Chapter 1: Principles of Postfire Restoration

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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 water-flows; 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

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.

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
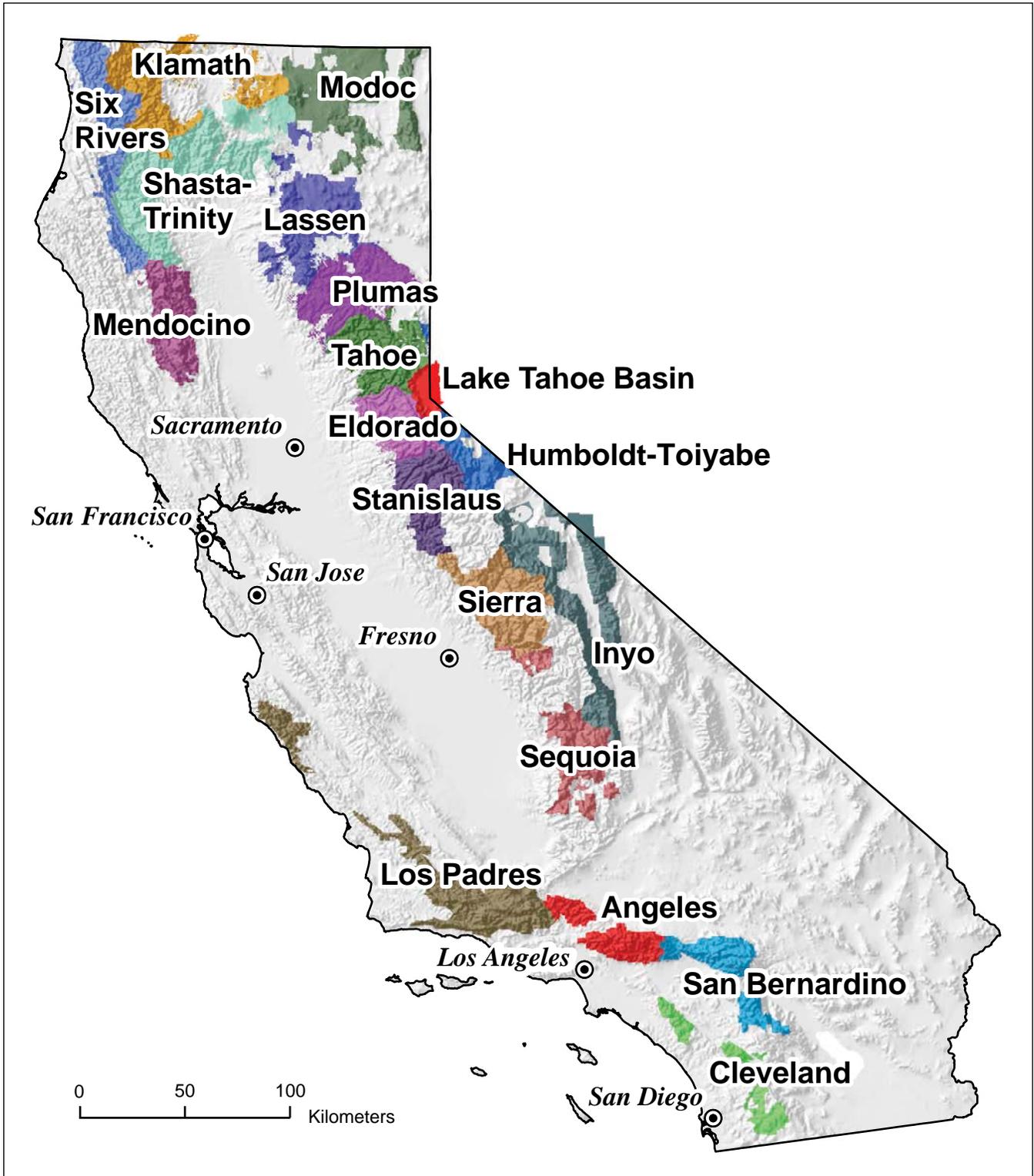
Figure 1.1—National forests in California.

Nicole Molinari

Fire interval departure

- High departure, -3
- Moderate departure, -2
- Low departure, -1
- Low departure, 1
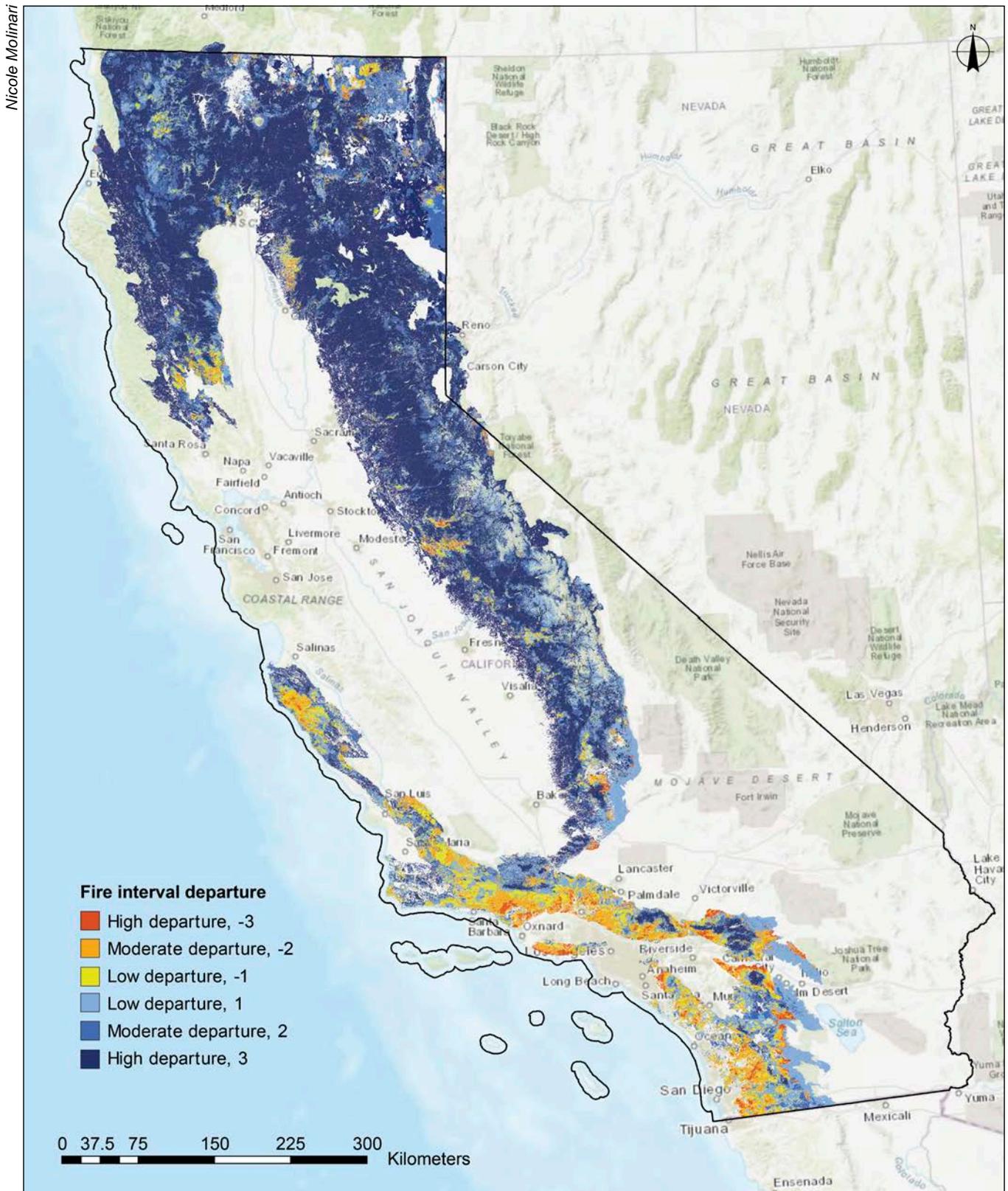- Moderate departure, 2
- High departure, 3

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 pur-poses, but often with more focus on ecosystem services related to human recre-ational 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 resil-ience 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 coloni-zation 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 increas-ing 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,
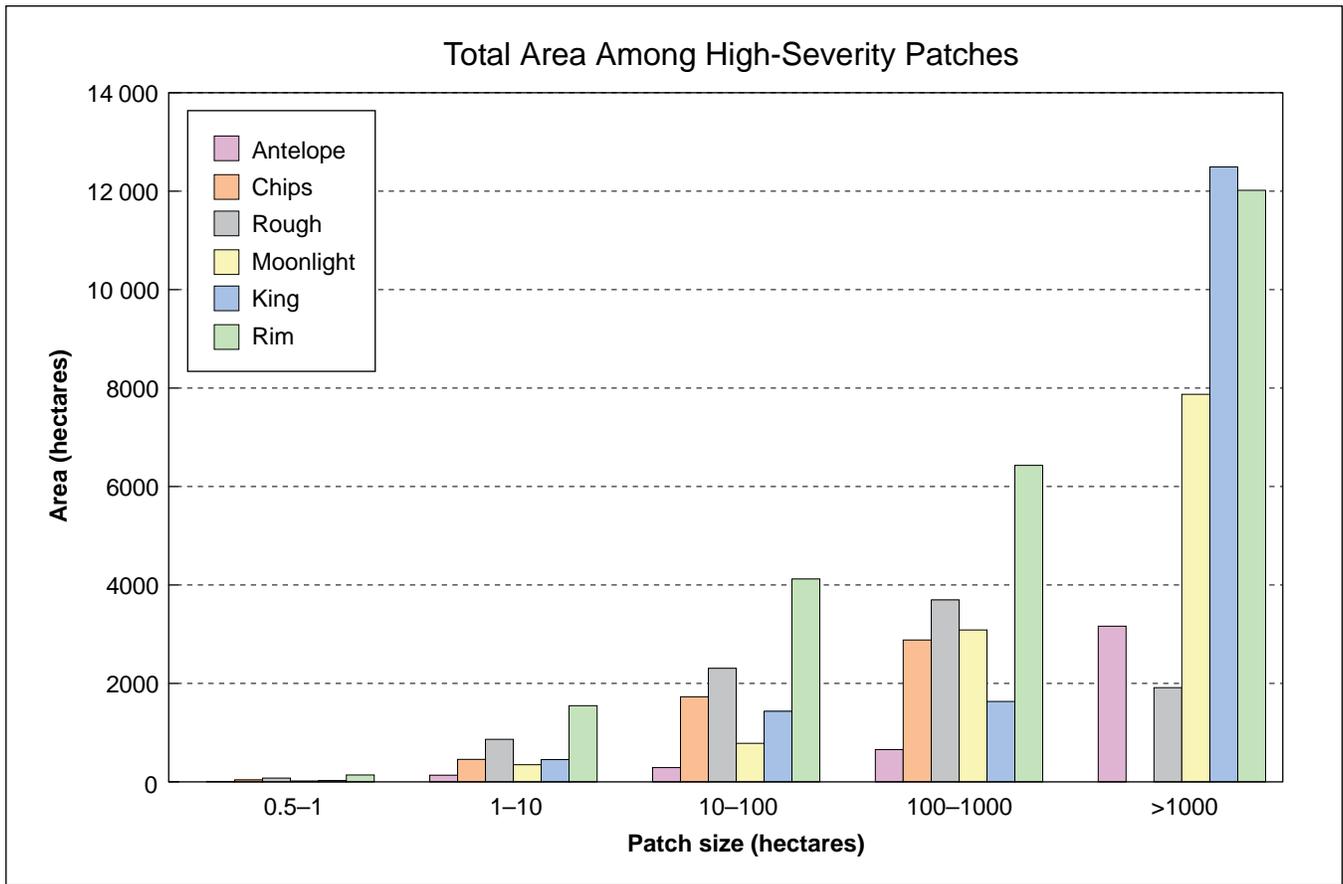
Total Area Among High-Severity Patches

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

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).

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).

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

Guiding Principles

1. Restore key ecological processes

2. Consider landscape context

3. Promote regional native biodiversity

4. Sustain diverse ecosystem services

5. Establish a prioritization approach for management interventions

6. Incorporate adaptation to agents of change

Restoration Framework
(five step process)

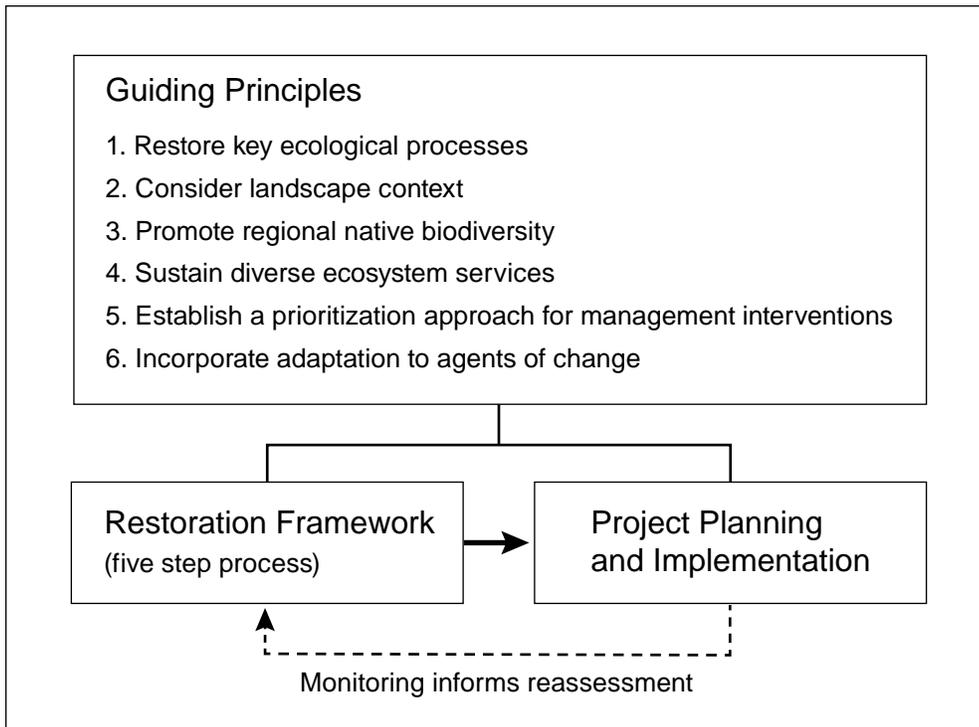**Project Planning and Implementation**

Monitoring informs reassessment

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 eco-systems. 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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