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.

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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).

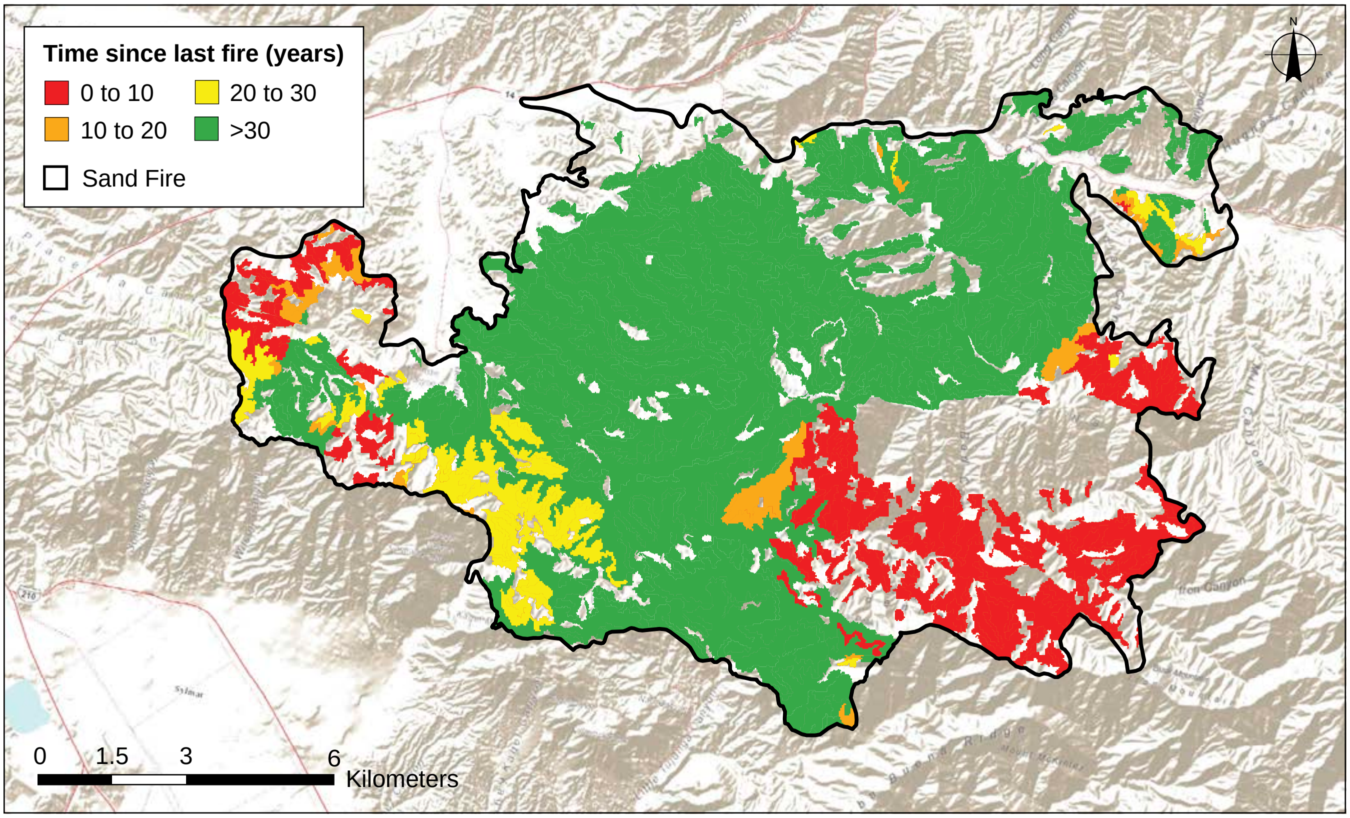

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Figure 5.2—Time since last fire represents the number of years between the Sand Fire and the previous fire occurring within the Sand Fire footprint. The colored parts of the map denote chaparral and serotinous conifer pre-Euro-American settlement type 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

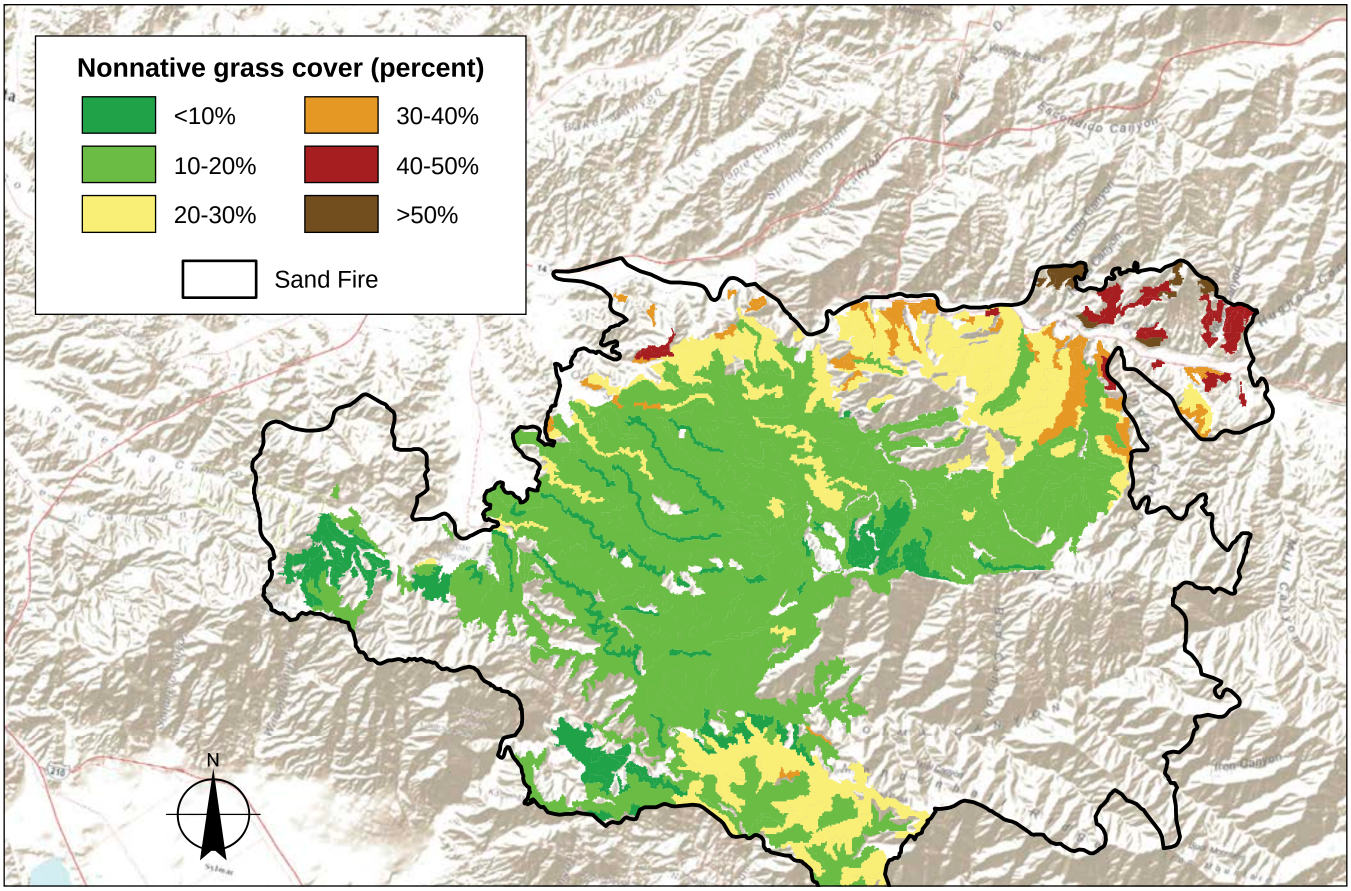

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Figure 5.3—The colored areas denote areas that had not experienced fire in the past 30+ years (see fig. 5.2) and based on past fire history are likely to recover on their own, unless additional stressors (e.g., nonnative species, drought) disrupt recovery. 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).

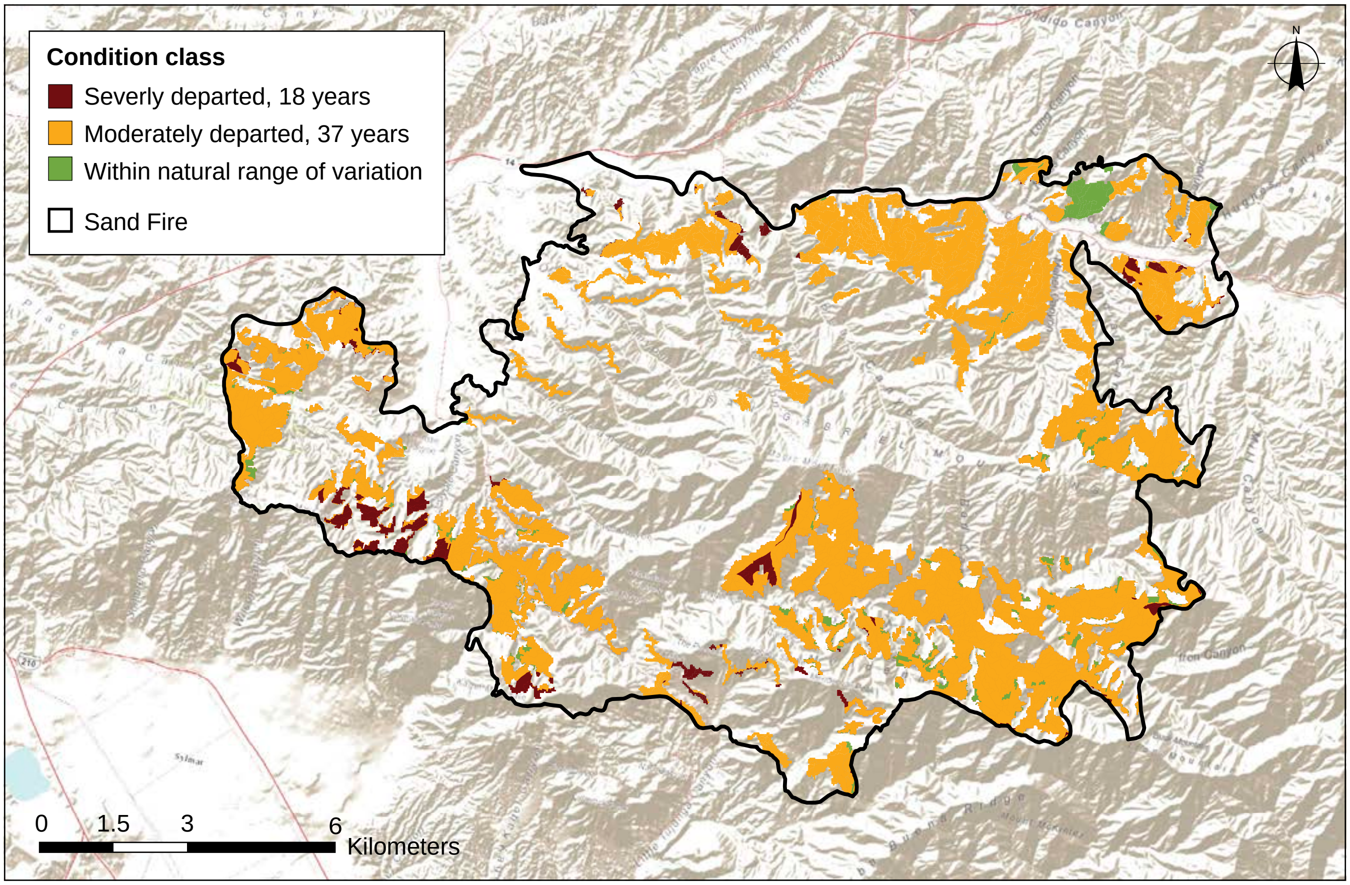

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Figure 5.4-Areas identified in Question C as being at risk of degradation due to reburning (time since fire < 30 years) or high nonnative cover (>20 percent). Condition class highlights the fire history of the area and identifies locations where fire 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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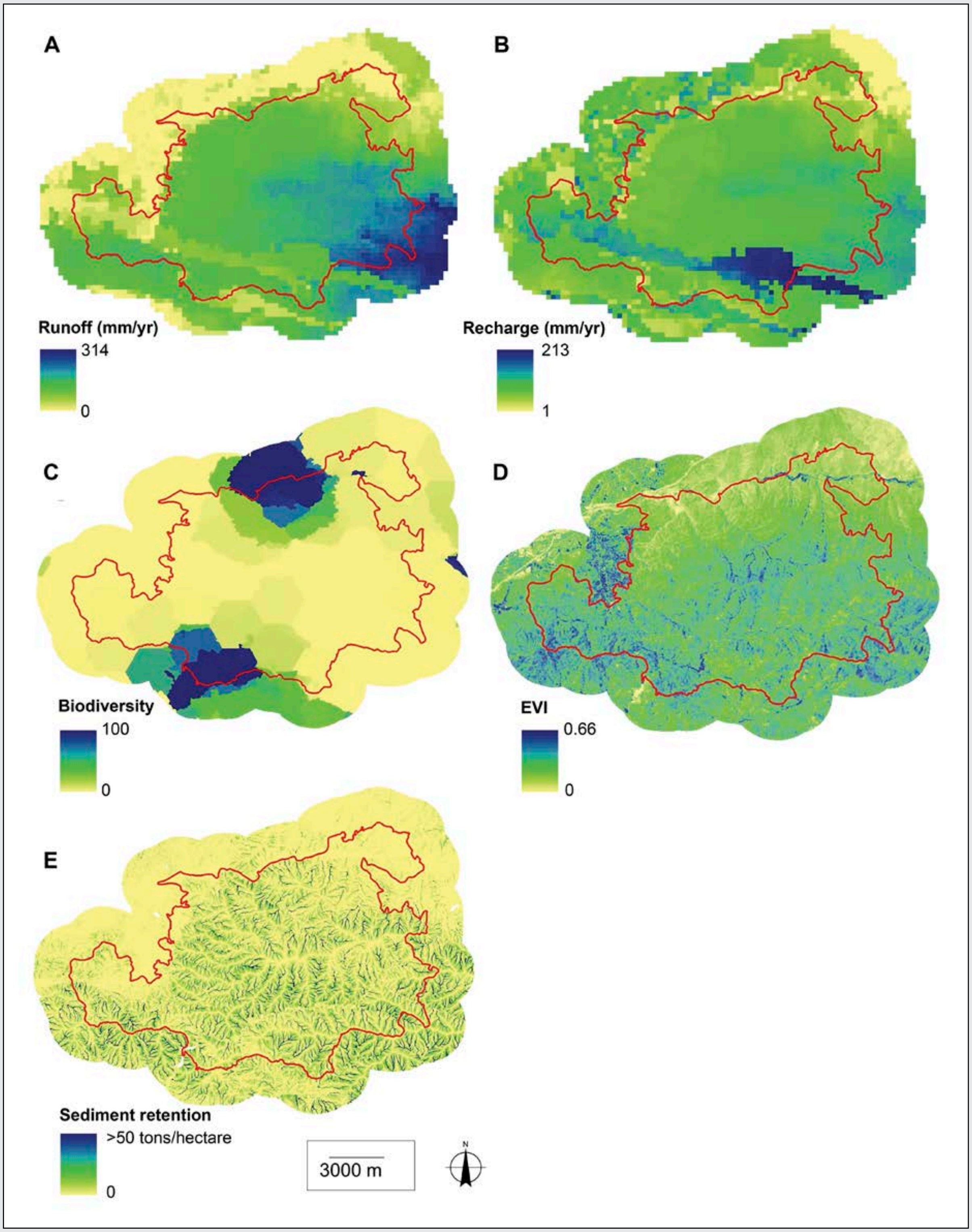

Figure 5.7—Prefire patterns of ecosystem services around the Sand Fire, including 2 km (1.2 mi) buffer shown in their original mapping units; (A) water runoff, (B) groundwater recharge, (C) biodiversity, (D) the Enhanced Vegetation Index from 2014 Landsat imagery as a proxy for carbon storage, and (E)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

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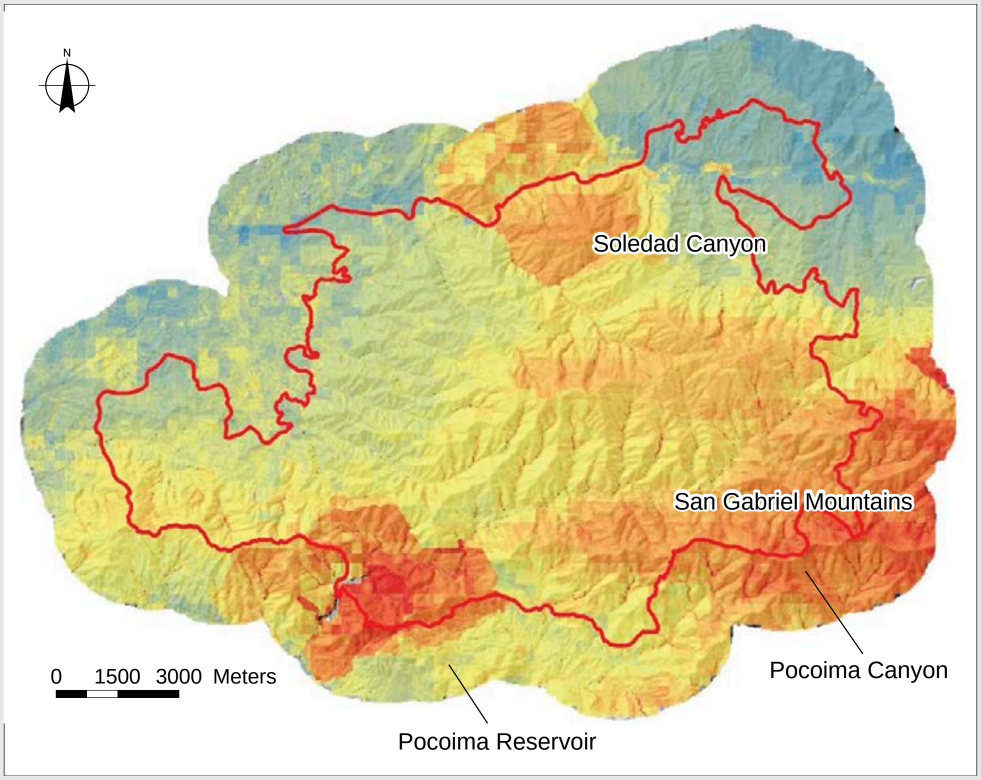

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Figure 5.8—Summation of values of five data layers indicating provision of ecosystem services (water runoff, groundwater recharge, sediment erosion retention, carbon storage, and biodiversity) across the Sand Fire (red perimeter); warm to cool colors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

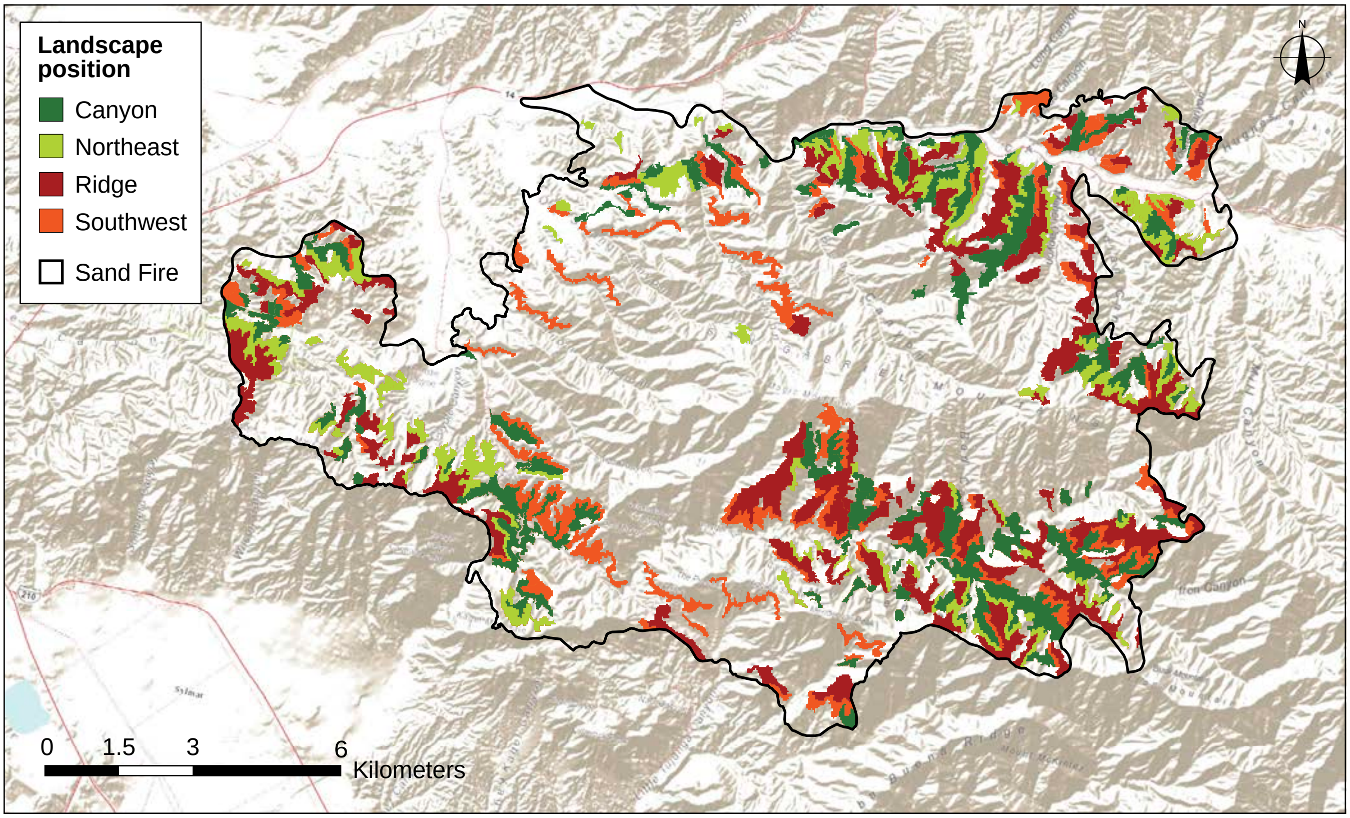

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Figure 5.5—Areas identified in question C as being at risk of degradation due to reburning (time since fire <30 years) or high nonnative cover (>20 percent). Landscape position, as determined from the landscape management unit tool, may be important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

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.

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.

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

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).

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

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.

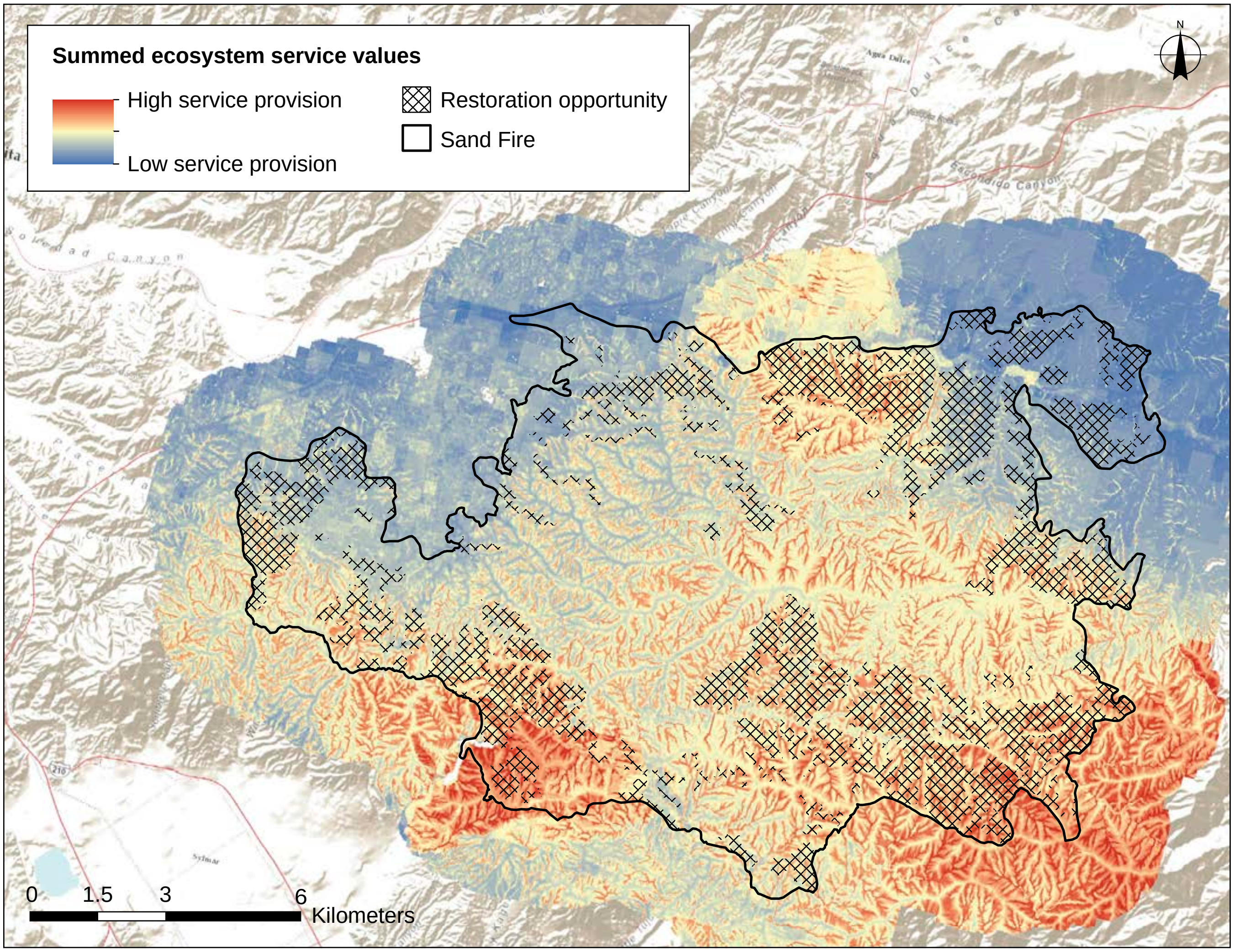

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Figure 5.6—Ecosystem service summation overlaid with the restoration areas identified in restoration opportunity 2. The southeast and southwest sections of the fire perimeter show areas where restoration need overlaps with high ecosystem service values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