. The PatchMorph tool can been used to delineate "ecologically meaningful" patches of high severity (Collins and Stephens 2010), and thereby help to identify areas that may be desirable targets for postfire management actions. Collins et al. (2017) developed the stand-replacing decay coefficient (SDC) to describe the continuous relationship between high-severity patch area and distance from edge, allowing comparisons of the spatial patterns of high-severity fire among different fires (Stevens et al. 2017). We describe applications of PatchMorph and SDC in greater detail below.

PatchMorph Tool

When defining patches from an underlying raster of landscape classes, one of the simplest ways to define a patch is to include adjacent pixels of the same class. However, the size, shape, and number of patches will strongly depend on the underlying scale. It is preferable to define patches based on ecologically relevant measures of size and dimension. The PatchMorph tool was developed for ArcMap to define patches based on ecologically meaningful inputs (Girvetz and Greco 2007). This tool has not been updated for recent versions of ArcMap; however, we obtained a Python script to run the tool using the original concept (Kramer 2019). There are two main tool settings that affect the size and shape of the resulting patches: the minimum patch width or spur, and the maximum width of gaps within the patch. A minimum patch area and a smoothing window tolerance that adjusts the patch perimeter relative to pixel boundaries can also be specified.

As an example, we used the PatchMorph tool to delineate high-severity patches for the Rough Fire, which burned in 2015 primarily on the Giant Sequoia National Monument. Our high-severity patches were based on classified values of the RdNBR calculated with imagery collected 1 year postfire. The high-severity class corresponded to pixels with RdNBR ≥641, which would be expected to have >95 percent basal area mortality in areas dominated by conifer forest and is the standard threshold used for the highest severity class in conifer-dominated vegetation in California (Lydersen et al. 2016, Miller and Thode 2007). Based on a simple summary of pixel values, 20 percent of the Rough Fire burned at high severity (fig. A4.1A). To define high-severity patches, we used spur and gap settings of 90 m (295 ft), a minimum

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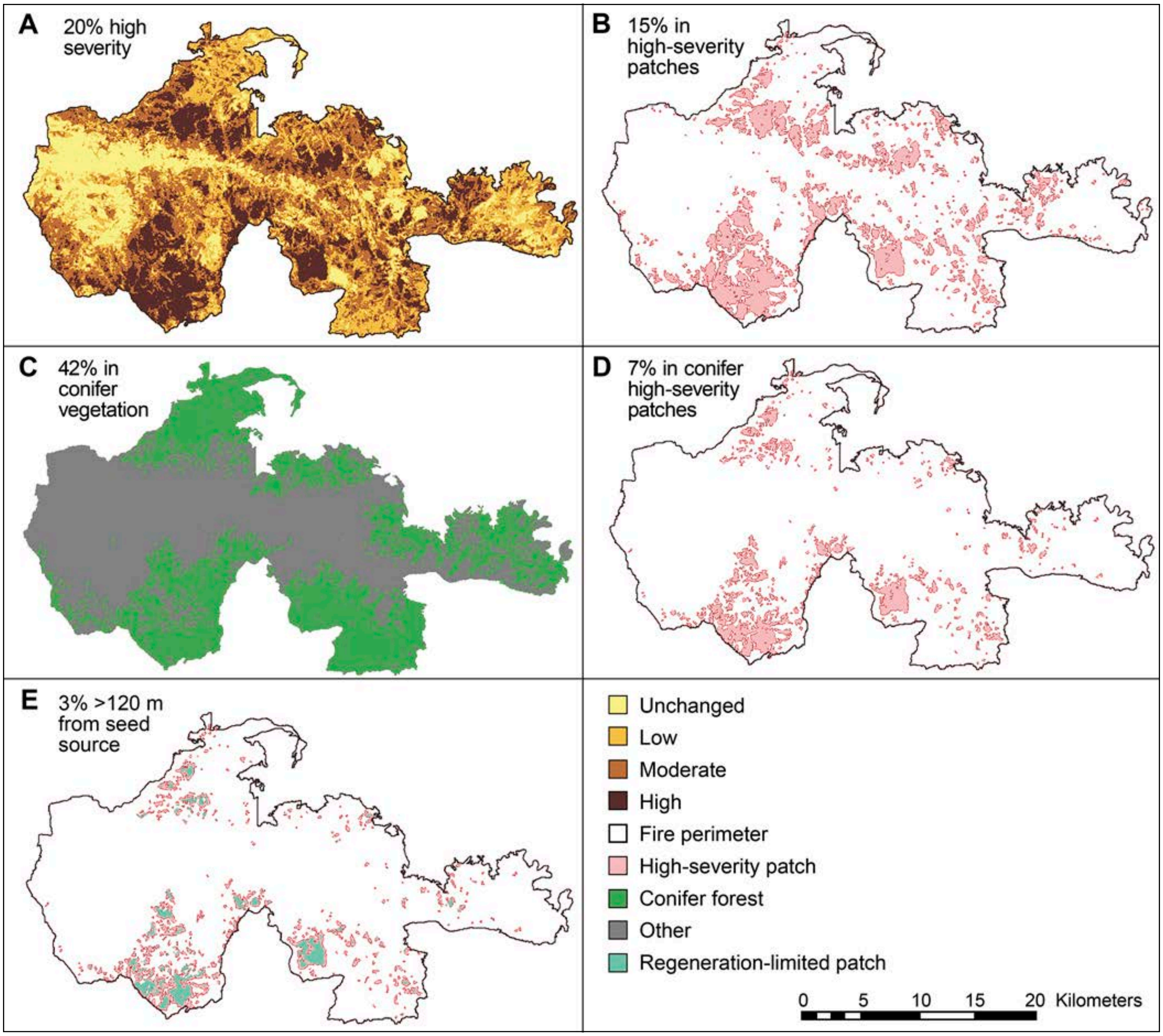

Figure A4.1—Different considerations for characterizing spatial patterns of high-severity fire for the 2015 Rough Fire. Based on the simple classification (thresholds from Miller and Thode 2007) 20 percent of the fire area is high severity (A). Using the PatchMorph tool to delineate contiguous patches of high severity, 15 percent of the area was included in patches (B). This percentage was further reduced when only conifer vegetation (C) was considered in the delineation of high-severity patches, resulting in 7 percent of the fire area (D). Considering conifer-dominated areas in high-severity patches that were >120 m from live conifers, this percentage was reduced to 3 percent (E).

patch area of 5000 m^2 (1.24 ac) and a smoothing tolerance of 90 percent within a 2-pixel window. For this example, we had no reason to restrict the minimum patch size and used 5000 m^2 because it is lower than the smallest area that would be possible within the specified spur distance, so that the spur and gap settings alone would determine the spatial configuration of patches. The smoothing tolerance setting was chosen to create a patch perimeter entirely within high-severity pixels (i.e., no slivers of other pixels along the inside of patch edges). Smaller spur settings resulted in patches that were more interconnected, as well as the creation of a greater number of smaller patches. Smaller gap settings also increased the interconnectivity of patches- and allowed for larger patches with a lower shape complexity. Based on these parameters, high-severity patches identified by PatchMorph within the Rough Fire accounted for 15 percent of the total area burned (fig. A4-1B). The difference between this proportion and that from the simple summary is mainly due to smaller, more isolated areas of high-severity area not meeting the patch delineation criteria.

Considering additional factors when analyzing patch configuration, such as prefire vegetation type, can help to distinguish between different kinds of fire effects. Vegetation type is a particularly relevant consideration when there are strong differences in regeneration responses following high-severity fire across types. To illustrate how this might be done, we performed a second patch delineation that included high-severity patches within conifer vegetation only, based on the California Wildlife Habitat Relationships attribute in the Forest Service Pacific Southwest Region 2000–2014 Existing Vegetation spatial dataset (see app. 2). While conifer forest was most prevalent at higher elevations within the Rough Fire footprint, other vegetation types such as shrub and oak woodland were common at lower elevations. Forty two percent of the area burned was in conifer forest (fig. A4.1C). Using the same settings for the PatchMorph algorithm on a raster that included both fire severity and vegetation type to delineate patches resulted in 7 percent of the fire area in patches of prefire conifer forest that burned at high severity (fig. A4.1D).

In addition to simply defining patches, this approach can be used to gain insight into processes such as expected vegetation recovery within patches. Regeneration of conifer species is typically reliant on wind-dispersed seeds and is therefore limited by distance to the nearest mature trees. This is a concern for large patches with greater interior, or core, area. For this example, we assessed patch interior area >120 m [>393.7 ft] from remaining conifer forest. This is a common dispersal distance threshold in conifer forests (Collins et al., 2017) and is twice the expected dispersal distance used by Welch et al. (2016), which found a steep decrease in regeneration with distance to nearest seed tree. These regeneration-limited areas accounted for 3 percent of the Rough Fire area (fig. A4.1E).

Stand-Replacing Decay Coefficient (SDC)

Because seed dispersal from patch edges contributes strongly to regeneration success (Shive 2017), and is a continuous function (e.g., dispersal does not necessarily change abruptly at a particular distance such as 120 m [393.7 ft]), it can be useful to describe stand-replacing area as a continuous function of distance inward from patch edge. The SDC was developed to characterize this relationship, using a single free parameter (Collins et al. 2017). The SDC is particularly useful as a single number that can be used to compare fires with different sizes and shapes of stand-replacing patches, without specifying a specific dispersal threshold. However, in the context of postfire restoration, SDC can help identify regeneration-limited, high-severity patches that could be targeted for management activities such as reforestation.

A geospatial vector layer of high-severity area can be processed using a series of internal buffers, where at each internal buffer distance (ranging from 0 to the maximum distance from edge), the proportion of the total high-severity area that is greater than the given distance inward from the edge is calculated. The relationship between those two variables is described as,

$$P \sim \frac{1}{10^{SDC * Dist}}$$

Where *P* = the proportion of total high-severity area
Dist = the internal buffer distance, and
SDC = the free parameter estimated through nonlinear least-squares estimation.

Smaller values of SDC indicate larger and more regularly shaped high-severity patches. See Collins et al. (2017) for more information on SDC calculation.

To illustrate the potential application of SDC, we use the Rough Fire example described above and compare it to the King Fire, which burned in 2014 primarily on the Eldorado National Forest and had one of the largest patches of stand-replacing fire observed on modern record. Again, this approach relies on classifying high-severity areas using a high percent-mortality threshold (Miller and Quayle 2015). In this example, we use the standard RdNBR threshold of 641. Because SDC was designed to compare fires that burned predominantly in forest, our examples here have not filtered out nonforest area to make comparisons more consistent. We filtered any “holes” of lower severity that were less than nine pixels (<0.81 ha [2 ac]) and contained entirely within high-severity patches, by incorporating them into the high-severity patch. These holes are analogous to “gaps” in PatchMorph. Larger holes were left intact and used in the buffer operation. In each case, we buffered inward to 1000 m (3,281 ft). This operation can be done most efficiently in the R software package using code available at http://dx.doi.org/10.5281/zenodo.1002242 (Stevens et al. 2017).

The Rough Fire burned approximately 60 000 ha (148,000 ac), with approximately 11 600 ha (28,660 ac) burning at high severity. The King Fire burned approximately 40 000 ha (99,000 ac), with approximately 18 500 ha (45,700 ac) burning at high severity. The fires had notably different SDC values (fig. A4.2). The Rough Fire had an SDC of 0.0049 (ln[SDC] = -5.319), which was more extreme (patches larger and more regularly shaped) than 81 percent of all fires that burned

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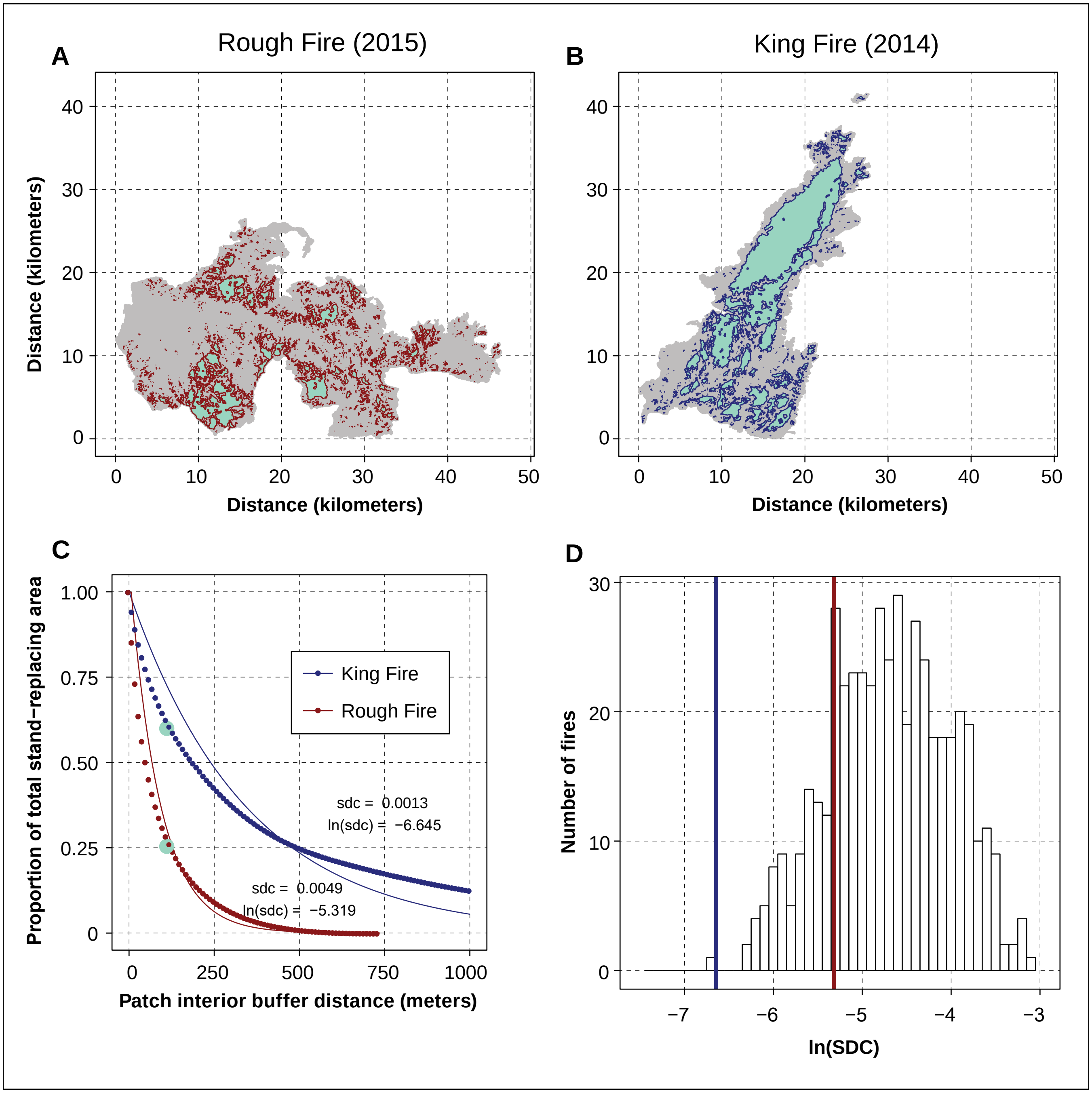

Figure A4.2—Example of stand-replacing decay coefficient (SDC) calculation and application. Fire perimeters for Rough (A) and King (B) fires are shown in gray; high-severity area is red and dark blue, respectively. The continuous relationship between proportion of total stand-replacing area and interior buffer distance is shown in panel (C), calculated using 10-m (33 ft) buffer distances. The teal-colored dots in (C) represents a 120-m (394 ft) internal buffer for each fire, also shown spatially by the teal color in (A, B). The natural log of SDC is shown for the Rough (red line) and King (blue line) fires, relative to 477 fires that burned in California interior conifer forests between 1984 and 2015 (See Stevens et al. 2017 for more details).

through primarily conifer forest in California since 1984 (fig. A4.2D). The King Fire had an extremely small SDC of 0.0013 (ln[SDC] = -6.645), which was more extreme than all other fires since 1984 (fig. A4.2D). The King Fire is unique among all modern forest fires in California, with more than 25 percent of its high-severity area at least 0.5 km (0.31 mi) from a live-forest edge, by far the lowest SDC of any fire in the past 33 years. This example shows how the SDC metric is particularly useful for comparing across fires.

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Appendix 5: Postfire Restoration Prioritization Tool for Chaparral Shrublands

Emma C. Underwood and Hugh D. Safford[1]

The concept and design of the Postfire Restoration Prioritization Tool (PReP) for chaparral shrublands is based on a spatial tool developed by the Mediterranean Center for Environmental Studies and the University of Barcelona (Duguy et al. 2012) to operationalize guidance for postfire restoration planning found in the Technical Guide for the Management of Burned Forests developed in Spain (Alloza et al. 2016). The original tool assesses the impact of forest fires based on a variety of detailed vegetation data and ecological criteria. Using the Copper Fire on the Angeles National Forest as a pilot case study, we collaborated with the original researchers to adapt and apply the Spanish tool to chaparral shrublands in southern California.

PReP is a dynamic tool that provides a transparent and repeatable framework for U.S. Forest Service resource managers to guide and prioritize postfire restoration efforts in shrublands. Generating this information efficiently is important given the often short timeframes involved in implementing restoration activities, such as the use of fire settlement funds or implementing emergency activities to reduce erosion, sediment transport, and infrastructure damage postfire. Objectives of PReP include the following:

- Assess the regeneration ability of native vegetation postfire
- Predict areas of degradation on the burned landscape
- Identify priorities for postfire restoration

The tool determines the intrinsic regeneration capacity of pixels within the fire perimeter based on the relative proportion of seeding, resprouting, and facultative-seeding shrub species. In contrast to the original tool which is informed by species-level maps, we developed landscape units based on vegetation type, aspect, and topographic position, and compiled data on species composition from U.S. Forest Service Forest Inventory and Analysis plots and the postfire reproductive strategies from ecological field guides for the region. The regeneration capacity of landscape units is then modified on a pixel-by-pixel basis according to fire history (number of fires in the past 40 years and time since last fire), drought occurrence pre- and postfire, and presence of nonnative grasses, which are major competitors with native seedlings. These three factors—absent in the original tool—have important impacts on woody plant regeneration on California shrublands (Allen et al. 2018). The final step of the tool integrates the modified

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regeneration capacity with soil erosion risk data (from the Burned Area Emergency Response program assessment) to identify areas at risk of ecosystem degradation.

PReP is designed to be a straightforward interface, using a conceptually simple scoring method, and is intended to be used as a management tool by resource staff working with chaparral shrublands. The tool uses a Jupyter Notebook framework that allows revisions to be made easily and efficiently. There is some preparation required to download and clip spatial data to the target fire, after which PReP can be run without further Geographic Information System (GIS) analysis. Input from a botanist or person familiar with the prefire vegetation is important, as well as is the validation of tool outputs in the field. Within PReP, there are options to download spatial outputs generated as geotiff rasters that can be viewed in GIS platforms such as ArcGIS. This also allows the outputs to be viewed with other spatial datasets, such as roads, trails, project area boundaries, ecosystem services (Underwood et al. 2018), etc. At this point, the PReP tool has been run on the Copper and Powerhouse Fires on the Angeles National Forest, and there are plans to expand the framework to include modules applicable to forested areas as well.

Users can run PReP by downloading the Jupyter Notebook and example data for the Copper fire pilot study contained in the zipped file ('PReP.zip') from https://github.com/adhollander/postfire. Also available on the site are a technical guide for the tool, installation instructions, and a case study for the Copper Fire (fig. A5.1) that shows and interprets the outputs of the tool.

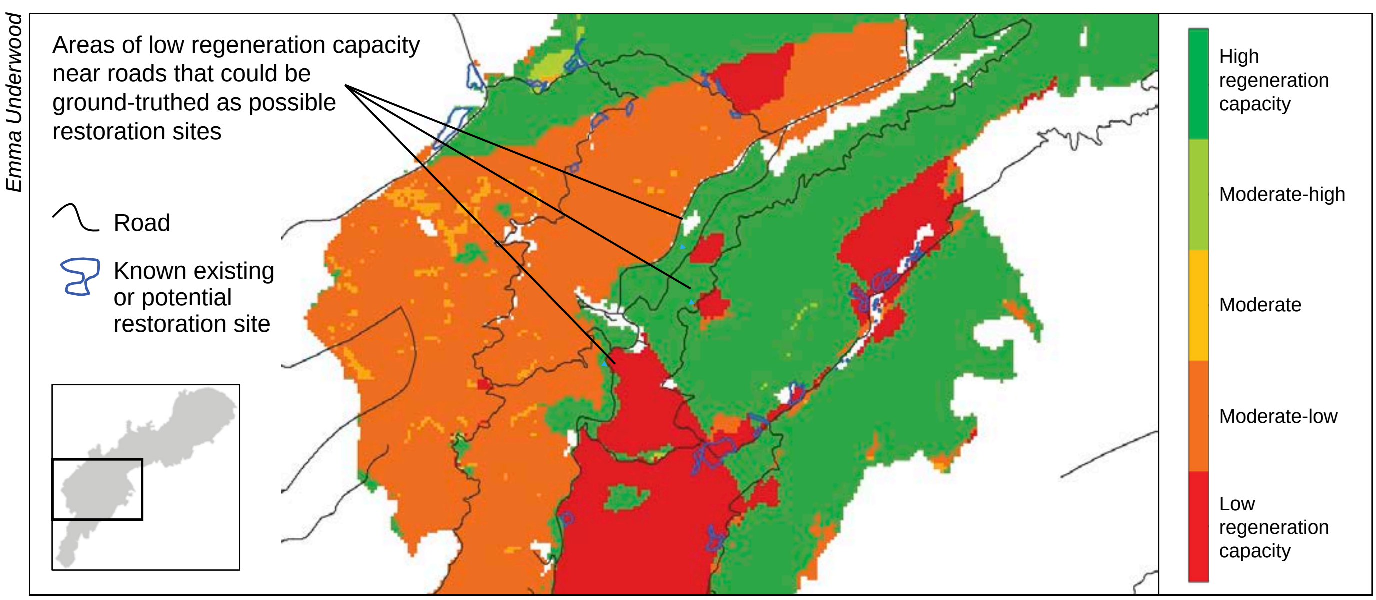

Figure A5.1—This output for the Copper Fire uses the penultimate output from the postfire restoration prioritization tool (PReP) before the integration of soil erosion risk. Because the fire occurred almost two decades ago, the risk of fire-caused erosion today is minimal. The figure shows calculated postfire regeneration capacity based on the postfire reproductive strategy of the vegetation-based landscape units, fire history, drought, and nonnative grasses. Overlain are existing restoration sites that have been identified by the Angeles National Forest and roads to indicate the accessibility of potential restoration sites.

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Appendix 6: Landscape Change Detection With the Ecosystem Disturbance and Recovery Tracker (eDaRT) in an Example Watershed

Shana E. Gross, Alex Koltunov, Michèle Slaton, and Scott Conway[1]

Given the important effects that drought can have on forest health and wildfire, we include a brief example of how a disturbance other than fire can be assessed. Here we present current condition using spatially explicit datasets of tree mortality (primarily because of drought and bark beetles) in the North Fork Tuolumne River watershed. Forest management questions associated with drought-induced beetle mortality have some similarities with questions associated with fire mortality. Current key questions that managers are asking include (1) how do we prioritize areas for restoration that have experienced low tree mortality to increase resilience to future disturbance events, and (2) where would we prioritize restoration of high-tree-mortality areas in order to reduce potential for severe effects of future disturbance events (e.g., fire on top of insect-driven mortality)?

We characterized current condition based on disturbance size and magnitude, using the Ecosystem Disturbance and Recovery Tracker (eDaRT) change detection data. The USDA Forest Service-University of California-Davis eDaRT system (see app. 2) is now routinely used to rapidly map mortality events at the 30-m scale by the U.S. Forest Service in California (Koltunov et al. 2019). This system provides sub-annual updates using all available Landsat imagery. The core version of eDaRT provides a proxy for disturbance magnitude, which was calibrated to match actual canopy cover loss. The eDART system has been applied in multiple vegetation types, including stands of low-moderate elevation ponderosa pine and mixed-conifer forests; higher elevation red fir, lodgepole pine, and subalpine forests; as well as areas including hardwoods, riparian species, and montane chaparral. Errors of commission (false positives) averaged 12 percent across vegetation types; those errors were lower in coniferous areas (10 percent), but they were higher in areas dominated by hardwoods (up to 34 percent), which were represented by a small number of reference events (Koltunov et al. 2019).

Our demonstration analysis involved first compiling 2015 and 2016 disturbance data to represent the time period when the greatest mortality occurred. Using

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high resolution imagery, we translated the disturbance magnitude proxy to actual classes of disturbance type and intensity (higher magnitude events are most reliably detected by eDaRT, and can be verified most accurately with high-resolution imagery.) In addition, we used the Forest Service Activity Tracking System database to identify where forest treatments occurred in 2015 and 2016. The classes we present included the following:

1. No disturbance detected
2. Low magnitude event (<10 percent canopy cover loss)
3. Moderate magnitude event (10 to 50 percent canopy cover loss)
4. High magnitude (severe) event (>50 percent canopy cover loss)
5. Areas that were treated in 2015 or 2016 were classified as their own category because we could not separate drought/insect mortality and treatment.

The disturbance data were then segmented with vegetation and topography data to evaluate current condition. This analysis indicated that 10 percent of conifer-dominated forests in the assessment area experienced some mortality event in 2015 and 2016 (fig. A6.1). The highest mortality was associated with ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) forest on mid-slopes less than 30 percent.

The current condition data could be combined with future condition and targeted local data to prioritize and evaluate landscape restoration strategies. Restoration opportunities on a landscape affected by drought-induced mortality may be similar to opportunities in a postfire landscape. Some potential opportunities for this landscape might include (1) focused thinning treatments in ponderosa pine stands on mid-slopes <30 percent to reduce competition and increase future resilience to drought and insects, and (2) removal of hazard trees in high mortality areas to evaluate natural regeneration in high mortality areas.

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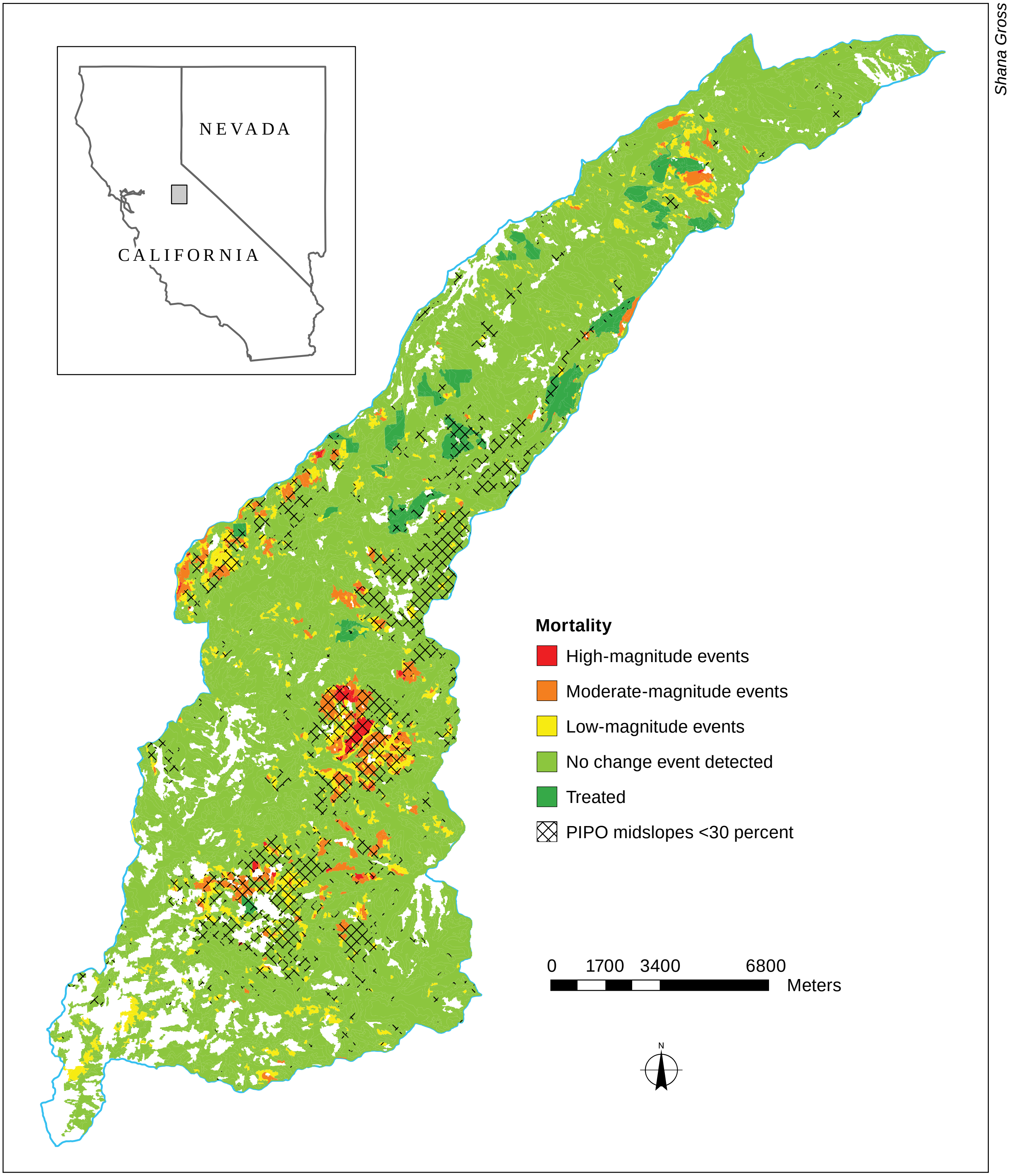

Figure A6.1—Magnitude of mortality events in the North Fork Tuolumne River watershed overlaid with *Pinus ponderosa* on midslopes <30 percent.

Appendix 7: Reforestation Tool for Tree Mortality Landscapes

Zachary L. Steel, Marc D. Meyer, Malcolm P. North, Amarina Wuenschel, Steven M. Ostoja[1]

Recent drought and bark beetle outbreaks in California have resulted in substantial impacts to forest ecosystems throughout the state, with thousands of acres in need of restoration or reforestation. This user-friendly, Web-based decision support tool is designed to assess priority areas for reforestation activities where tree mortality is high within the national forests of the Sierra Nevada bioregion. The tool consists of three components: (1) spatial prioritization tool, (2) stand data summary tool, and (3) reforestation best management practices guide. The spatial prioritization tool allows the user to view data layers related to tree mortality, forest type, mechanical treatment opportunities, fire severity, and other relevant datasets (e.g., wildland-urban interface, wildlife habitat, and landscape management units) (fig. A7.1). This tool permits users to select their geographic area of interest (national forest or district), relevant data layers, and the relative importance of individual data layers. The tool identifies areas of low, moderate, and high reforestation priority in either map, summary table, or raster datasets that can be further analyzed in Geographic Information System (GIS) if desired. The stand data summary tool uses field plot data collected from forest stands in the Sierra Nevada immediately after the 2012–2016 drought (collected in 2016–2017) to summarize post-drought stand conditions. This tool summarizes both overstory (e.g., stand densities and basal area by species) and understory (e.g., tree regeneration by species, total shrub cover) conditions. Finally, the best management practices guide embedded within the tool summarizes published reforestation methods and approaches that are based on climate adaptation and forest resilience principles. The guide describes innovative approaches to reforestation under specific topic areas, including seed zonation, spatial arrangement (e.g., regular vs. cluster planting), seedling densities, species composition, management of competing vegetation, and other considerations. A summary of relevant published literature and a user guide are also provided through the tool's weblink (https://www.climatehubs.usda.gov/hubs/california/tools/climate-wise-reforestation-toolkit).

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Zachary Steel

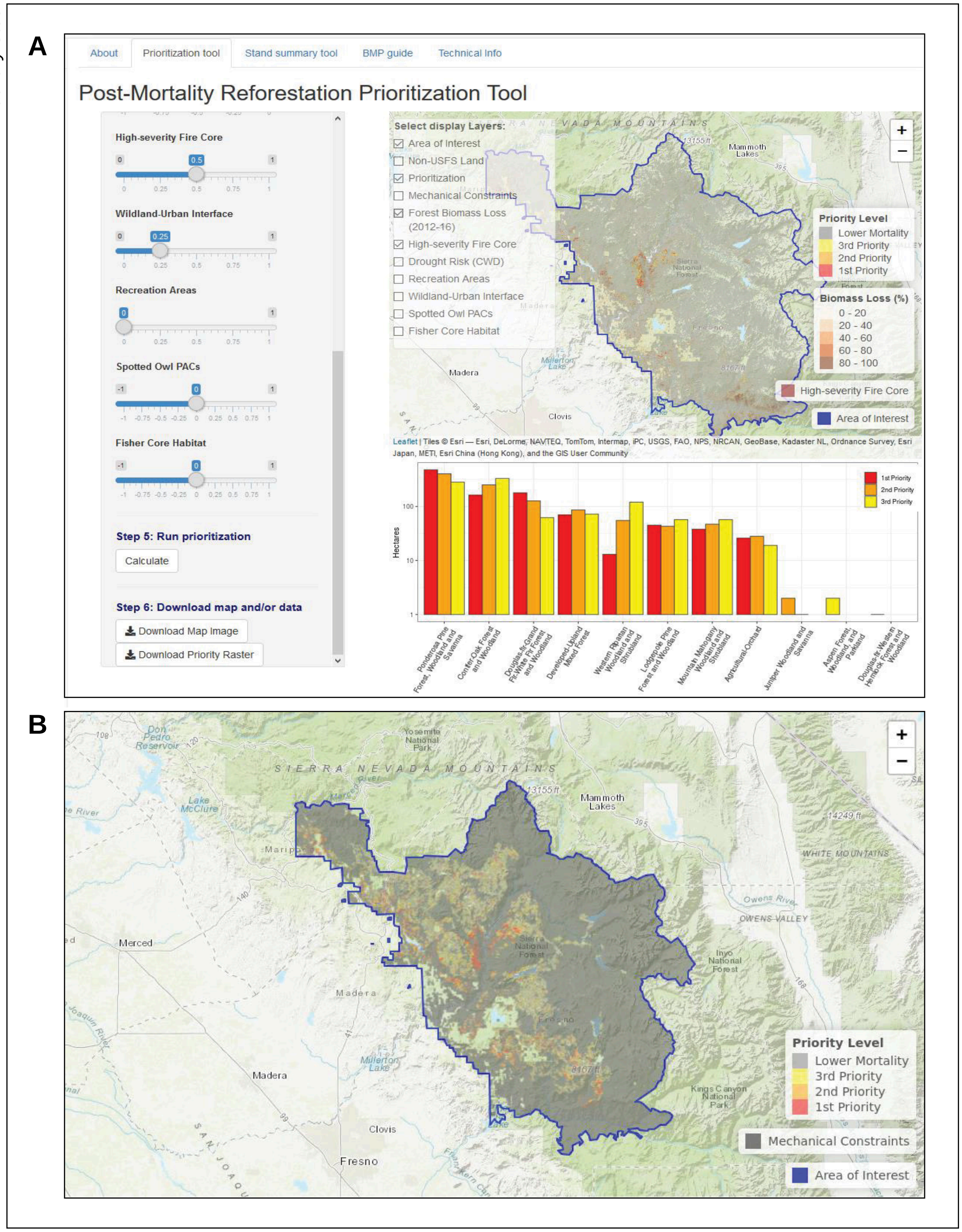

Figure A7.1—Web-based interface of the reforestation prioritization tool for tree mortality landscapes (panel a) permits the user to select a specific area of interest (e.g., Sierra National Forest) and relevant data layers (e.g., loss of forest biomass, wildlife habitat) to identify potential high-, moderate-, and low-priority areas for reforestation activities. Tool outputs include static maps (panel b), as well as data summaries and raster datasets.

Glossary

active restoration or management—Direct interventions to achieve desired outcomes (including restoration), which may include harvesting and planting of vegetation and the intentional use of fire, among other activities (Carey 2003).

actual evapotranspiration (AET)—Amount of water that evaporates from the soil surface and is transpired by plants if current water availability is constrained. AET measures when conditions (energy + water) for plants are favorable to support photosynthesis.

adaptive capacity—The ability of ecosystems and social systems to respond, cope, or adapt to disturbances and stressors, including environmental change, to maintain options for future generations.

adaptive management—A structured, cyclical process for planning and decisionmaking in the face of uncertainty and changing conditions with feedback from monitoring, which includes using the planning process to actively test assumptions, track relevant conditions over time, and measure management effectiveness. Additionally, adaptive management includes iterative decisionmaking through which results are evaluated and actions are adjusted based upon what has been learned.

at-risk species—The set of at-risk species for planning purposes includes federally recognized threatened, endangered, proposed and candidate species, and species of conservation concern.

biodiversity—In general, the variety of life forms and their processes and ecological functions, at all levels of biological organization from genes to populations, species, assemblages, communities, and ecosystems.

biophysical settings (BpS)—The biophysical settings layer from LANDFIRE is a potential natural vegetation layer. It represents the vegetation that may have been dominant on the landscape prior to Euro-American settlement and is based on both the current biophysical environment and an approximation of the historical disturbance regime.

climate adaptation—Management actions to reduce vulnerabilities to climate change and related disturbances.

climate change—Changes in average weather conditions (including temperature, precipitation, and risk of certain types of severe weather events) that persist over multiple decades or longer, and that result from both natural factors and human activities such as increased emissions of greenhouse gases (U.S. Global Change Research Program 2017).

climatic water deficit (CWD) —Annual evaporative demand that exceeds available water, summed annually. It is calculated based on potential evapotranspiration minus actual evapotranspiration. CWD measures when plants have insufficient water to support photosynthesis and is a measure of plant drought stress.

community (plant and animal)—A naturally occurring assemblage of plant and animal species living within a defined area or habitat.

composition—The biological elements within the various levels of biological organization, from genes and species to communities and ecosystems.

connectivity (of habitats) —Environmental conditions that exist at several spatial and temporal scales that provide landscape linkages that permit (1) the exchange of flow, sediments, and nutrients; (2) genetic interchange of genes among individuals between populations; and (3) the long distance range shifts of species, such as in response to climate change.

designated area—An area or feature identified and managed to maintain its unique special character or purpose. Some categories of designated areas may be designated only by statute, and some categories may be established administratively in the land management planning process or by other administrative processes of the federal executive branch. Examples of statutorily designated areas are national heritage areas, national recreational areas, national scenic trails, wild and scenic rivers, wilderness areas, and wilderness study areas. Examples of administratively designated areas are experimental forests, research natural areas, scenic byways, botanical areas, and significant caves.

desired conditions—A description of specific social, economic, or ecological characteristics toward which management of the land and resources are directed.

digital elevation model—A 3-dimensional spatial data layer representing ground surface topography.

disturbance regime—A description of the characteristic types of disturbance on a given landscape; the frequency, severity, and size distribution of these characteristic disturbance types and their interactions.

disturbance—Any relatively discrete event in time that disrupts ecosystem, watershed, community, or species population structure or function and changes resources, substrate availability, or the physical environment.

early-seral vegetation—Vegetation conditions in the early stages of succession following a disturbance that removes forest canopy (e.g., timber harvest, wildfire, windstorm), on sites that are capable of developing a closed canopy (Swanson et al. 2014). A nonforest or pre-forest condition occurs first, followed by an "early seral forest" as young trees develop during the process of succession.

ecological conditions—The biological and physical environment that can affect the diversity of plant and animal communities, the persistence of native species, invasibility, and the productive capacity of ecological systems. Ecological conditions include habitat and other influences on species and the environment. Examples of ecological conditions include the abundance and distribution of aquatic and terrestrial habitats, connectivity, roads and other structural developments, human uses, and occurrence of other species.

ecological integrity—The quality or condition of an ecosystem when its dominant ecological characteristics (e.g.,, composition, structure, function, connectivity, and species composition and diversity) occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influence.

ecological restoration—"The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER 2004). Ecological restoration focuses on reestablishing the composition, structure, pattern, and ecological processes necessary to facilitate terrestrial and aquatic ecosystems sustainability, resilience, and health under current and future conditions (36 CFR 219.19).

ecosystem—A spatially explicit, relatively homogeneous unit of the earth that includes all interacting organisms and elements of the abiotic environment within its boundaries.

ecosystem services—Benefits people obtain from ecosystems, including provisioning services (e.g., clean air, fresh water, food, wood products), regulating services (e.g., carbon storage, water filtration and storage; regulation of disturbances and diseases), supporting services (e.g., pollination, seed dispersal, soil formation, and nutrient cycling), and cultural services (e.g., spiritual, recreational, and aesthetic experiences). Some references distinguish "ecosystem goods" from services, while others categorize "goods" under "provisioning services.

endangered species—Any species or subspecies that the secretary of the Interior or the secretary of commerce has deemed in danger of extinction throughout all or a significant portion of its range.

endemic—Native and restricted to a specific, geographical area.

exposure—The sum of climate and climate-related changes that may negatively or positively affect an ecosystem, population, or other resource.

fire-dependent vegetation types—A vegetative community that evolved with fire as a necessary contributor to vitality and renewal of habitat for its member species.

fire exclusion—Curtailment of wildland fire because of deliberate suppression of ignitions, as well as unintentional effects of human activities such as intensive grazing that removes grasses and other fuels that carry fire (Keane et al. 2002).

fire intensity—The amount of energy or heat released during a fire.

fire regime—A characterization of long-term patterns of fire in a given ecosystem over a specified and relatively long period of time, based upon multiple attributes including frequency, severity, extent, spatial complexity, and seasonality of fire occurrence.

fire return interval—The amount of time between successive fire events in a given area.

fire return interval departure—Comparison between pre-Euro-American settlement and contemporary fire return intervals.

fire risk—The likelihood of a negative outcome and the severity of subsequent negative consequences resulting from fire.

fire severity—The magnitude of the effects of fire on ecosystem components, including vegetation or soils.

fire suppression—The act of extinguishing wildfires by humans (Keane et al. 2002).

founder stand—Small groups of trees strategically planted in mesic and less fire-prone locations to serve as the future seed source for trees in the surrounding area (North et al. 2019).

fuelbed—A combination of one or more fuel strata.

fuels (wildland)—Combustible material in wildland areas including live and dead plant biomass such as trees, shrubs, grass, leaves, litter, snags, and logs.

fuels management—Manipulation of wildland fuels through mechanical, chemical, biological, or manual means, or by fire, in support of land management objectives to control or mitigate the effects of future wildland fire.

function (ecological) —Ecological processes, such as energy flow; nutrient cycling and retention; soil development and retention; predation and herbivory; and natural disturbances such as wind, fire, and floods that sustain composition and structure.

future range of variation (FRV)—The natural fluctuation of pattern components of healthy ecosystems that might occur in the future, primarily affected by climate change, human infrastructure, invasive species, and other anticipated stressors.

goals (in land management plans)—Broad statements of intent, other than desired conditions, that do not include expected completion dates.

guideline—A constraint on project and activity decisionmaking that allows for departure from its terms, so long as the purpose of the guideline is met. Guidelines are established to help achieve or maintain a desired condition or conditions, to avoid or mitigate undesirable effects, or to meet applicable legal requirements.

habitat—An area with the environmental conditions and resources that are necessary for occupancy by a species and for individuals of that species to survive and reproduce.

habitat fragmentation—Discontinuity in the spatial distribution of resources and conditions present in an area at a given scale that affects occupancy, reproduction, and survival in a particular species.

heterogeneity (forest)—Diversity, often applied to variation in forest structure within stands in horizontal (e.g., single trees, clumps of trees, and gaps of no trees) and vertical (e.g., vegetation at different heights from the forest floor to the top of the forest canopy) dimensions, or across large landscapes (North et al. 2009).

heterotrophic respiration—Carbon dioxide emitted by all heterotrophic organisms (i.e., consumers) in an ecosystem, including animals, fungi, and other organisms that do not produce their own food.

high-severity burn patch—A contiguous area of high severity or stand-replacing fire.

historical range of variation (HRV)—Past fluctuation or range of ecosystem conditions over a specified area and period of time.

invasive species—Any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to a particular ecosystem, and whose deliberate, accidental, or self-introduction is likely to cause economic or environmental harm or harm to human health.

land and resource management plan (USDA Forest Service)—A document or set of documents that provide management direction for national forest administrative unit.

land type association — Landscape-scale terrestrial ecosystems used in national forest planning as a framework for analysis, conservation design, and project planning.

landscape—A defined area irrespective of ownership or other artificial boundaries, encompassing a mixture of terrestrial and aquatic ecosystems, landforms, and plant communities, repeated in similar form throughout such a defined area.

landscape management unit (LMU)—Broad topographic categories based on slope position and aspect (North et al. 2012).

LiDAR—(Light Detection and Ranging)–Remote sensing survey method that uses pulsed laser light to measure the height and coverage of terrain and vegetation.

mixed chaparral—Shrubland vegetation type confined to Mediterranean climate zone in California that occurs in the lower elevation foothill zone generally below 1520 m (5,000 ft).

montane chaparral—Shrubland vegetation type confined to Mediterranean climate zone in California that generally occurs with the montane or upper montane zones.

monitoring—A systematic process of collecting information to track implementation (implementation monitoring), to evaluate effects of actions or changes in conditions or relationships (effectiveness monitoring), or to test underlying assumptions (validation monitoring).

native species—A species historically or currently present in a particular ecosystem as a result of natural migratory or evolutionary processes and not as a result of an accidental or deliberate introduction or invasion into that ecosystem.

natural range of variation (NRV)—Spatial and temporal variation in ecosystem characteristics under historical disturbance regimes during a reference period or from a reference location (Safford and Stevens 2017).

nitrophilic—capable of thriving in a nitrogen-rich habitat.

objective (in land management plans)—Concise, measurable, and time-specific statement of a desired rate of progress toward a desired condition.

old-growth forest—A forest distinguished by old trees (>150 years) and related structural attributes that often (but not always) include large trees, high biomass of dead wood (i.e., snags, downed coarse wood), multiple canopy layers, distinctive species composition and functions, and vertical and horizontal diversity in the tree canopy. In dry, fire-frequent forests, old growth is characterized by large, old fire-resistant trees and relatively open stands without canopy layering.

passive management—A management approach where natural processes are allowed to occur without human intervention to desired outcomes.

patch—A relatively small area with similar environmental conditions, such as vegetative structure and composition. Sometimes used interchangeably with vegetation or forest stand.

potential evapotranspiration—Amount of water that evaporates from the soil surface and is transpired by plants if water were not a limiting factor.

potential natural vegetation (PNV)—Vegetation that a landscape would support given environmental conditions (e.g., geology, soils, climate) and functioning natural disturbance regimes in the absence of "unnatural" anthropogenic activities.

potential wildland fire operational delineation unit (POD)—Spatial representation of an area that summarizes wildfire risk in a meaningful operational fire management context. Potential operational delineations can follow fine-scale features such as ridgetops, water bodies, roads, barren areas, elevation changes, or major fuel changes.

pre-settlement fire regime groups (PFR)—Classes of vegetation that are categorized based on the characteristic fire regime prior to settlement/colonization by European Americans in California (generally before the mid- to late-19th century) that led to extensive impacts on vegetation, fire regimes, and indigenous peoples within natural ecosystems.

prescribed fire—A wildland fire originating from a planned ignition to meet specific objectives identified in a written, approved, prescribed fire plan for which National Environmental Policy Act requirements (where applicable) have been met prior to ignition (synonymous with controlled burn).

reburn—Fire that burns an area where fuels (such as scorched needles, twigs, branches, and tree boles that fall to the surface) are primarily derived from a previous burn. Reburns may result in reduced ecosystem integrity when they facilitate fire regime transitions outside the natural range of variation, such as fire burning too frequently or severely.

recovery (ecosystem)—The reestablishment of essential ecosystem structure, composition, and function that supports long-term ecological integrity, health, and sustainability. Recovered ecosystems contain sufficient biotic and abiotic resources to continue successional development without assistance, are functionally self-sustaining, exhibit resilience to anticipated environmental stressors and perturbations, and interact with adjoining connected ecosystems (SER 2004) (see "ecological restoration").

refugia—An area that remains less altered by climatic and environmental change (including disturbances such as wind and fire) affecting surrounding regions and that therefore forms a haven for relict fauna and flora.

resilience—The capacity of an ecosystem to absorb disturbance and reorganize (or return to its previous organization) so as to retain essentially the same function, structure, identity, and feedbacks. Definitions emphasize the capacity of a system or its constituent entities to respond or regrow after mortality induced by a disturbance event, although broad definitions of resilience may also encompass "resistance" (see below), under which such mortality may be averted.

resistance—The capacity of an ecosystem or an entity to withstand a disturbance event without much change or alteration in essential characteristics.

restoration, ecological—see "ecological restoration."

restoration, functional—Restoration of dynamic abiotic and biotic processes in degraded ecosystems, without necessarily a focus on structural condition and composition.

restoration strategy—A strategic vision that describes broad ecological restoration approaches that support ecosystem management goals and objectives within a specific landscape of interest.

riparian areas—Three-dimensional ecotones (the transition zone between two adjoining communities) of interaction that include terrestrial and aquatic ecosystems that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at variable widths (36 CFR 219.19).

scale—In ecological terms, the extent and resolution in spatial and temporal terms of a phenomenon or analysis, which differs from the definition in cartography regarding the ratio of map distance to earth surface distance (Jenerette and Wu 2000).

segmentation—A process for subdividing spatial data into ecologically similar landscape units.

sensitive species—Plant or animal species that receive special conservation attention because of threats to their populations or habitats, but which do not have special status as listed or candidates for listing under the U.S. Endangered Species Act.

serotinous—An ecological adaptation in some plants in which seed release occurs in response to an environmental trigger such as heat or smoke from a fire.

shrubfield—A vegetation patch (relatively small area) dominated by shrubs.

shrubland—An area (generally large and persistent) dominated by shrubs.

soil burn severity—The effect of fire on ground surface characteristics, including organic matter loss, reduced infiltration, char accumulation, and altered soil structure.

special status species—Species that have been listed or proposed for listing as threatened or endangered under the U.S. Endangered Species Act.

species of conservation concern—A species, other than federally recognized threatened, endangered, proposed, or candidate species, that is known to occur in the plan area and for which the regional forester has determined that the best available scientific information indicates substantial concern about the species' capability to persist over the long term in the plan area.

stand—A land management unit consisting of a contiguous group of trees sufficiently uniform in age-class distribution, composition, and structure, and growing on a site of sufficiently uniform quality, to be a distinguishable unit.

stand-replacing fire—High-severity fire, where fire kills more than 75 percent of the dominant vegetation (see "vegetation burn severity").

stressors—Factors that may directly or indirectly degrade or impair ecosystem composition, structure or ecological process in a manner that may impair its ecological integrity, such as an invasive species, loss of connectivity, or the disruption of a natural disturbance regime (36 CFR 219.19).

structure (ecosystem)—The organization and physical arrangement of biological elements such as snags and down woody debris, vertical and horizontal distribution of vegetation, stream habitat complexity, landscape pattern, and connectivity.

sustainability—The capability to meet the needs of the present generation without compromising the ability of future generations to meet their needs. Sustainability is sometimes defined in terms of three dimensions: ecological (capability to maintain ecological integrity), economic (capability to produce and benefit from goods and services), and social (capability to support networks of relationships, traditions, culture, and activities that connect people to the land and to one another in vibrant communities). (36 CFR 219.19)

sustainability (ecological)—The capability of ecosystems to maintain ecological integrity (36 CFR 219.19).

succession—Nonseasonal and directional change in species composition and structure in an ecological community over time.

timber harvest—The removal of trees for wood fiber use and other multiple-use purposes.

understory—Vegetation growing below the tree canopy in a forest, including shrubs, herbs, and short-statured trees.

vegetation burn severity—The magnitude of the effect of fire on vegetation (see "fire severity"), often classified as (1) low severity, with <25 percent mortality of the dominant vegetation (e.g., trees, shrubs); (2) moderate severity, with 25 to 75 percent mortality of the dominant vegetation; and (3) high severity, with >75 percent mortality of the dominant vegetation (also referred to as "stand-replacing fire").

vegetation type—A general term for a combination or community of plants (including grasses, forbs, shrubs, or trees), typically applied to existing vegetation rather than potential vegetation.

vulnerability—The degree to which a system is susceptible to, or unable to cope with, change.

watershed—A region or land area drained by a single stream, river, or drainage network; a drainage basin.

watershed condition class—a category that reflects the level of watershed health or integrity relative to natural potential condition (Potyondy and Geier 2011).

watershed restoration—Restoration activities that focus on restoring the key ecological processes required to create and maintain favorable environmental conditions for aquatic and riparian-dependent organisms.

wilderness—Any area of land designated by Congress as part of the National Wilderness Preservation System that was established in the Wilderness Act of 1964.

wildlife—Undomesticated animal species including amphibians, reptiles, birds, mammals, fish and invertebrates or even all biota that live wild in an area without being introduced by humans.

wildfire—Unplanned ignition of a wildland fire (such as a fire caused by lightning, volcanoes, unauthorized and accidental human-caused fires) and escaped prescribed fires.

wildland-urban interface (WUI)— The line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetation fuels.

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