Chapter 3: Data Gathering and Analysis

Becky L. Estes, Shana E. Gross, Nicole A. Molinari, Angela M. White, Scott Conway, Dana Walsh, Clint Isbell, and Dave Young [1]

Introduction

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

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

[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; **Shana E. Gross** is an ecologist, U.S. Department of Agriculture, Forest Service, Central Sierra Province, 35 College Drive, South Lake Tahoe, CA 96151; **Nicole A. Molinari** is an ecologist, U.S. Department of Agriculture, Forest Service, Southern California Province, Los Padres National Forest, 6755 Navigator Way, Suite 150, Goleta, CA 93117; **Angela M. White** is a research ecologist, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 1731 Research Park Drive, Davis, CA 95618; **Scott Conway** was formerly an ecologist, U.S. Department of Agriculture, Forest Service, Pacific Southwest Region Remote Sensing Laboratory, 3237 Peacekeeper Way, Suite 201, McClellan, CA 95652; **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; **Dave Young** is a soil scientist, U.S. Department of Agriculture, Forest Service, Shasta-Trinity National Forest, 3644 Avtech Parkway, Redding, CA 96002.

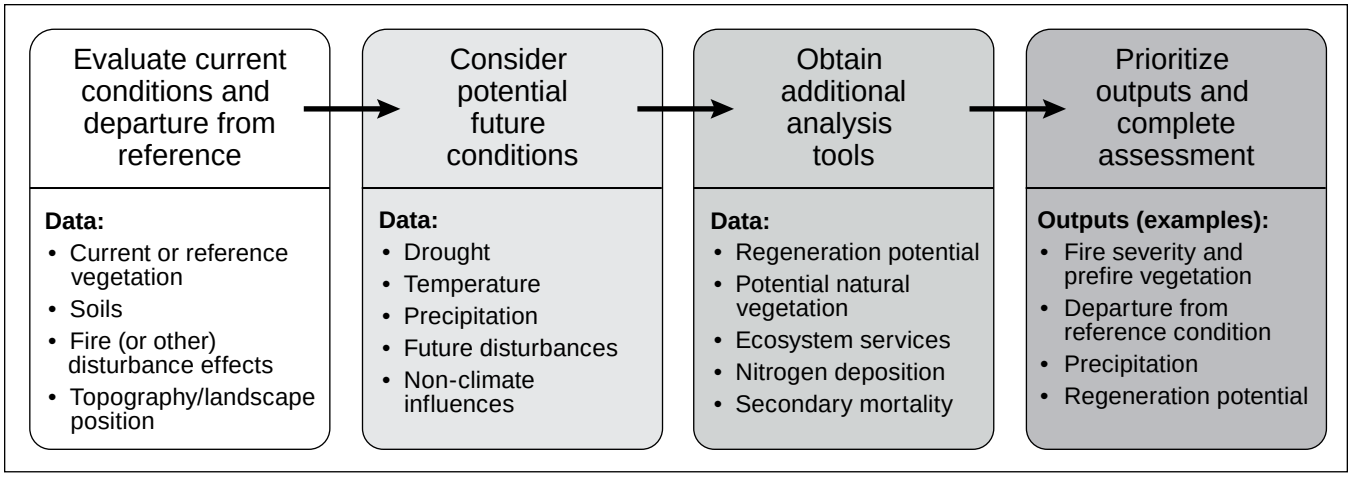

Figure 3.1—Flowchart of the data gathering and analysis step that feeds into the postfire flowchart (step 2 in fig. 2.2).

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

The ECOP Process and Important Considerations

Scale

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

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

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

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

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

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

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

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

Box 3A:
Terrestrial Ecological Unit Inventory

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

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

Vegetation

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

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

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

Topography

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

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

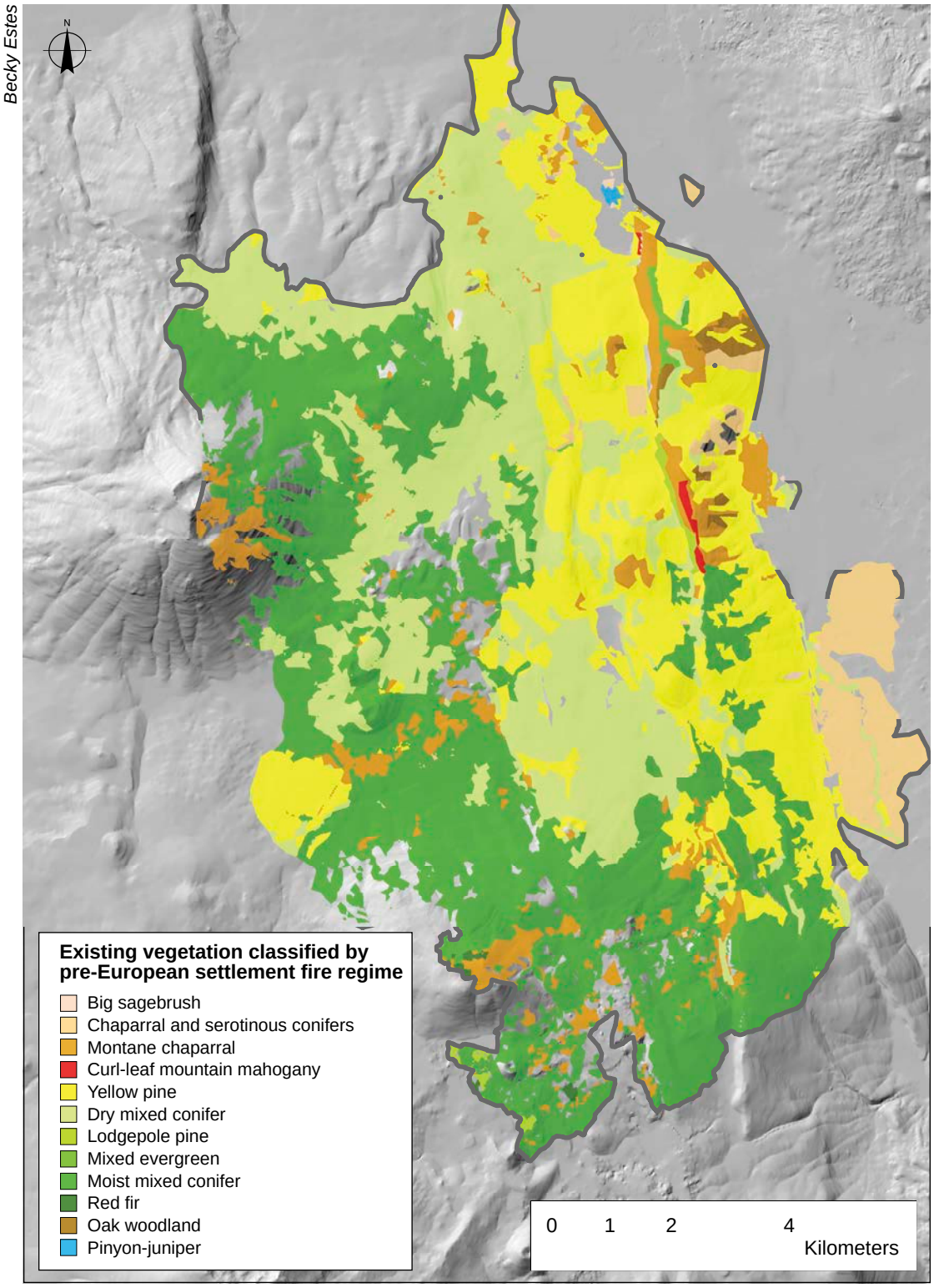

Figure 3.2—Prefire existing vegetation reclassified as pre-Euro-American settlement fire regimes within the Eiler Fire (2014) perimeter on the Lassen National Forest.

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

Fire

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

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

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

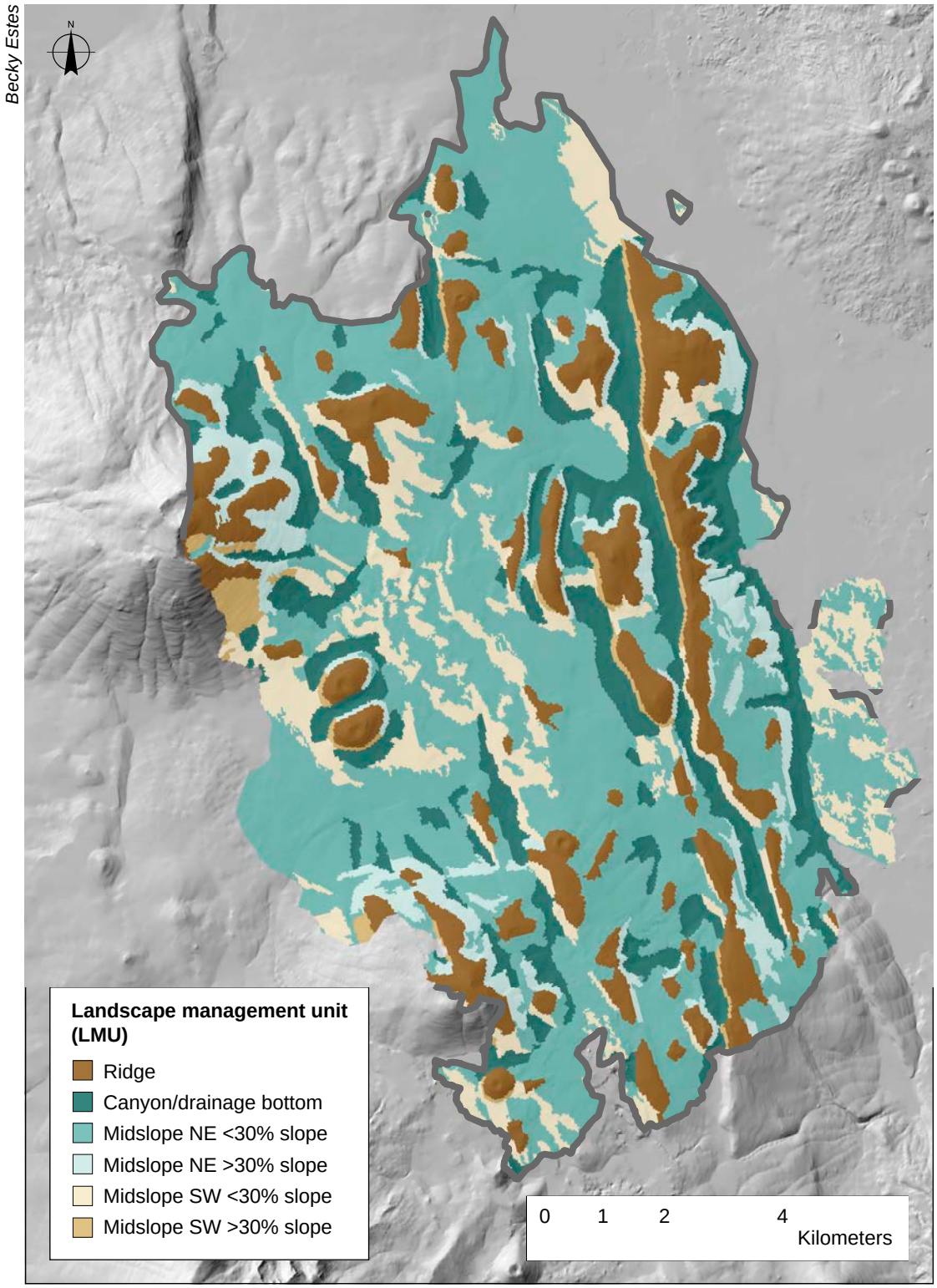

Figure 3.3—Landscape position classified by the landscape management unit tool within the Eiler Fire (2014) perimeter on the Lassen National Forest. Canyons and drainages are shown in dark blue and ridges are shown in dark brown.

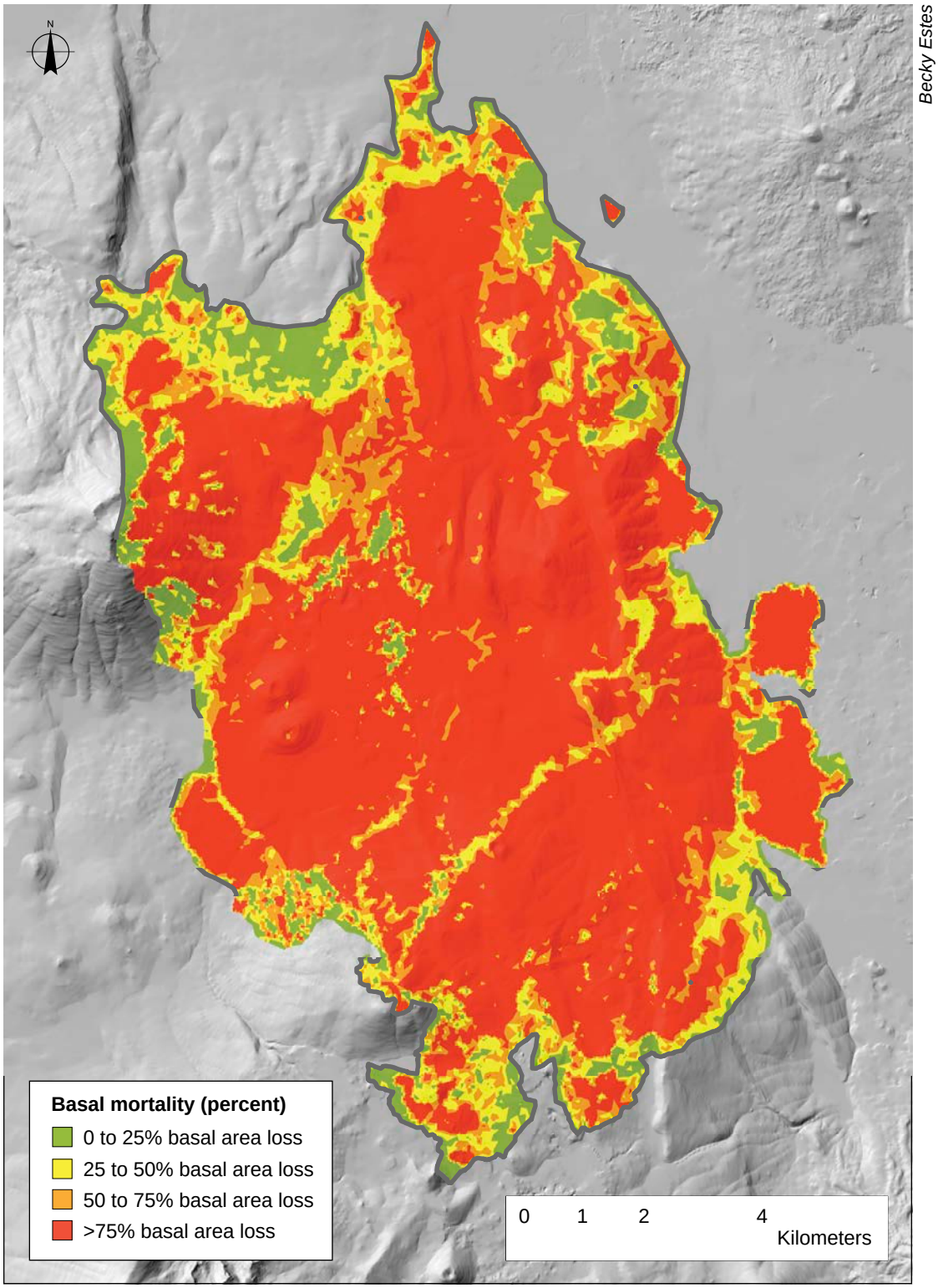

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Figure 3.4—Percentage of tree basal area mortality after fire, classified into four classes, within the Eiler Fire (2014) perimeter on the Lassen National Forest.

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

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

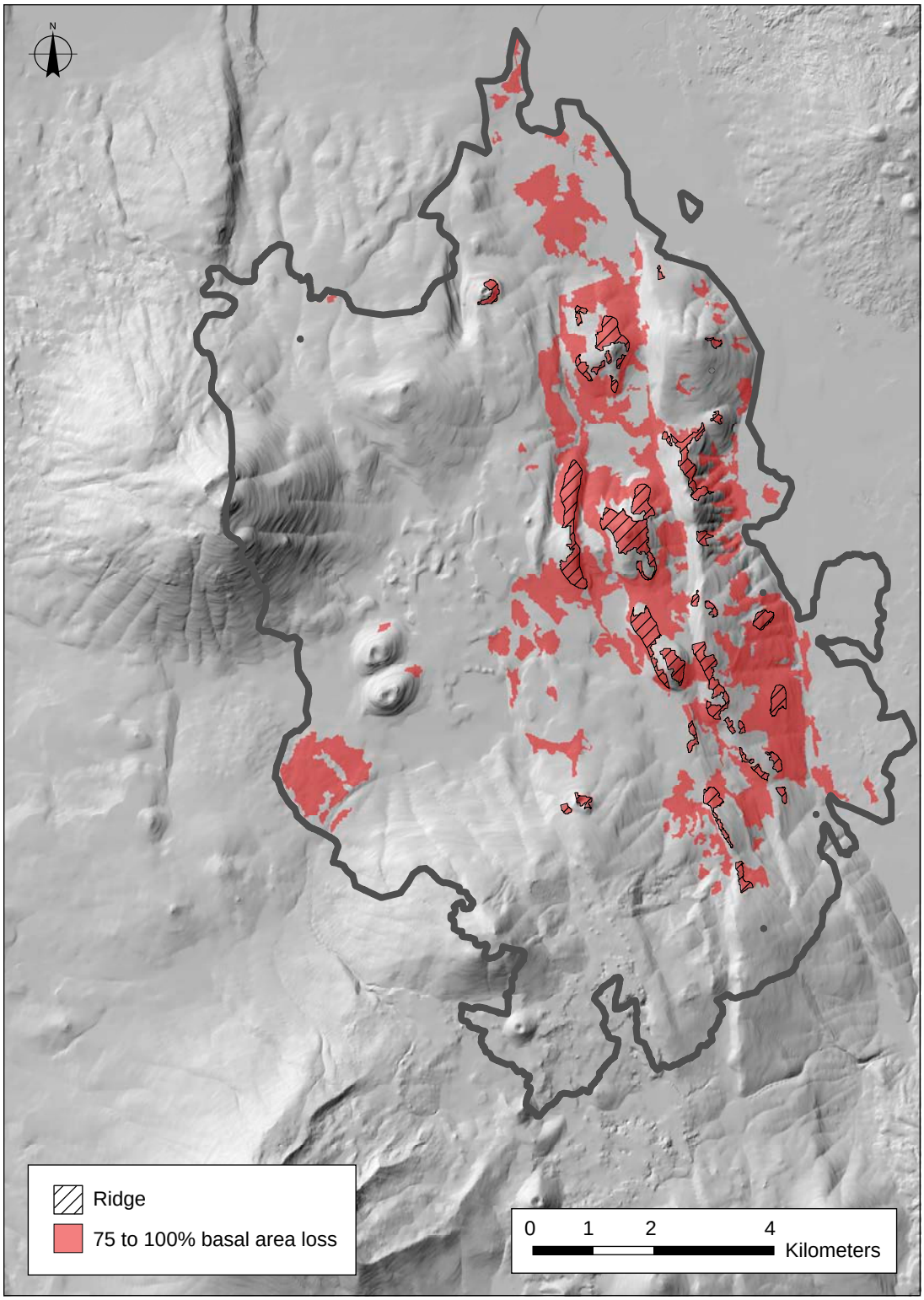

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Figure 3.5—Segmented landscape displaying yellow pine forests on ridges that burned at high severity within the Eiler Fire (2014) perimeter on the Lassen National Forest.

Consider Potential Future Conditions

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

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

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

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

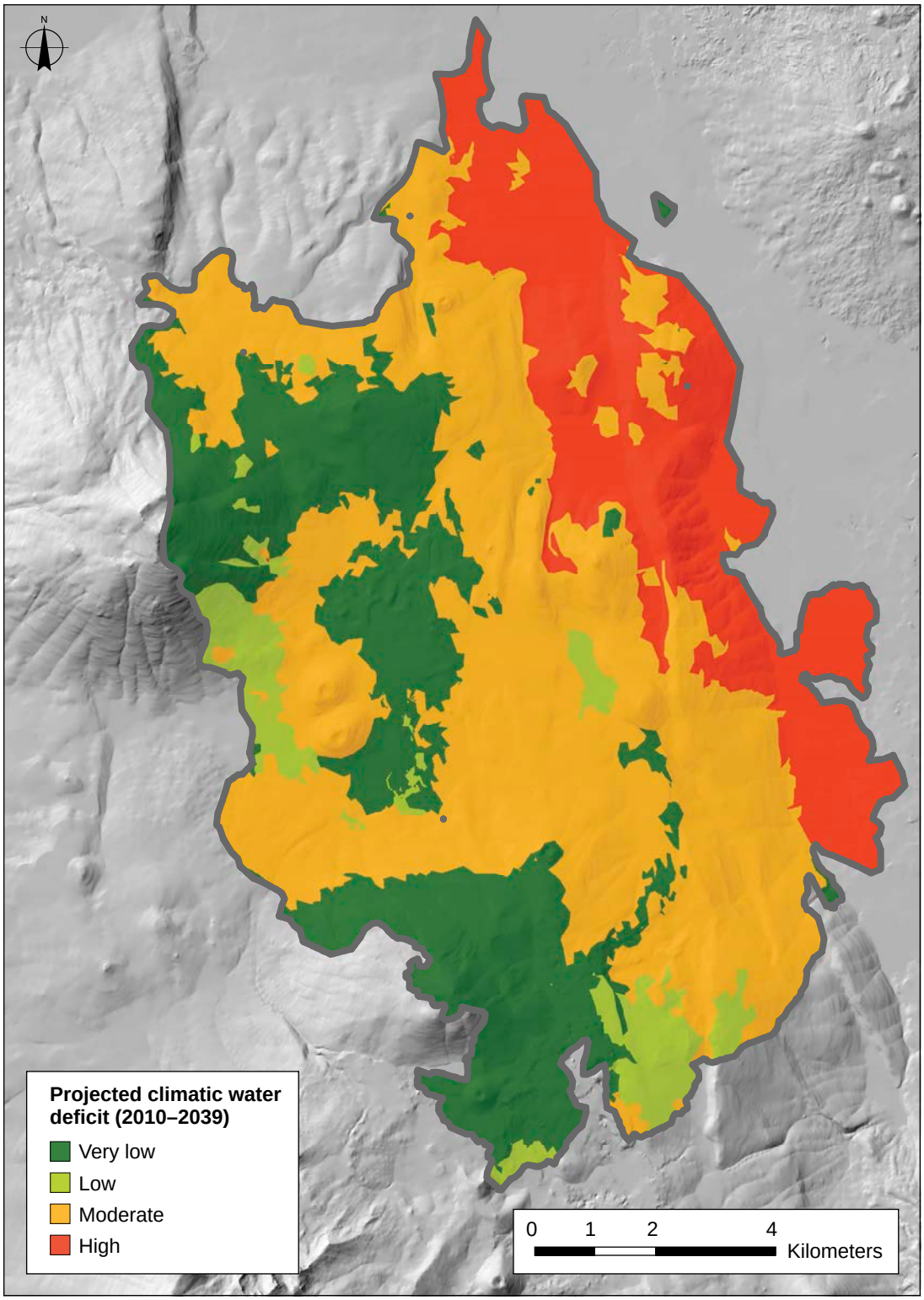

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Figure 3.6—Future projected climatic water deficit (CWD) for the 2010–2039 climate period, provided by the Parallel Climate Model Global Circulation Model (emissions scenario A2) shown within the Eiler Fire (2014) perimeter on the Lassen National Forest.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

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

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

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Additional Analysis Tools

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

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

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

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

regeneration is a seed source (Bonnet et al. 2005). Areas that have experienced high-severity fire have been shown to have dramatically lower regeneration rates for nonserotinous conifers (especially pines) compared to areas burned at moderate or low severity (Crotteau et al. 2013, Welch et al. 2016). Higher conifer regeneration densities in low- and moderate-severity burns are due primarily to nearby seed-bearing trees that survived fire. In addition to seed production, the remnant over-story in low- and moderate-severity burns produces intermittent canopy shading, a factor that may limit shrub competition and lower water stress, further permitting certain conifer seedlings to establish (Dobrowski et al. 2015, Smith et al. 1997). Uncharacteristically large high-severity patches (identified based upon NRV), on the other hand, have so few surviving mature trees that distance to seed source becomes a limiting factor (Bonnet et al. 2005) (see chapter 4). High-severity burned areas may be less likely to naturally reforest if the patch size is sufficiently large to preclude seed-tree adjacency (Bonnet et al. 2005, Sessions et al. 2004, Turner et al. 1997). Although only a few studies have directly associated tree regeneration

patterns in stand-replacing patches with patch characteristics (size, perimeter-to-area ratio, or distance to edge), seedling regeneration and especially pine regeneration are clearly reduced in patches of high-severity fire (Collins and Roller 2013, Crotteau et al. 2013, Shive et al. 2018, Welch et al. 2016). Considering the probability of natural regeneration can help to identify and prioritize reforestation needs postfire, especially for lands with considerable acreage of high-severity fire and large high-severity patches. Spatial tools to assess the natural regeneration potential on postfire landscapes are discussed in the case studies, appendices, and associated references in this document (apps. 3, 4, and 5), and related publications.

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

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

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

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

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

Secondary mortality via insects and disease—
Native insects and diseases create small minor disturbances at low, endemic levels, but will respond rapidly when conditions change that are conducive to epidemic expansion (Raffa et al. 2008). Fire-damaged trees are prime candidates for pest infestation as these types of injuries allow pathways for infection and weaken resistance to insect attack. When trees are injured, they can emit volatile organic compounds that attract bark beetles (Hood et al. 2010, Lombardero et al. 2006). Subsequent mortality varies because of the type and degree of injury to the tree, with the highest risk occurring within the first 5 years postfire (Hood et al. 2010). Regional guidelines (nonspatial) were developed for land managers to determine

the mortality probability of trees still alive after fire (Smith and Cluck 2011). Aerial detection survey data and 2014 Farm Bill Insect and disease designations can help to identify existing mortality and thus identify additional areas for removal of dead trees (app. 2). Hyperspectral imagery that can help to define moisture content of trees may be a useful tool in identifying secondary mortality on postfire landscapes (Asner et al. 2016). Additionally, change detection algorithms can identify landscape-scale changes in stand structure after drought and insect outbreaks (i.e., primary mortality) (app. 6) and assist in prioritizing areas for management actions (e.g., reforestation) after tree mortality events (app. 7).

Prioritize Outputs for Developing the Restoration Portfolio

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

Conclusions

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

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