# Chapter 4: Mixed-Conifer Forest Case Study

*Becky L. Estes, Marc D. Meyer, Shana E. Gross, Dana Walsh, and Clint Isbell*[1]

## Introduction

### Sierra Nevada Mixed-Conifer Forest Ecosystems

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

[1] **Becky L. Estes** is an ecologist, U.S. Department of Agriculture, Forest Service, Central Sierra Province, Eldorado National Forest, 100 Forni Road, Placerville, CA 95667; **Marc D. Meyer** is an ecologist, Southern Sierra Province, Inyo National Forest, 351 Pacu Lane, Bishop, CA 93514; **Shana E. Gross** is an ecologist, U.S. Department of Agriculture, Forest Service, Central Sierra Province, 35 College Drive, South Lake Tahoe, CA 96151; **Dana Walsh** is a silviculturist, U.S. Department of Agriculture, Forest Service, Eldorado National Forest, 7600 Wentworth Springs Road, Georgetown, CA 95634; **Clint Isbell** is a fire ecologist, U.S. Department of Agriculture, Forest Service, Klamath National Forest, 1711 South Main Street, Yreka, CA 96097.

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

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

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

## Large High-Severity Patches

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

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

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

## The 2015 Rough Fire

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

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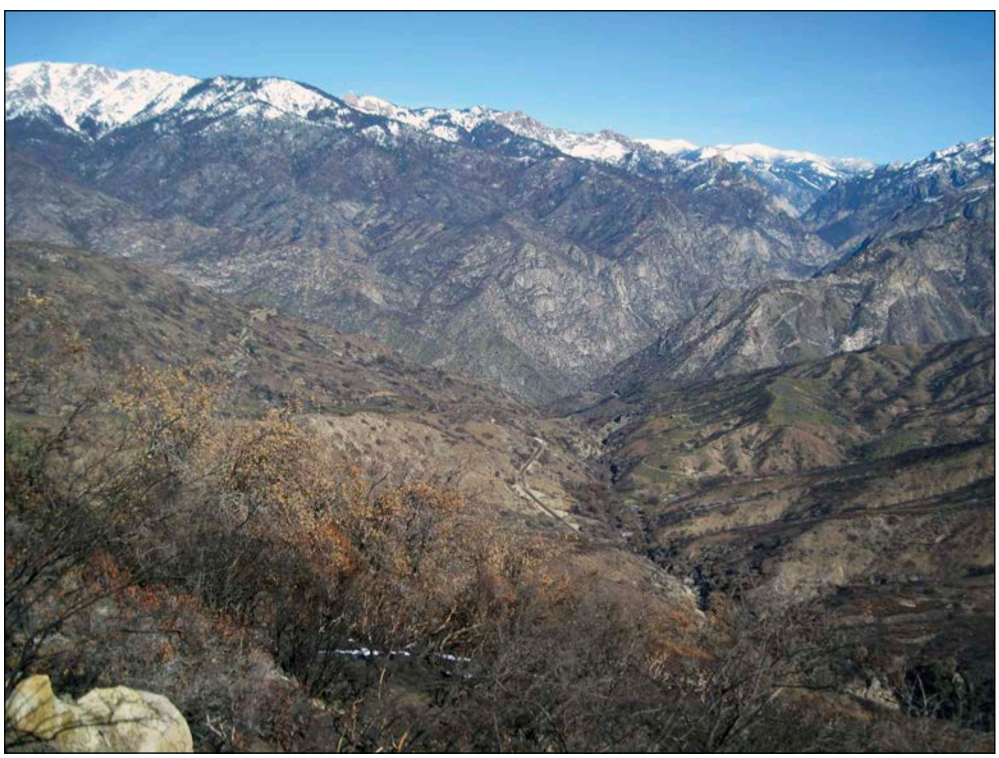

Figure 4.1—Landscape-scale vegetation conditions 1 year after the 2015 Rough Fire, showing a variety of fire effects on mixed-conifer, chaparral, and oak woodland vegetation.

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

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

## Postfire Restoration Framework

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

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

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

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

## Step 2: Gather and Review Relevant Spatial Data

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

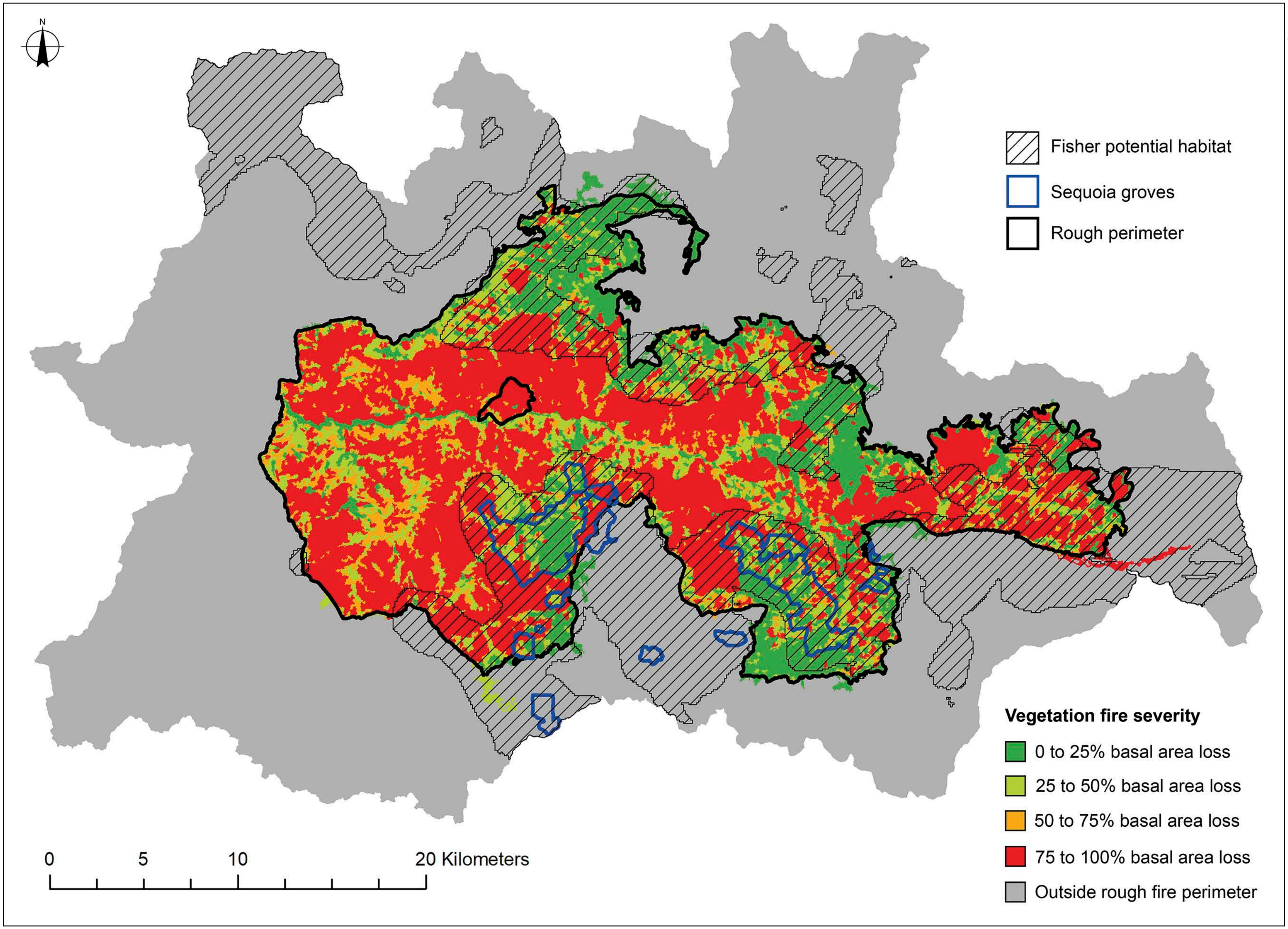


Figure 4.2—Vegetation burn severity after the 2015 Rough Fire, classified by percentage of change in basal area classes ranging from 0 to 100 percent. The analysis area outside of the Rough Fire is highlighted in grey, fisher habitat is shown in hashed polygons, and sequoia groves are displayed in the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

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

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

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

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

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

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

**Box 4A:**
**Using LiDAR to Inform Postfire Restoration Treatments**

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


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

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

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

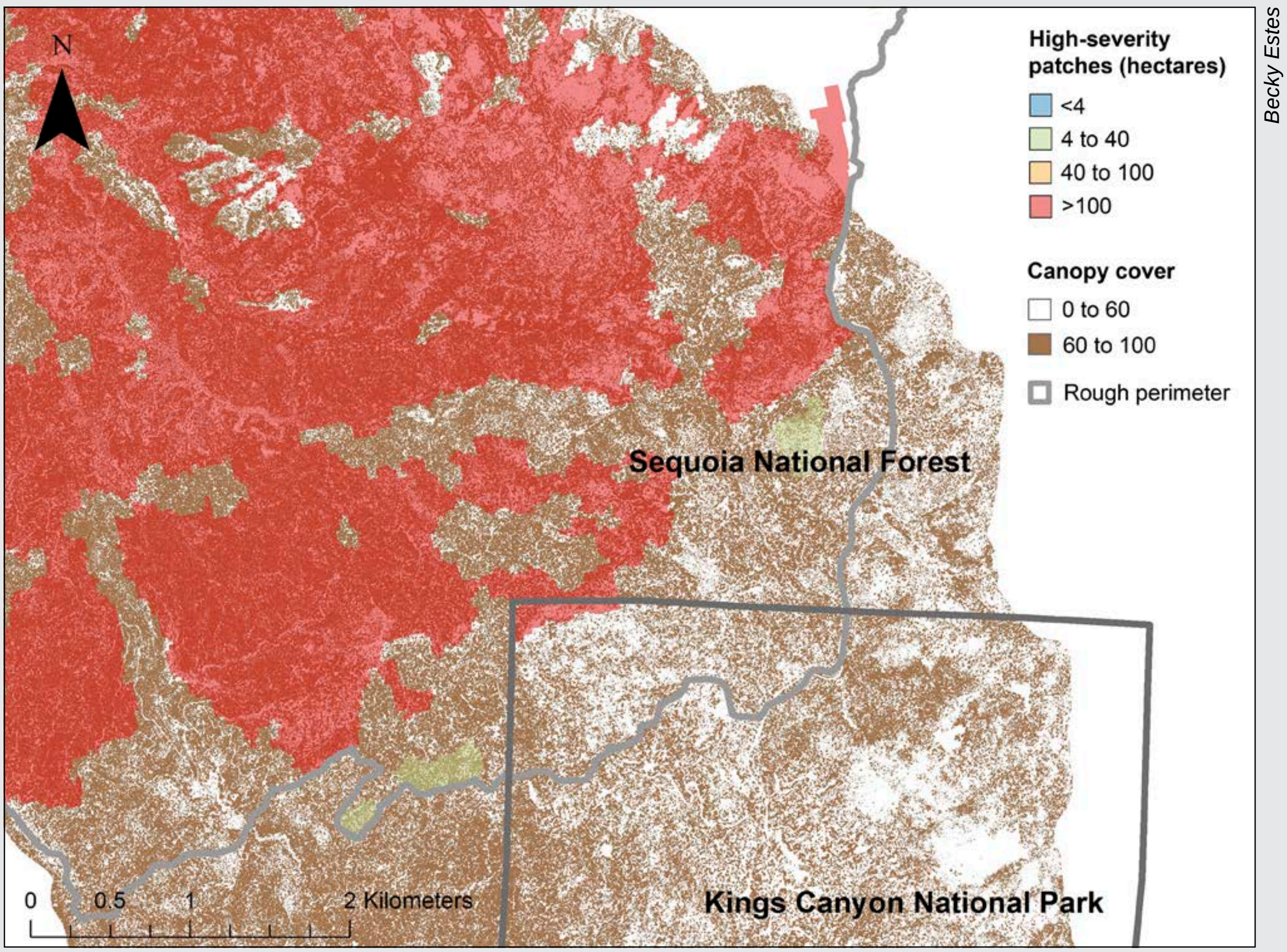


Figure 4.4. LiDAR-based map of canopy cover prior to the 2015 Rough Fire, overlaid with high-severity patches from the Rough Fire that burned on the Sequoia National Forest (Giant Sequoia National Monument) and Kings Canyon National Park.

## Step 3: Use the Postfire Flowchart to Identify Restoration Opportunities

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

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

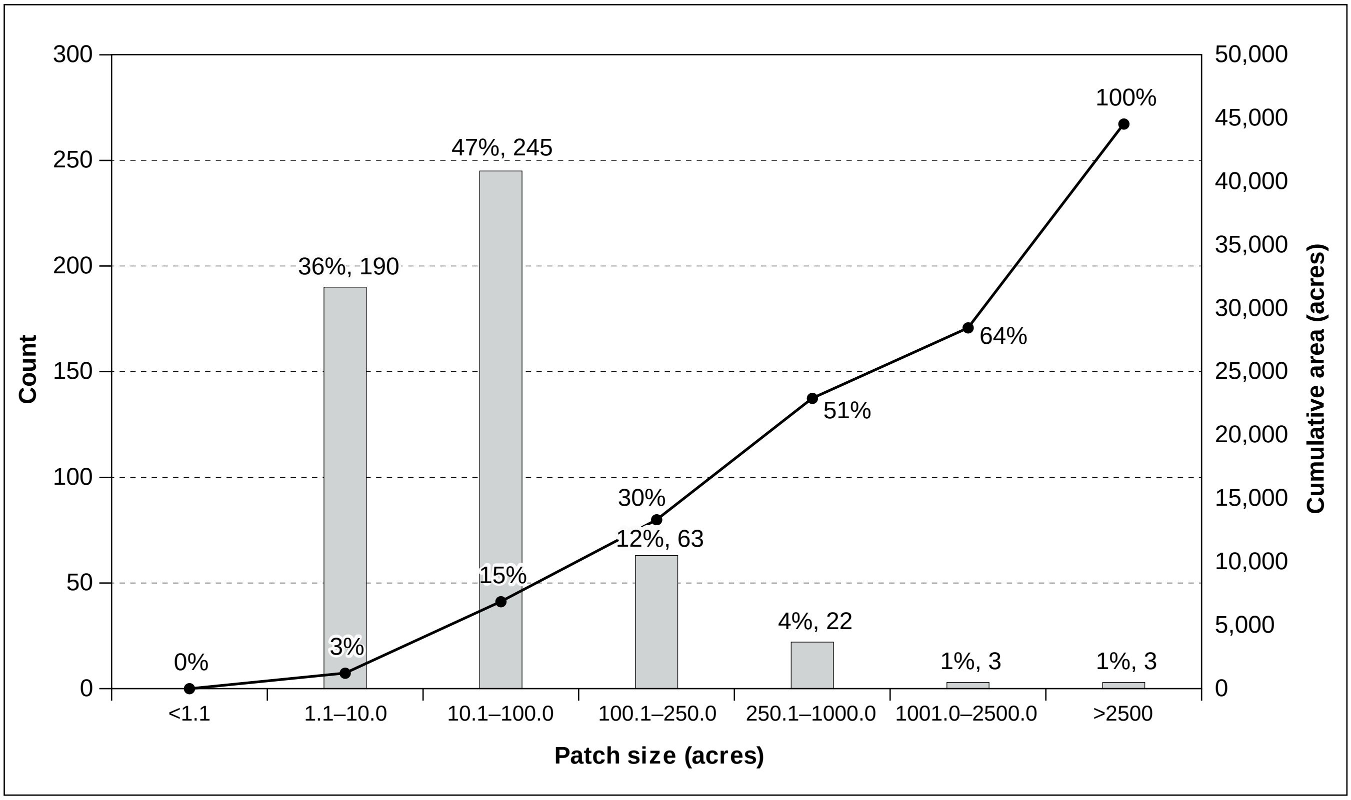


Figure 4.5—Histogram of high-severity patches in mixed-conifer forests of the 2015 Rough Fire, showing the log-transformed patch sizes (acres) to display large patch frequency. Many patches are small to moderate in size, which includes values less than 32 to 40 ha, or 80 to 100 ac. A lower proportion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

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

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

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

Becky Estes

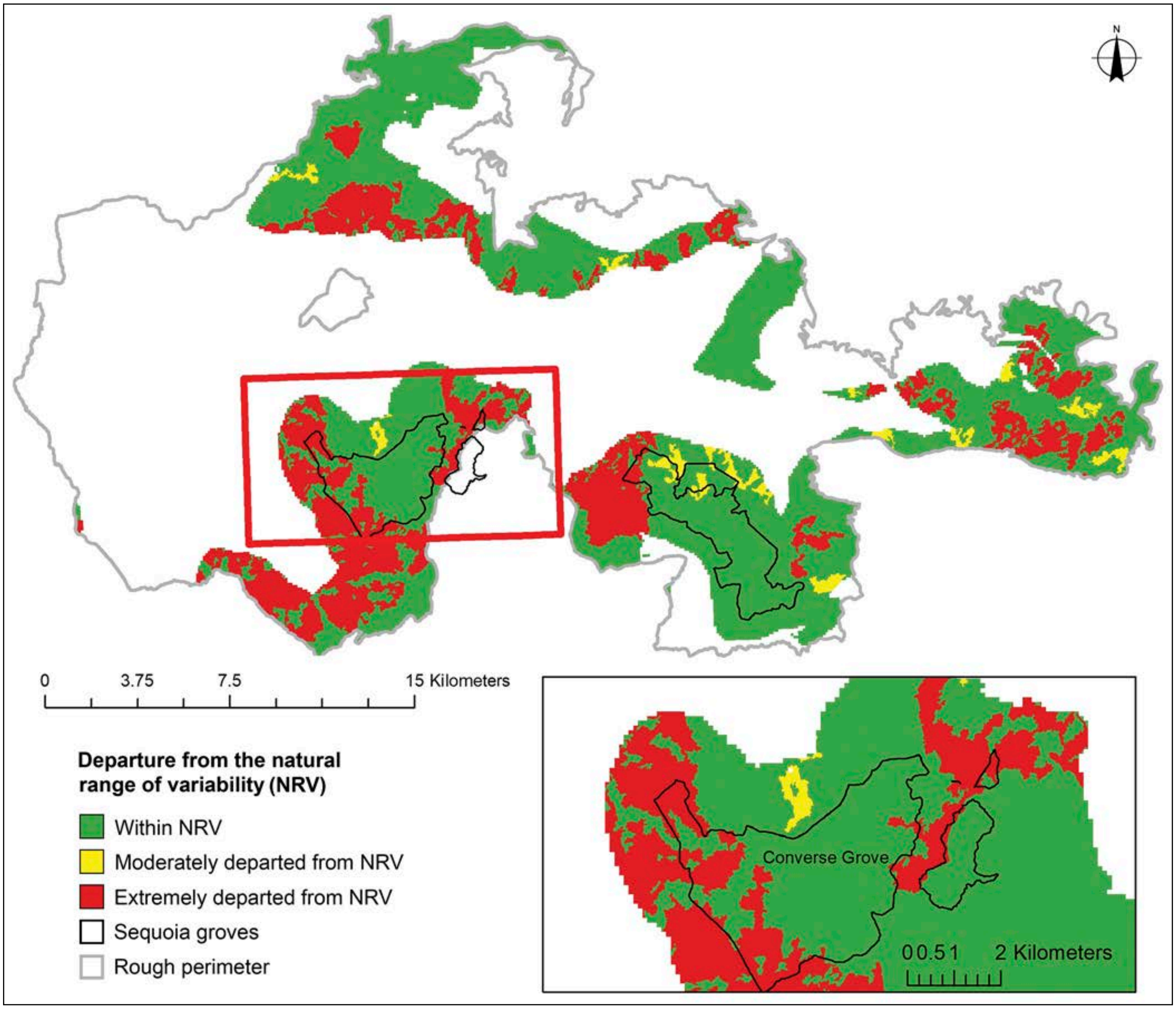


Figure 4.6—Departure from natural range of variation (NRV) within the 2015 Rough Fire in Pacific fisher habitat and giant sequoia groves. This assessment used fire severity class and high-fire severity patch size (see Step 2: Gather and Review Relevant Spatial Data for definition of classes). High fire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

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

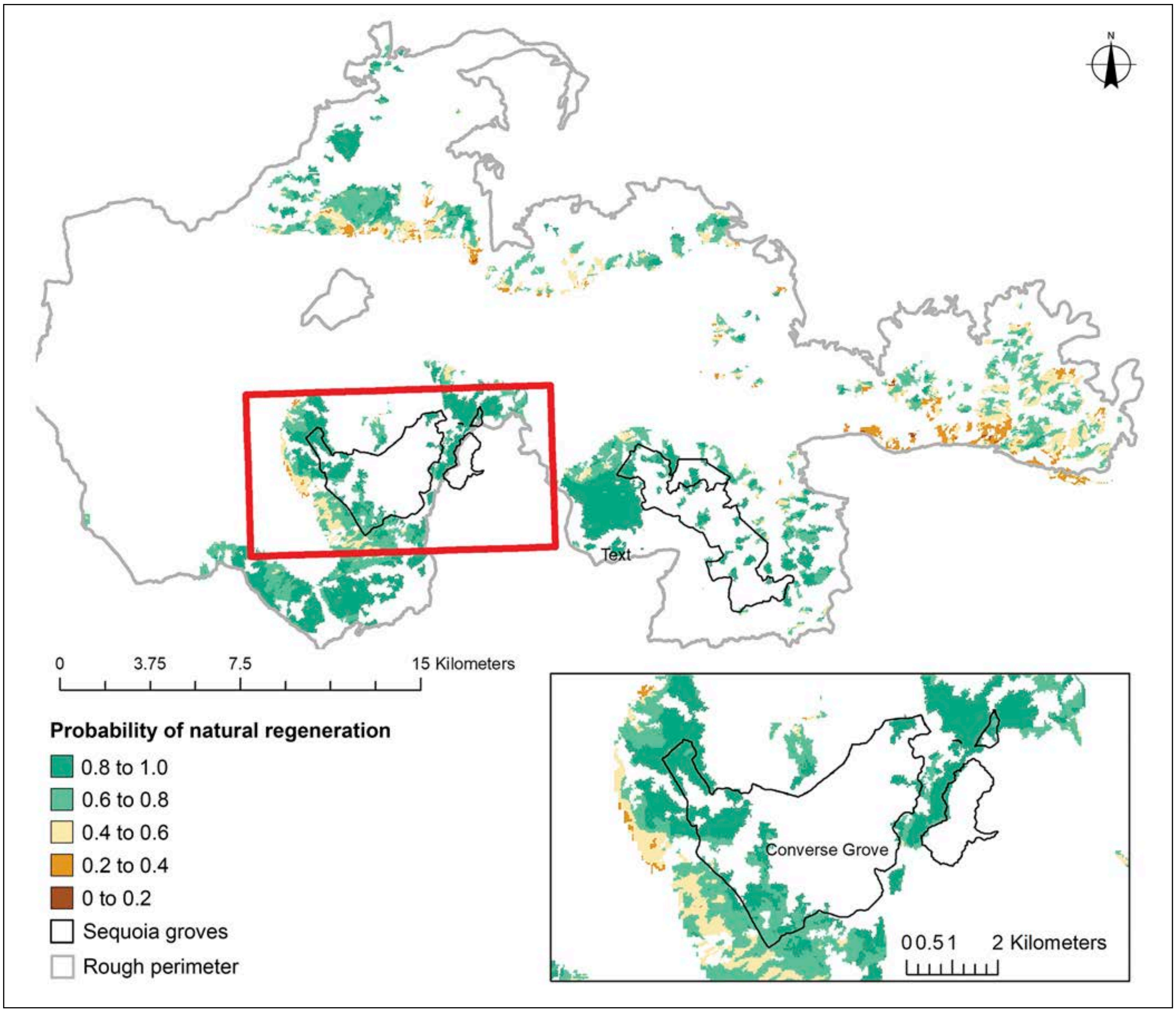


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Figure 4.7—Predictive map of the probability of natural conifer regeneration in mixed-conifer forest in Pacific fisher habitat and giant sequoia groves 5 years postfire in the 2015 Rough Fire using the POSCRPT methodology detailed in appendix 3. Areas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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

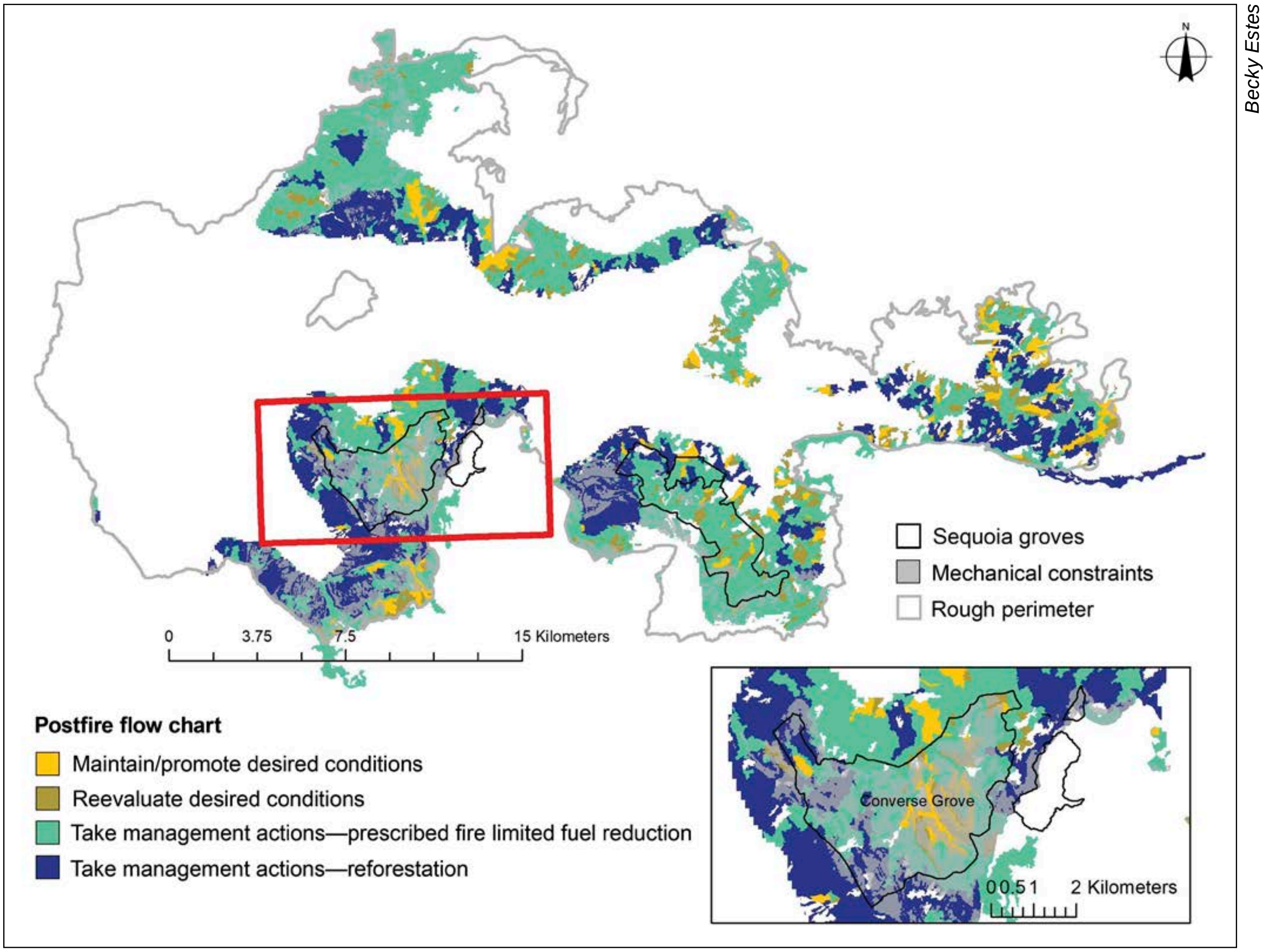


Figure 4.8—Spatial outputs of the postfire flowchart (upper panel) for the 2015 Rough Fire, with a subset of recommended restoration actions in Pacific fisher habitat and giant sequoia management areas. The inset map in the bottom right displays a portion of the analysis area focused in and around the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

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

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

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

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

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

### Step 5: Build a Restoration Portfolio by Prioritizing Actions

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

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

## Conclusions

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

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

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

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