

Chapter 3: Climate Change and the Relevance of Historical Forest Conditions

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Introduction

Increasing human emissions of greenhouse gases are modifying the Earth's climate. According to the Intergovernmental Panel on Climate Change (IPCC), "Warming of the climate system is unequivocal, as is now evident from observation of increases in average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level" (IPCC 2007). The atmospheric content of carbon dioxide (CO₂) is at its highest level in more than 650,000 years and continues to rise. Mean annual surface air temperatures in California are predicted to increase by as much as 10 °F (5.6 °C) in the next century, creating climatic conditions unprecedented in at least the last 2 million years (IPCC 2007, Moser et al. 2009). Yet climate change is by no means the only stress on forest ecosystems. Growing human populations and economies are dramatically reducing the extent of the Earth's natural habitats. Land use change has reduced the availability of suitable habitat for native plants and wildlife, and, in many places, fragmentation of habitat has led to highly disconnected natural landscapes that are only weakly connected via dispersal and migration. Biotic response to climate and land use change is further complicated by other anthropogenic stressors, including exotic invasives, altered disturbance regimes, air and water pollution, and atmospheric deposition (Noss 2001, Sanderson et al. 2002).

Traditionally, restoration and ecosystem management practices depend on the characterization of "properly functioning" reference states, which may constitute targets or desired conditions for management activities. Because human-caused modifications to ecosystems have been so pervasive, fully functional contemporary reference ecosystems are difficult to find, and reference states must often be defined from historical conditions. One of the implicit assumptions of restoration ecology and ecosystem management is the notion that the historical range of variation (HRV) represents a reasonable set of bounds within which contemporary ecosystems should be managed. The basic premise is that the ecological conditions most likely to preserve native species or conserve natural resources are those that

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Summary of Findings

- 1. Effects of climate change are already apparent in rising minimum temperatures, earlier snowpack melting, changing stream hydrology, and increased frequency of large, severe wildfires.** Tree mortality rates are increasing in lower and mid-elevation forests but may be decreasing for some subalpine species as well. Some animal species are changing their geographic ranges in response to climatic shifts.
- 2. Over the next century, average temperature is predicted to increase by 2 to 4 °F (1.1 to 2.2 °C) in the winter and 4 to 8 °F (2.2 to 4.4 °C) in the summer in the Sierra Nevada.** Changes in precipitation are more difficult to model and may differ between northern and southern California. Models suggest that snowpack in the Sierra Nevada could decrease by 20 to 90 percent. The annual summer drought in California may become more pronounced in its direct and indirect impacts on biota. Changing disturbance regimes (e.g., increases in fire frequency and burned area, and, in some forest types, fire severity) are likely to be the most significant influence on changes in vegetation types and distributions.
- 3. In preparing forests for changing climatic conditions, the value of historical ecology is the insight it provides into “the way things work” rather than “the ways things were.”** This suggests a management focused on ecological processes (e.g., fire, hydrology, etc.) rather than forest structure. It may be necessary to begin by restoring forest conditions and fuel loadings, but that should not be construed as the final goal.
- 4. Management practices may enhance ecosystem resilience and sustainability by removing or reducing other, nonclimate stressors.** A key management focus should be restoration of heterogeneity in forest conditions. In low- and mid-elevation Sierra Nevada forests, such general practices might include reductions of stem densities of smaller fire-intolerant trees and increased use of wildland fire (prescribed fire and managed wildfire).

sustained them in the past, when ecosystems were less affected by people (Egan and Howell 2001; Manley et al. 1995; Wiens et al., in press). However, rapid and profound changes in climate and land use (as well as other anthropogenic stressors) raise questions about the use of historical information in resource management. In the last decade, as the scale and pace of climate change have become more apparent, many scientists have questioned the uncritical application of historical reference conditions to contemporary and future resource management (e.g., Craig 2010, Harris et al. 2006, Millar et al. 2007, Stephenson et al. 2010, White and Walker 1997). What role can historical ecology still play in a world where the environmental baseline is shifting so rapidly?

In this chapter, we review the nature of climate change in the Sierra Nevada, focusing on recent, current, and likely future patterns in climates and climate-driven ecological processes. We then discuss the value of historical reference conditions to restoration and ecosystem management in a rapidly changing world. The climate trend portion of this chapter is drawn from a series of climate change trend summaries that were conducted for the California national forests by the U.S. Forest Service, Pacific Southwest Region Ecology Program in 2010 and 2011 (available at <http://fsweb.r5.fs.fed.us/program/ecology/>). The historical ecology portion is based on work the first author contributed to Wiens et al. (in press), especially Safford et al. (in press a and b).

Recent Trends in Climate and Climate-Driven Processes in the Sierra Nevada

Climate

The Western United States is warming at a faster rate than any other part of the country (Saunders et al. 2008). In the Sierra Nevada, mean annual temperatures have generally increased by around 1 to 2.5 °F (0.5 to 1.4 °C) over the last 75 to 100 years, although some areas of the northern Sierra have experienced slight decreases in temperature (fig. 3-1). Warming temperatures are mostly driven by increases in nighttime minima over the last two to four decades. Over the same period, most weather stations do not show an appreciable increase in mean daily maximum temperatures. At higher elevations, the annual number of days with below-freezing temperatures is dropping, and at lower elevations, there has been an increase in the number of extreme heat days (Moser et al. 2009).

The Sierra Nevada (together with northwestern California) is one of the few places in the Western United States with a positive water balance (precipitation minus potential evapotranspiration) over the last half century. Precipitation has

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been steady or increasing over much of the area (fig. 3-1), although year-to-year variability in annual precipitation (i.e., higher highs and lower lows) is also increasing at many stations. At higher elevations, the proportion of precipitation falling as rain (vs. snow) is increasing. Over the last 50 years, spring snowpack has decreased by ~~70 to 120~~ percent across most of the northern Sierra Nevada, but snowpack is up in much of the southern Sierra Nevada, owing to the combination of higher precipitation and the terrain's higher elevation (fig. 3-2).

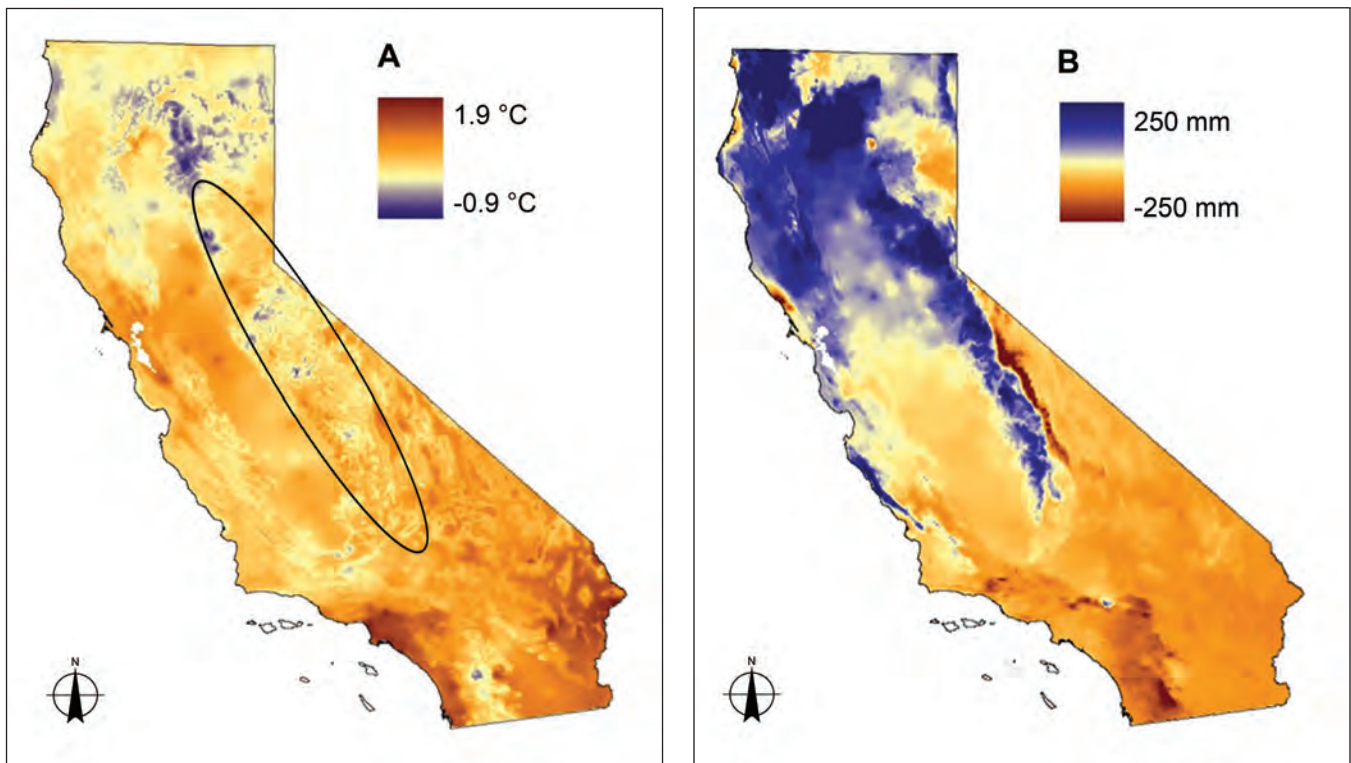


Figure 3-1—Differences in mean annual temperature (A), and mean annual precipitation (B) between the 1930s and 2000s, as derived by the PRISM climate model. Temperatures have risen across most of the Sierra Nevada (with some local areas of decrease), while precipitation has increased along most of the west slope. (Graphic courtesy of S. Dobrowksi, University of Montana.)

Hydrology

Stewart et al. (2005) showed that the onset of spring thaw in most major streams in the central Sierra Nevada occurred 5 to 30 days earlier in 2002 than in 1948, and peak streamflow (measured as the center of mass annual flow) occurred 5 to 15 days earlier. During the same period, March flows in the studied streams were mostly higher by 5 to 20 percent, but June flows were mostly lower by the same amount. Overall spring and early summer streamflow was down in most studied streams. Rising winter and spring temperatures appear to be the primary driver of these patterns (Stewart et al. 2005).

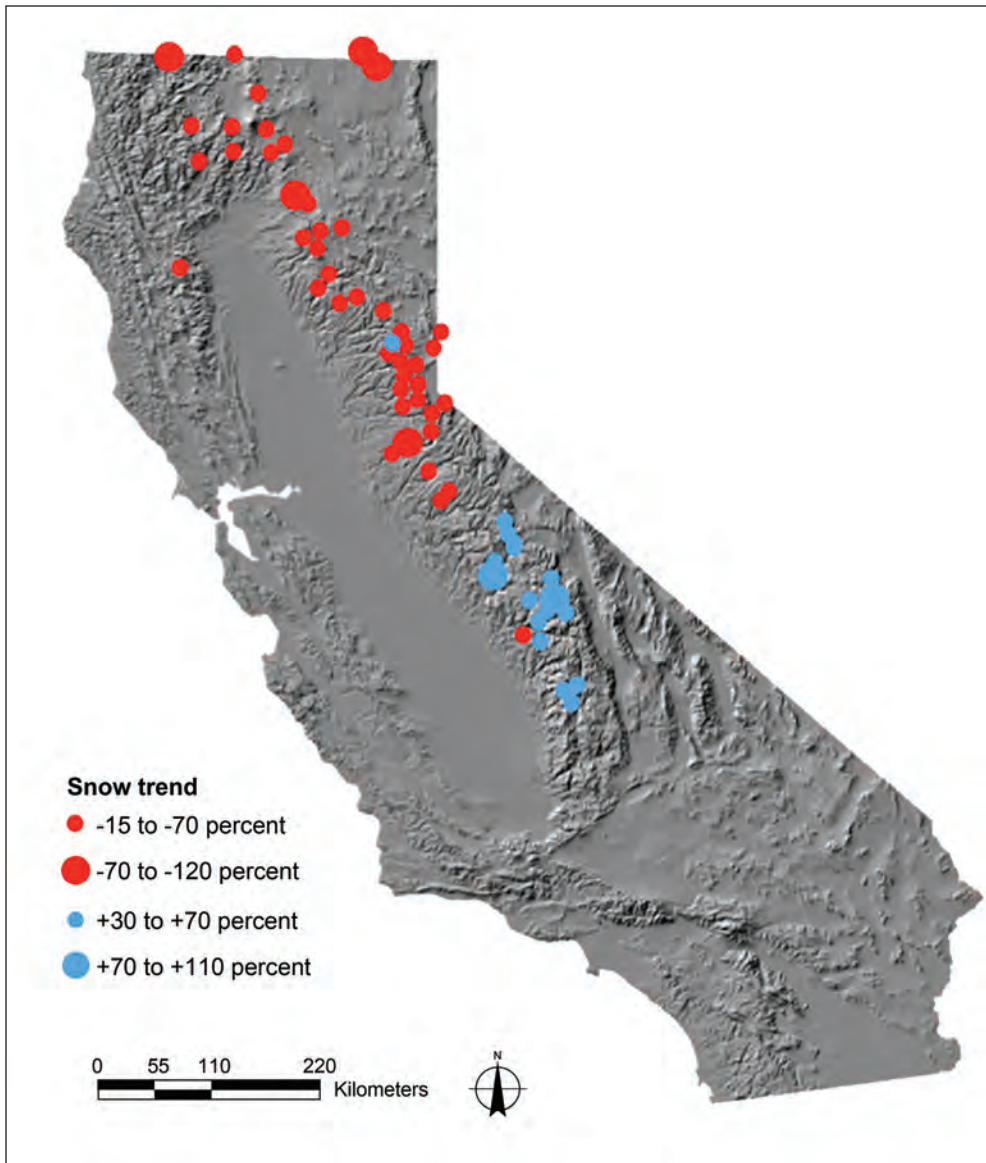


Figure 3-2—Trends in the amount of water contained in the snowpack (“snow water equivalent”) on April 1, for the period 1950–1997. Red circles indicate percentage of decrease in snow water; blue circles indicate increase in snow water. (Redrawn from Moser et al. 2009.)

Mean and maximum fire size, and total burned area in the Sierra Nevada, have increased strongly between the early 1980s and 2007.

Thirty five to 50 percent of the pattern in fire size and area can now be explained by spring climate variables.

Fires at the beginning of the record burned at an average of about 17 percent high severity, while the average for the last 10-year period was 30 percent.

Forest Fires

Data on forest fire frequency, size, total area burned, and severity all show increases in the Sierra Nevada over the last two to three decades. Westerling et al. (2006) found that increasing frequencies of large fires (>1,000 ac) (405 ha) across the Western United States since the 1980s were strongly linked to increasing temperatures and earlier spring snowmelt. The Sierra Nevada was one of two geographic areas of especially increased fire activity, which Westerling et al. (2006) ascribed to an interaction between climate and increased fuels owing to fire suppression. Westerling et al. (2006) also identified the Sierra Nevada as being one of the geographic regions most likely to see further increases in fire activity on account of future increases in temperature. Miller et al. (2009) showed that mean and maximum fire size, and total burned area in the Sierra Nevada, have increased strongly between the early 1980s and 2007. Climatic variables explain very little of the pattern in fire size and area in the early 20th century. In contrast, over the last 25 years, 35 to 50 percent of the pattern in fire size and area can now be explained by spring climate variables (spring precipitation and minimum temperature). The mean size of escaped fires in the Sierra Nevada was about 750 ac (304 ha) until the late 1970s, but the most recent 10-year average has climbed to about 1,100 ac (445 ha). Miller et al. (2009) also showed that forest fire severity (a measure of the effect of fire on vegetation) rose strongly during the period 1984 to 2007, with the pattern concentrated in middle-elevation conifer forests. Fires at the beginning of the record burned at an average of about 17 percent high (stand-replacing) severity, while the average for the last 10-year period was 30 percent. Miller et al. (2009) found that both climate change and increasing forest fuels were necessary to explain the patterns they analyzed.

Forest Structure

Fire suppression has been practiced as a general federal policy since the 1920s. Pre-Euro-American fire frequencies in high-elevation forests such as red fir (*Abies magnifica* (Gordon & Glend.) Lindl. ex Hildebr.) (>40 to 50 years in many places) and subalpine forest (>100 years) were long enough that fire suppression has had little or no impact on ecological patterns or processes (Miller et al. 2009, Van de Water and Safford 2011). Higher elevation forests are also much more remote, less likely to have economic uses, and often protected in wilderness areas and national parks, so impacts from logging or recreation use are generally minimal. Subalpine tree growth is strongly influenced by higher precipitation and warm summers (Graumlich 1991). Long-term changes in stand structure in higher elevation forests are thus more likely to represent responses to changes in exogenous factors like climate.

In the early 1930s, the Forest Service mapped vegetation on national forest lands in the Sierra Nevada and sampled thousands of vegetation plots (Wieslander 1935). Bouldin (1999) compared the 1930s plots with the modern Forest Inventory and Analysis plots and described changes in forest structure for the Sierra Nevada from Yosemite National Park to the Plumas National Forest, that is, primarily north of the Sierra National Forest. In red fir forest, Bouldin (1999) found that densities of young trees had increased by about 40 percent between 1935 and 1992, but densities of large trees had decreased by 50 percent during the same period. In old-growth stands, overall densities and basal areas were higher, and the number of plots in the red fir zone dominated by shade-tolerant species increased at the expense of species like Jeffrey pine (*Pinus jeffreyi* Balf.) and western white pine (*Pinus monticola* Douglas ex. D. Don). In old-growth subalpine forests, Bouldin (1999) found that young mountain hemlock (*Tsuga mertensiana* (Bong.) Carriere), a shade-tolerant species, was increasing in density and basal area while larger western white pine was decreasing. In whitebark pine stands, overall density was increasing owing to increased recruitment of young trees, but species composition had not changed. Lodgepole pine (*Pinus contorta* Douglas ex. Louden) appears to be responding favorably to increased warming or increased precipitation throughout the subalpine forest.

Bouldin (1999) also studied mortality patterns in the 1935 and 1992 data sets. He found that mortality rates had increased in red fir (*Abies magnifica* A. Murray bis), with the greatest increases in the smaller size classes. At the same time, in subalpine forests, lodgepole pine, western white pine, and mountain hemlock all showed decreases in mortality. The subalpine zone was the only forest type Bouldin (1999) studied in which mortality had not greatly increased since the 1935 inventory. This suggests that climate change (warming, plus higher precipitation in some cases) is actually making conditions better for some tree species in this stressful environment. Dolanc et al. (2012) recently completed a study that resampled the 1930s Forest Service (Wieslander) plots in the subalpine zone between Yosemite National Park and the Lake Tahoe Basin. Corroborating Bouldin (1999), they found that growing conditions in the subalpine zone were probably better today than in the 1930s, as the density of small trees of almost all species had increased greatly in the 75-year period. Dolanc et al.'s (2012) direct plot-to-plot comparison also found that mortality of large trees had decreased the density of the subalpine forest canopy, but the overall trend was for denser forests with no apparent change in relative tree species abundances.

Van Mantgem et al. (2009) recently documented widespread increases in tree mortality in old-growth forests across the Western United States, including in the

Sierra Nevada. Their plots had not experienced increases in density or basal area during the 15- to 40-year period between first and last census. The highest mortality rates were documented in the Sierra Nevada, and in middle-elevation forests (3,300 to 6,700 ft) (1006 to 2042 m). Higher elevation forests (>6,700 ft) (2042 m) showed the lowest mortality rates, corroborating the Bouldin (1999) findings. Van Mantgem et al. (2009) ascribed the mortality patterns they analyzed to regional climate warming and associated drought stress.

Comparisons of the 1930s Forest Service vegetation inventories and map with modern vegetation maps and inventories show changes in the distribution of many Sierra Nevada vegetation types over the last 70 to 80 years (Bouldin 1999, Moser et al. 2009). The principal trends are (1) loss of yellow pine-dominated forest, (2) increase in the area of forest dominated by shade-tolerant conifers (especially fir species), (3) loss of blue oak woodland, (4) increase in hardwood-dominated forests, (5) loss of subalpine and alpine vegetation, and (6) expansion of subalpine trees into previous permanent snowfields. Trends four through six appear to have a strong connection to climate warming, while trends one through three are mostly the product of human management choices, including logging, fire suppression, and urban expansion.

Wildlife

Between 1914 and 1920, the Museum of Vertebrate Zoology (MVZ) at the University of California Berkeley surveyed the terrestrial vertebrate fauna at 41 sites along a transect that extended from the western slope of Yosemite National Park to an area near Mono Lake (Grinnell and Storer 1924). In the past decade, MVZ resurveyed the Yosemite transect to evaluate the near century-long changes in Yosemite's vertebrate fauna across this elevation gradient, stretching across numerous vegetation types (Moritz et al. 2008). By comparing earlier and recent MVZ small mammal surveys, Moritz et al. (2008) came to several conclusions: (1) the elevation limits of geographic ranges shifted primarily upward, (2) several high-elevation species (e.g., alpine chipmunk [*Tamias alpinus*]) exhibited range contraction (shifted their lower range limit upslope), while several low-elevation species expanded their range upslope, (3) many species showed no change in their elevational range, (4) elevational range shifts resulted in minor changes in species richness and composition at varying spatial scales, (5) closely related species responded idiosyncratically to changes in climate and vegetation, and (6) most upward range shifts for high-elevation species are consistent with predicted climate warming, but changes in most lower to mid-elevation species' ranges are likely the result of landscape-level vegetation dynamics related primarily to changes in fire regimes.

Closely related species responded idiosyncratically to changes in climate and vegetation.

Similar distribution patterns have been observed for other faunal taxa throughout the Sierra Nevada. Forister et al. (2010) tracked 159 species of butterflies over 35 years in the central Sierra Nevada and observed upward shifts in the elevational range of species, a pattern consistent with a warming climate. Tingley et al. (2009) resurveyed bird distributions along the Grinnell transects in the entire Sierra Nevada and concluded that 91 percent of species distributions shifted with changes in temperature or precipitation over time and 26 percent of species tracked both temperature and precipitation. This suggests that birds move in response to changing climates in order to maintain environmental associations to which they are adapted. The authors also suggested that combining climate and niche models may be useful for predicting future changes in regional bird distributions (Tingley et al. 2009). In contrast with other faunal studies, Drost and Fellers (1996) found that most frog and toad species in Yosemite exhibited widespread decline over the past several decades, regardless of elevation. Primary factors that may contribute to this faunal collapse throughout the Sierra Nevada include introduced predators, a fungal pathogen, pesticides, and climate change (Wake and Vredenburg 2008).

Projected Trends in Climate and Climate-Driven Processes

Climate

Currently, no published climate change or vegetation change modeling has been carried out for the Sierra Nevada alone. Indeed, few future-climate modeling efforts have treated areas as restricted as the state of California. The principal limiting factor is the spatial scale of the General Circulation Models (GCMs) that are used to simulate future climate scenarios. Most GCMs produce raster outputs with pixels that are 10,000s of square acres in area. To be used at finer scales, these outputs must be downscaled by using a series of algorithms and assumptions—these finer scale secondary products currently provide the most credible sources we have for estimating potential outcomes of long-term climate change for California. Another complication is the extent to which GCMs disagree with respect to the probable outcomes of climate change. For example, a recent comparison of 21 published GCM outputs that included California found that estimates of future precipitation ranged from a 26 percent increase per 1.8 °F (1 °C) increase in temperature to an 8 percent decrease (Gutowski et al. 2000, Hakkarinen and Smith 2003). That said, there was some broad consensus. All of the reviewed GCMs predicted warming temperatures for California, and 13 of 21 (62 percent) predicted higher precipitation (three showed no change, and five predicted decreases). According to Dettinger (2005), the most common prediction among the most recent models (which are

considerably more complex and, ideally, more credible) is temperature warming by about 9 °F (5 °C) by 2100, with precipitation remaining similar or slightly reduced compared to today. Most models agreed that summers will be drier than they are currently, regardless of levels of annual precipitation.

The most widely cited of the recent modeling efforts is probably Hayhoe et al. (2004). They used two contrasting GCMs (much warmer and wetter, vs. somewhat warmer and drier) under low and high greenhouse gas emission scenarios to make projections of climate change impacts for California over the next century. By 2100, under all GCM-emissions scenarios, April 1 snowpack was down by 22 percent to 93 percent in the 6,700- to 10,000-ft (2042 to 3048 m) elevation belt, and the date of peak snowmelt was projected to occur from 3 to 24 days earlier in the season. Average temperatures were projected to increase by 2 to 4 °F (1.1 to 2.2 °C) in the winter and 4 to 8 °F (2.2 to 4.4 °C) in the summer. Finally, three of the four GCM-emissions scenarios employed by Hayhoe et al. (2004) predicted strong decreases in annual precipitation by 2100, ranging from 91 to 157 percent; the remaining scenario predicted a 38 percent increase. Although the southern Sierra Nevada snowpack has generally remained steady (or risen) over the past half-century (fig. 3-2) (Moser et al. 2009), continued warming is likely to erode the temperature buffer that is currently observed in the high southern Sierra Nevada. Most modeling projects a continuous increase in the rain:snow ratio and earlier runoff dates for the next century, with decreased snowpack (late winter snow accumulation decreases by 50 percent by 2100) and growing-season streamflow even in the higher elevation river basins (Miller et al. 2003, Moser et al. 2009).

Most modeling projects a continuous increase in the rain:snow ratio and earlier runoff dates for the next century, with decreased snowpack.

Hydrology

Miller et al. (2003) modeled future hydrological changes in California as a function of two contrasting GCMs (the same GCMs used in Hayhoe et al. [2005] and Lenihan et al. [2003; see below]) and a variety of scenarios intermediate to the GCMs. Miller et al. (2003) found that annual streamflow volumes were strongly dependent on the precipitation scenario, but changes in seasonal runoff were more complex. Predicted spring and summer runoff was lower in all of the California river basins they modeled, except where precipitation was greatly increased, in which case runoff was unchanged from today (Miller et al. 2003). Runoff in the winter and early spring was predicted to be higher under most of the climate scenarios because higher temperatures cause snow to melt earlier. In California rivers that are fed principally by snowmelt (i.e., higher elevation streams), flood potential was predicted to increase under all scenarios of climate change, principally owing to earlier dates of peak daily flows and the increase in the proportion of precipitation falling as rain. These increases in peak daily flows are predicted under all climate change

scenarios, including those assuming reduced precipitation (Miller et al. 2003). The predicted increase in peak flow was most pronounced in higher elevation river basins, owing to the greater reliance on snowmelt. If precipitation does increase, streamflow volumes during peak runoff could greatly increase. Under the wettest climate scenario modeled by Miller et al. (2003), by 2100 the volume of flow during the highest flow days could more than double in many Sierra Nevada rivers. This would result in a substantial increase in flood risk in flood-prone areas in the Central Valley. According to Miller et al. (2003), increased flood risk is highly probable under current climate change trends, because temperature, not precipitation, is the main driver of higher peak runoff. If climate change leads not only to an increase in average precipitation but also a shift to more extreme precipitation events, then peak flows would be expected to increase dramatically.

Fire

The combination of warmer climate and increased fuel production (owing to higher CO₂ fertilization) will likely cause more frequent and more extensive fires throughout western North America (Flannigan et al. 2000, Price and Rind 1994). Fire responds rapidly to changes in climate and will likely overshadow the direct effects of climate change on tree species distributions and migrations (Dale et al. 2001, Flannigan et al. 2000, National Research Council 2011). A temporal pattern of climate-driven increases in fire activity is already apparent in the Western United States (Westerling et al. 2006). Modeling studies specific to California expect increased fire activity to persist and possibly accelerate under most future climate scenarios, owing to increased production of fuels under higher CO₂ (and in some cases, precipitation), decreased fuel moistures from warmer dry season temperatures, and possibly increased thundercell activity (Lenihan et al. 2003, 2008; Miller and Urban 1999; Price and Rind 1994; Westerling and Bryant 2006). By 2100, Lenihan et al.'s (2003, 2008) simulations suggest about a 5 to 8 percent increase in annual burned area across California, depending on the climate scenario. Increased frequencies or intensities of fire in coniferous forest in California will almost certainly drive changes in tree species compositions (Lenihan et al. 2003, 2008), and will likely reduce the size and extent of late-successional refugia (McKenzie et al. 2004, USDAFS and USDI 1994). Thus, if fire becomes more active under future climates, there may be significant repercussions for old-growth forest and old-growth-dependent flora and fauna.

A key question is to what extent future fire regimes in montane California will be characterized by either more or less severe fire than is currently (or was historically) the case. Fire regimes are driven principally by the effects of weather/climate and fuel type and availability (Bond and van Wilgen 1996). Seventy years

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of effective fire suppression in the semiarid American West have led to fuel-rich conditions that are conducive to intense forest fires that remove significant amounts of biomass (Arno and Fiedler 2005, McKelvey et al. 1996, Miller et al. 2009). Most future climate modeling predicts climatic conditions that will likely exacerbate these conditions. Basing their analysis on two GCMs under the conditions of doubled atmospheric CO₂ and increased annual precipitation, Flannigan et al. (2000) predicted that mean fire severity in California (measured by difficulty of control) would increase by about 10 percent averaged across the state. Vegetation growth models that incorporate rising atmospheric CO₂ show an expansion of woody vegetation on many Western landscapes (Hayhoe et al. 2004; Lenihan et al. 2003, 2008), which could feed back into increased fuel biomass and connectivity and more intense (and thus more severe) fires. Use of paleoecological analogies also suggests that parts of the Pacific Northwest (including northern California) could experience more severe fire conditions under warmer, more CO₂-rich climates (Whitlock et al. 2003). Fire frequency and severity (or size) are usually assumed to be inversely related (Pickett and White 1985), and a number of researchers have demonstrated this relationship for Sierra Nevada forests (e.g. Miller and Urban 1999, Swetnam 1993). However, if fuels grow more rapidly and dry more rapidly—as is predicted under many future climate scenarios—then both severity and frequency may increase, at least in the short term. In this scenario, profound vegetation-type conversion is likely. Lenihan et al.'s (2003, 2008) results for fire intensity predict that large proportions of the Sierra Nevada landscape may see mean fire intensities increase over current conditions by the end of the century, with the actual change in intensity depending on future precipitation patterns.

Vegetation

Lenihan et al. (2003, 2008) used a dynamic ecosystem model (“MC1”) that estimates the distribution and productivity of terrestrial ecosystems such as forests, grasslands, and deserts across a grid of 100 km² (38.6 mi²) cells. To date, this is the highest resolution at which a model of this kind has been applied in California. Based on their modeling results, Lenihan et al. (2003, 2008) projected that forest types and other vegetation dominated by woody plants in California would migrate to higher elevations as warmer temperatures make those areas suitable for colonization and survival. For example, with higher temperatures and a longer growing season, the area occupied by subalpine and alpine vegetation was predicted to decrease as evergreen conifer forests and shrublands migrate to higher altitudes (fig. 3-3). Under their “wetter” future scenarios (i.e., slightly wetter or similar to today), Lenihan et al. (2003, 2008) projected a general expansion of forests in the Sierra Nevada, especially in the north and at higher elevations. With higher rainfall and

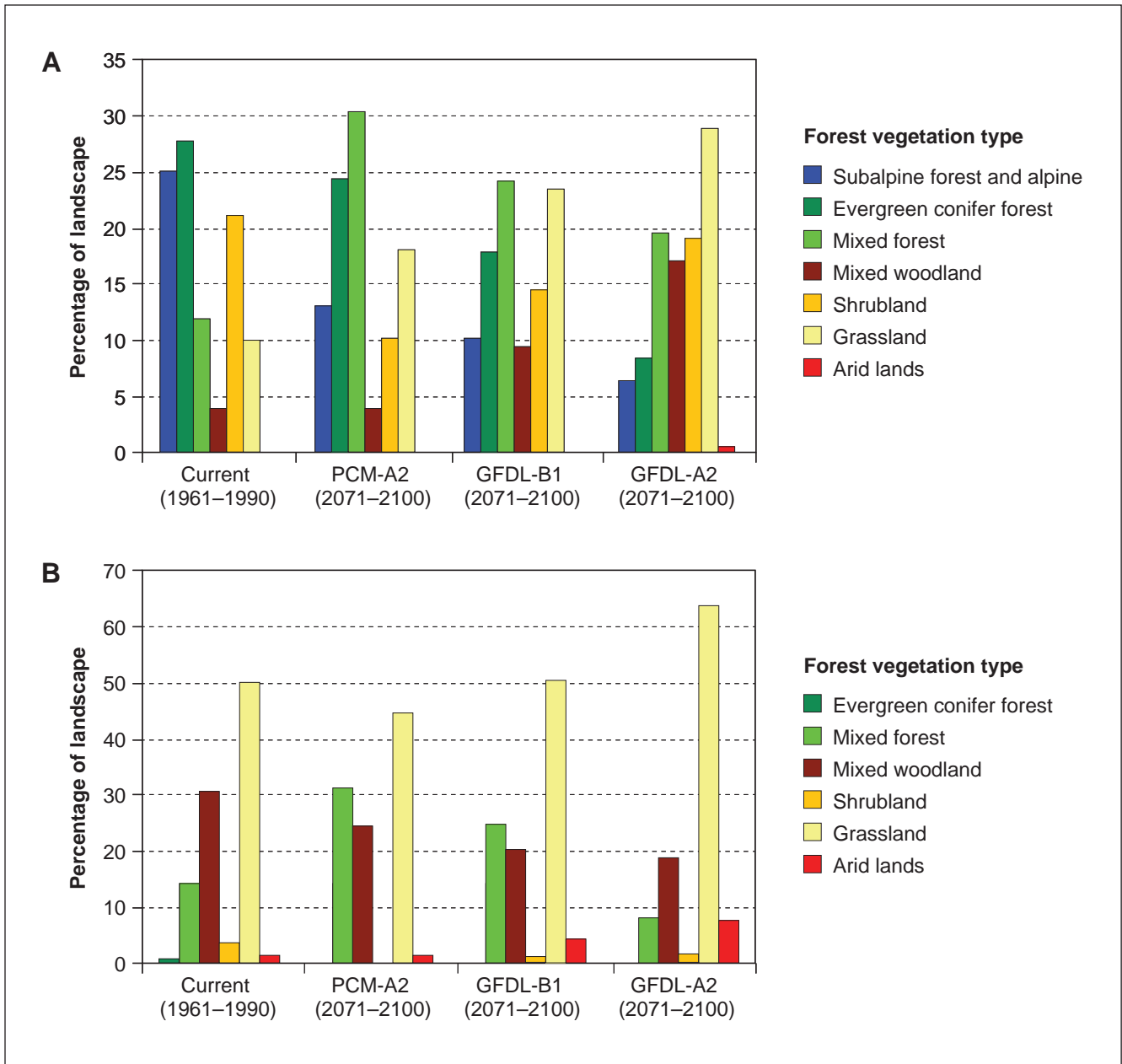


Figure 3-3—MC1 outputs for the Sierra Nevada (A) and Sierra Nevada Foothills (B) ecological sections, current vs. future projections of vegetation extent. These ecological sections include most of the Sierra Nevada west slope. The PCM-A2 scenario = similar precipitation to today, with <math><5.5\text{ }^\circ\text{F}</math> (<math><3.1\text{ }^\circ\text{C}</math>) temperature increase; GFDL-B1 = moderately drier than today, with a moderate temperature increase (<math><5.5\text{ }^\circ\text{F}</math>) (<math><3.1\text{ }^\circ\text{C}</math>); GFDL-A2 = much drier than today and much warmer (>math>>7.2\text{ }^\circ\text{F}</math>) (>math>>4\text{ }^\circ\text{C}</math>). All scenarios project significant loss of subalpine and alpine vegetation. Most scenarios project lower cover of shrubland (including west-side chaparral and east-side sagebrush), resulting principally from increasing frequencies and extent of fire. Large increases in the hardwood component of forests are projected in all scenarios except for the hot-dry scenario in the foothills. Large increases in cover of grassland are projected for the Sierra Nevada section. The drier scenarios project moderate expansion of arid lands. In the Sierra Nevada section, conifer forest decreases in cover under all scenarios. (Graphic developed using data from Lenihan et al. 2008.)

higher nighttime minimum temperatures, broadleaf trees (especially oak species) were predicted to replace conifer-dominated forests in many parts of the low- and middle-elevation Sierra Nevada. Under their drier future scenarios, Lenihan et al. (2003, 2008) predicted that grasslands would expand, and that increases in the extent of tree-dominated vegetation would be minimal. An expansion of shrublands into conifer types was also predicted, owing to drought and increases in fire frequency and severity, but increasing fire frequency in the Sierra Nevada may replace much low- to middle-elevation shrubland with grassland (fig. 3-3). Hayhoe et al. (2004) also used the MCI ecosystem model to predict vegetation and ecosystem changes under a number of different future greenhouse gas emissions scenarios. Their results were qualitatively similar to the Lenihan et al. (2003, 2008) results.

Wildlife

Projected changes in California's terrestrial fauna and flora are expected over the next century. Stralberg et al. (2009) developed current and future species distribution models for 60 focal bird species and found that novel avian assemblages with no modern analogy could occupy over half of California. This implies a dramatic reshuffling of avian communities and altered pattern of species interactions, even in the upper elevations of the Sierra Nevada, where only a modest proportion of novel avian communities were projected. Using species distribution modeling, the California Avian Data Center (2011) projected that approximately 60 percent of coniferous forest bird species in the Sierra Nevada will exhibit substantial range reductions within the next 40 to 90 years (using 21 focal avian species). Based on bioclimatic models, Lawler et al. (2009a,b) projected high (>50 percent) turnover and vulnerability of California's amphibian fauna and moderate (10 to 40 percent) turnover in California's mammalian fauna under a high greenhouse gas emissions scenario by the end of the century. In a similar study, Loarie et al. (2008) projected that 66 percent of California's native flora will experience >80 percent reduction in range size within a century. Their study identified the southern Sierra Nevada and the coastal mountains of northwest California as climate change refugia, defined as areas projected to harbor species with shrinking ranges (presumably retaining subsets of regional species assemblages over time). Authors from these studies recommended novel adaptive management approaches and large-scale planning efforts that promote landscape/regional habitat connectivity. Loarie et al. (2008) also recommended serious consideration of human-assisted dispersal of California's flora and prioritization of climate change refugia for conservation and restoration.

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Is History Still Relevant?

In the Sierra Nevada, much has been made of the drastic ecosystem changes wrought by Euro-Americans since their arrival en masse in California in the mid-19th century. Numerous scientific studies have documented these changes, which result from—among other things—changed fire regimes, logging, livestock grazing, mining, agriculture, hunting, growing human populations and their infrastructure, air and water pollution, species introductions, water diversion, and, most recently, climate warming. In lower and middle-elevation forests of the Sierra Nevada, the combined impacts of these human influences have resulted in significant habitat loss in some forest types (oak woodlands and low-elevation riparian forests, for example), and major changes in forest composition and structure in others (e.g., in many conifer-dominated forest types at lower and middle elevations, especially yellow pine [ponderosa and Jeffrey pine] and mixed-conifer forests). Higher elevation forests, especially in the subalpine zone, have suffered much less from human impacts.

In the face of this ecosystem degradation, there is an understandable tendency to “get back to the good old days.” In this school of thought, ecosystem status before the arrival of Euro-Americans is assumed to be optimal, while current conditions are impaired. The goal then is to return the ecosystem to its historical state, trajectory, or range of variation (HRV) before Euro-Americans arrived. This approach has been a foundation for conservation, preservation, and restoration management in the United States, but rapidly and profoundly shifting environmental baselines threaten our ability to continue this approach (Craig 2010; Harris et al. 2006; Millar et al. 2007; Stephenson et al. 2010; White and Walker 1997; Wiens et al., in press).

The major concern is that intrinsic assumptions of environmental “stationarity” that pervade traditional conservation, preservation, and restoration practices are no longer valid (if they really ever were) (Craig 2010; Milly et al. 2008; Wiens et al., in press). “Stationarity” is the idea that:

“...the long-term mean is more or less invariant and the range of past conditions encompasses current and future conditions as well. The reasoning is that, although true environmental stationarity may not exist over the long term, the periodicity or rate of change may be slow enough compared to human experience to permit the useful assumption of stationarity” (Safford et al., in press).

With environmental conditions changing as rapidly and as extensively as they are, critics question the relevance of applying historically based targets in environments that are fundamentally different from what they were in the past.

Conservation and resource management often focuses on preservation of specific species, species assemblages, or a relatively static notion of the habitat required to maintain populations. In light of rapid global change, an alternative perspective is developing, one that is more focused on management of ecosystem structure and process rather than specific species or their habitat.

Given all of this change, are historical forest conditions irrelevant? Absolutely not! However, the way that history is used in ecosystem management, restoration or conservation should change. For example, the HRV concept was developed to ensure that ecosystem functions, especially disturbance processes, were incorporated into management (Landres et al. 1999, Morgan et al. 1994). However, as currently practiced, conservation and resource management often focuses on preservation of specific species, species assemblages, or a relatively static notion of the habitat required to maintain populations. In light of rapid global change, an alternative perspective is developing, one that is more focused on management of ecosystem structure and process rather than specific species or their habitat (Harris et al. 2006, Hunter et al. 1988, Stephenson et al. 2010). This perspective emphasizes the ecological function or ecological integrity of a site, and is less concerned with the identities, numbers, or arrangements of biota.

In this changed management environment, the role of historical ecology is to inform a management response to global change rather than resisting global change. Historical ecology can, among other things, identify important broad-scale and long-term processes that influence local ecological outcomes under different climate conditions or disturbance regimes. Historical conditions also can provide clues to mechanisms underlying ecosystem dynamics and resilience (i.e., Why have some systems persisted through climatic changes in the past?), guide the development and validation of predictive models, suggest appropriate future trajectories, define parameters by which we will recognize “properly functioning” ecosystems, help us to operationally define concepts like “ecological integrity” and “resilience,” allow us to determine expected levels of ecosystem services, and inform us if current conditions are anomalous and worthy of management intervention (Landres et al. 1999; Millar and Woolfenden 1999; Safford et al., in press a and b; Swetnam et al. 1999). In essence, historical ecology represents our clearest window into ecological patterns and processes that occur at temporal scales beyond the scope of human observation.

Forest Heterogeneity and Climate Change

Given the uncertainties associated with climate change, focusing on the reduction or removal of nonclimate stressors can be prudent management. Historical conditions in active-fire forests suggest burning created fine- and large-scale heterogeneity in stand structure, wildlife habitat, fuel loads, and understory conditions. Human management of Sierra Nevada forests over the last century and a half has greatly reduced this heterogeneity. It is difficult to quantify forest heterogeneity from limited historical data, and unlikely that frequent fire would reproduce the

same forest structure under current conditions. However, management practices following those in U.S. Forest Service General Technical Report PSW-GTR-220 that increase variation in forest conditions may help increase forest resilience to changes in climate and climate-related processes such as fire. For example, variation in stem density and fuel loads can limit the extent and severity of drought stress and high-severity fire, such that resulting mortality contributes to forest heterogeneity. Many fire-suppressed forests are now in an “alternative stable state” where disturbance, whether a result of beetle, drought, or fire mortality, tends to reinforce current structural and compositional homogeneity. Such uniform conditions promote low resilience to disturbances and projected changes in climate. A goal of current management could be to alter forest conditions past a threshold where disturbance processes act to increase rather than reduce forest heterogeneity. Heterogeneity in structure, function, and composition can provide ecosystems with the ecological “flexibility” (Holling 1973) to withstand and persist through both expected and unexpected environmental stresses.

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