

Section 6. Responding to Disturbances

Chapter 6.1. Ecological Disturbance in the Context of a Changing Climate: Implications for Land Management in Northeastern California

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Introduction

Ecosystems of the Lassen and Modoc National Forests depend on disturbance as part of the natural process. However, climate change, a source of disturbance itself, has also been changing patterns of other ecological disturbances, including the frequencies and intensities of fire, pests, and pathogens. This chapter presents a review and synthesis of peer-reviewed literature focused on natural disturbance processes and how those processes relate to and interact with a changing climate. The chapter begins with an overview of different ways climate change can impact the ecosystems of these two national forests in relation to current versus past evidence of climate change, fire frequencies and intensities, changes in patterns of snowfall and snow melt, tree and plant distributions, and insects and pests. Impacts on animal species, particularly species of concern are discussed, along with effects on aquatic systems. The chapter concludes with a discussion of impacts of climate change on seeding projects.

As discussed in Chapter 1.1 (Dumroese, this synthesis, *The Northeastern California Plateaus Bioregion Science Synthesis: Background, Rationale, and Scope*), two other science syntheses have relevance for the Lassen and Modoc National Forests (hereafter the Lassen and the Modoc), namely the *Science Synthesis to Support Socioecological Resilience in the Sierra Nevada and Southern Cascade Range* (hereafter, Sierra Nevada Science Synthesis) (Long et al. 2014a) and *Synthesis of*

Science to Inform Land Management within the Northwest Forest Plan Area (hereafter, Northwest Forest Plan Science Synthesis) (Spies et al. 2018). Both syntheses have extensive discussions pertaining to changes in climate (table 6.1.1). Thus, for this chapter, the discussion is primarily on how changes in climate affect other disturbances, such as fire, pests, and restoration for the Lassen and Modoc ecosystems not covered extensively by the other two syntheses.

Overview

Climate change on the Lassen and Modoc is anticipated to impact a number of resources on the forests and their associated plants and animals. First, the discussion focuses on recent studies and science syntheses that include climate models that present potential climate alternative futures for the Lassen and Modoc. Second, these models are put into an historical context, examining the evidence showing how the climate in the study area has changed during the last several thousand years.

Cayan et al. (2008) modeled a set of future climate alternatives for California based on International Panel on Climate Change (IPCC) emissions scenarios. For Northern California, all models show rising temperatures with precipitation expected to remain steady or decrease slightly and continue to follow a Mediterranean pattern, with most precipitation falling in the winter months. Given warmer temperatures, less precipitation is expected to fall as snow. However, Allen and Luptowitz (2017), using a set of newer models, show that precipitation in California may, in fact, increase under climate change because of higher ocean temperatures and shifting precipitation patterns.

In this chapter, discussion focuses mainly on climate change impacts to the parts of the Lassen and Modoc considered to be part of the Great Basin. As stated earlier, other areas of these Forests have already been addressed in the Sierra Nevada Science Synthesis and the Northwest Forest Plan Science Synthesis. The Sierra Nevada Science Synthesis notes that the local climate has already changed during the last 80 years, with warmer temperatures and more frequent drought. With warmer temperature comes less precipitation as snow, and spring thaws that occur earlier, which, in turn, extends the fire season. Many studies also suggest changes in vegetation across the Sierra

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Table 6.1.1—Summary of climate change topics contained within the Sierra Nevada Science Synthesis and the Northwest Forest Plan Science Synthesis.

Sierra Nevada Science Synthesis	
Chapter	Topic
1.4	Forest management issues and research needs
3.1	Seed transfer implications
6.1	Potential impacts on stream flow and temperature; changes in precipitation from snow to rain
7.1	Potential impacts on marten (<i>Martes caurina</i>) and fisher (<i>Martes pennant</i>)
7.2	Potential impacts on California spotted owl (<i>Strix occidentalis occidentalis</i>)
8.1	Interactions with air pollution
9.3	Public perceptions of climate change
9.4	Rural economy resilience
Northwest Forest Plan Science Synthesis	
2	Potential impacts on vegetation, modeling effects, potential management responses, and research needs
3	Impacts on old-growth forests
4	Anticipated effects on northern spotted owl (<i>Strix occidentalis caurina</i>) habitat
5	Anticipated effects on terrestrial nesting habitats and marine food resources critical to the marbled murrelet (<i>Brachyramphus marmoratus</i>)
6	Effects on old-growth forest biodiversity with discussion on amphibian communities and connectivity for carnivores
7	Potential impacts on aquatic systems with specific attention to Salmonids
8	Socioeconomic well-being
9	Changing public values, for example, as it pertains to recreation
10	Environmental justice issues
11	Changes to tribal ecocultural resources and engagement
12	Climate change uncertainties and research needs

Nevada, with an increase in oaks and other broadleaved trees. Subsequently, in Chapter 1.4 of the Sierra Nevada Science Synthesis, Jardine and Long (2014) present a set of management issues and research needs, all of which are relevant to the Lassen and Modoc:

- **“Recognize and address scale mismatches.**
- **Consider long-term (more than 50 years) risks** in addition to short-term (less than 10 years) expected outcomes.
- **Set adaptable objectives and revisit them,** because there may be a lack of clear solutions, certain options may prove unrealistic, and new opportunities may become apparent as conditions change.
- **Rely more on process-based indicators than static indicators of structure and composition, while recognizing that restoration of structure and process must be integrated.**

- **Integrate valuation tools, decisionmaking tools, modeling, monitoring, and, where appropriate, research** to evaluate responses and better account for the risks and tradeoffs involved in management strategies.
- **Consider the integrated nature of socioecological systems;** approaches that address only one dimension of a problem are less likely to succeed in the long run than strategies that consider ecological, social, economic, and cultural components.
- **Use participatory and collaborative approaches to facilitate adaptive responses and social learning.”**

Evidence for Past Climate Change on the Lassen and Modoc

The climate in the Great Basin has changed dramatically since the Last Glacial Maximum and the beginning of the

Holocene approximately 20,000 years ago. Data from lake sediment cores, tree ring data, and packrat and woodrat (*Neotoma* species) middens have been used to develop an understanding of past climate. Each type of data has its strengths and limitations, but together they paint a clear picture that the climate has not remained stable in the Great Basin during the last 20,000 years; periods of drought, warming, and cooling have all been common. These data show changes spanning thousands of years, which is very different from the rapid changes in climate that are being observed today.

Lake sediment contains minerals, pollen, plant debris, and diatoms that can be dated using radioisotopes. These data can help indicate how hot or dry an area was in a given period of time. Benson et al. (2002) found that the Great Basin was cooler in the early Holocene (11,600 to 8,000 years ago), followed by a warmer, and particularly dry, middle Holocene (8,000 to 3,000 years ago). Using pollen

cores collected from lakes across the Great Basin, Mensing et al. (2008, 2013) found evidence for an extended drought from 2,800 to 1,850 years ago and a number of drought events each lasting 50 to 100 years since then. Despite this, the forest composition has remained relatively stable for the past 4,300 years near Paterson Lake in Northern California and the vegetation surrounding Lily Lake on the California-Oregon boundary has not changed for more than 10,000 years (Minckley et al. 2007). Comparing sediment cores from lakes across the Great Basin, Wahl et al. (2015) note that the Western and Eastern Great Basin have experienced different climate histories, in part due to the influence of the Pacific Ocean, particularly during the last 2,000 years (fig. 6.1.1).

Tree ring data from long-lived species provide another line of evidence for changing climates in the Great Basin. Salzer et al. (2014) documented changes in temperature during the last 5,000 years based on tree ring data from

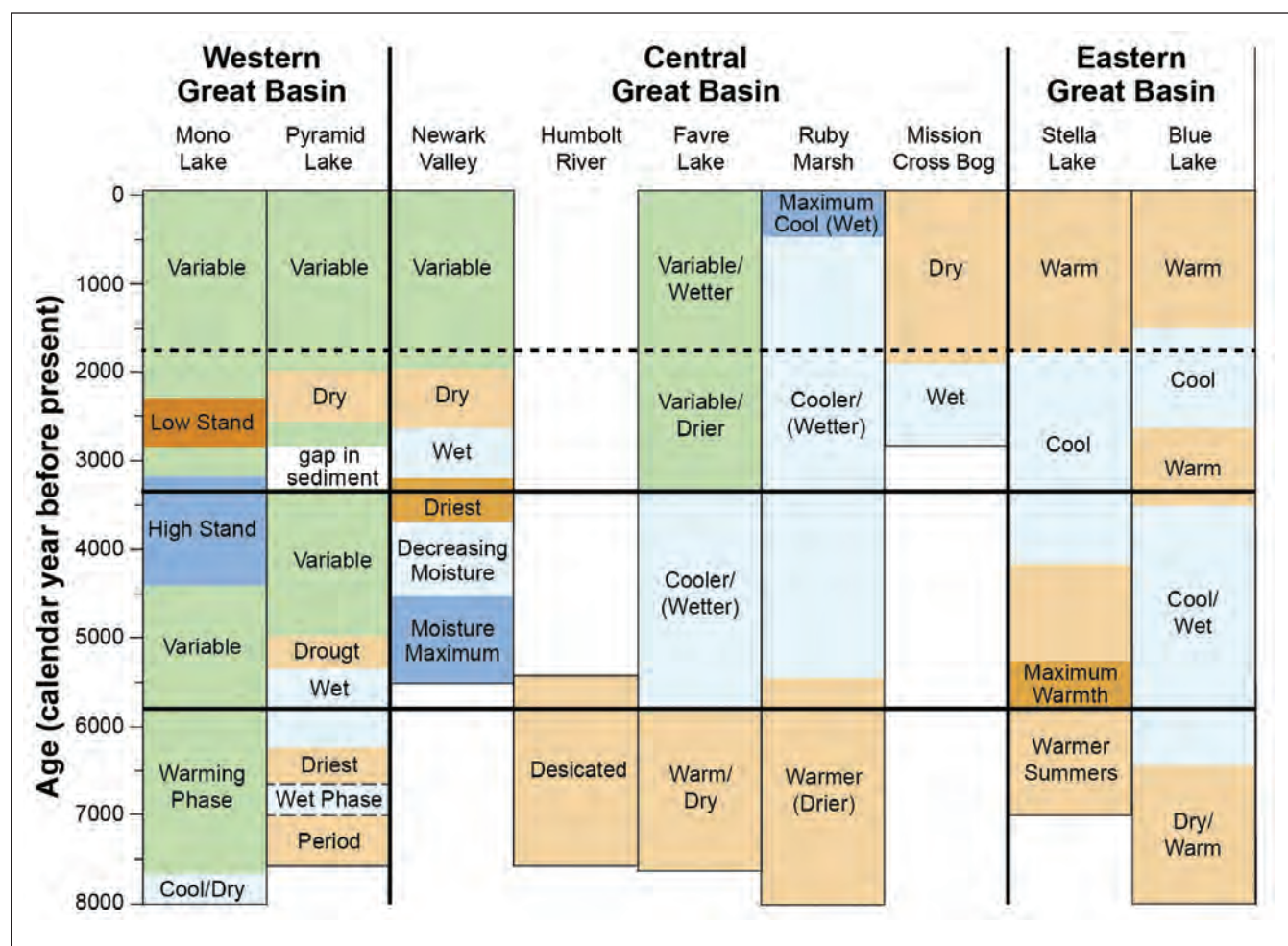


Figure 6.1.1—Sediment core data reveals that climate across the Great Basin has varied spatially and temporally during the past 8,000 years (modified from figure 10 in Wahl et al. 2015).

Great Basin bristlecone pine (*Pinus longaeva*) trees in Nevada. Ring data show that the tree line reached a maximum elevation approximately 5,000 years ago, with the current tree line established in the 1300s. Tree ring data show that since 1900, temperatures have dramatically increased, and are hotter than at any time since 850 CE.

Rodents, such as packrats and woodrats, often make large garbage piles, or middens. These locations can be occupied by the rodents for tens of thousands of years, and the middens become records of the plant community in an area during the period of occupation. Becklin et al. (2014) point out that atmospheric carbon dioxide concentrations were lowest (180 ppm) during the Last Glacial Maximum (21,000 years ago) and are now above 400 ppm. Concurrent with this increase in carbon dioxide concentration, packrat middens show, as evidenced through carbon isotopes of plant material, that the plant community has changed dramatically. In the Reno, NV, area, woodrat middens at different elevation sites showed two very different tree responses to a changing climate: Utah juniper trees (*Juniperus osteosperma*) tended to persist in the same locations and were therefore able to tolerate a range of climates, while singleleaf piñon (*Pinus monophylla*) has changed its distribution over time, disappearing in locations with unsuitable climate (Nowak et al. 1994).

Animal populations also changed throughout the Holocene. Caves where owls have roosted for years are an excellent source of information about these communities. Owl pellets contain small-mammal bones, which can often be identified to species and dated to get a picture of the fauna in a given area at a given time. Grayson (2000) reviewed mammal diversity during the Middle Holocene (8,000 to 5,000 years ago), a period warmer and drier than the time before and after it. Mammal diversity decreased during this period, with kangaroo rats (*Dipodomys* species) becoming much more common as conditions became more arid. Genetic data suggest that kangaroo rats have remained within their current geographic distribution since the Last Glacial Maximum despite changes in climate across the Great Basin, suggesting that they adjusted their niche to survive in whatever the local climate was (Jezkova et al. 2011).

Human settlements were found throughout the Great Basin during the Holocene and have received much research attention. Excavations from a human settlement in Long

Valley, NV, as well as other records, showed that the end of the Pleistocene was in a warming trend associated with abundant moisture, and several very large lakes occurred in the Great Basin. This was followed by a cooling trend and then a drying trend until 4,000 years ago, when moisture levels increased once again (Huckleberry et al. 2001). The Younger Dryas period (12,900 to 11,600 years ago) was characterized by cooler temperatures and more available water (Goebel et al. 2011). Many human settlements existed in the Great Basin at that time, though some settlements appear to be more temporary, suggesting a more mobile lifestyle. Vegetation was dominated by sagebrush and grasses. Greater sage-grouse (*Centrocercus urophasianus*) was a common item in the human diet, as were grasshoppers (*Caelifera*), pronghorn (*Antilocapra americana*), mule deer (*Odocoileus hemionus*), and bighorn sheep (*Ovis canadensis*) (Goebel et al. 2011). Jones and Schwitalla (2008) examined the Medieval Climate Anomaly that led to three strong periods of drought in California between 1000 and 1375 CE and found evidence from across California for widespread movement in human populations during that time and that diets changed and health problems increased.

Together these various sources of data about historical climate provide a consistent picture of climate transitions across the Great Basin since the Last Glacial Maxima. They also put the current changes in climate being observed into a historical perspective. The historical climate of the Lassen and Modoc was also reviewed by Merriam et al. (2013) as part of the Forest Revision Planning process. Reviewing weather station and PRISM data, they discuss the historic range of variation for several important climate variables. Their analysis showed that temperatures have increased by 1.7 to 2 °F (0.9 to 1.1 °C) and precipitation has remained steady since 1895.

Projected Climate Change Effects on the Lassen and Modoc

Projecting forward, one recent study shows some interesting insight. Wintertime temperature and precipitation, using oxygen isotopes found in cave stalagmites in the Great Basin, reflect levels of arctic ice for the last 160,000 years. If levels of arctic ice decline as predicted as a result of a changing climate, then more warming and drying trends in the Great Basin can also be anticipated (Lachniet et al. 2017).

Snowpack Accumulation and Melt

Climate change is expected to have a dramatic impact on snowpack depth and subsequent melting in the Lassen and Modoc. Warmer temperatures are expected to cause more precipitation to fall as rain rather than snow resulting in reduced snowpack, and warmer temperatures occurring earlier in spring are expected to melt that limited snowpack faster (fig. 6.1.2). Indeed, this trend is being observed in weather station data (reviewed in Merriam et al. 2013). This may have implications for the plants associated with the Lassen and Modoc. A number of studies, reviewed below, have looked at how reduced snowpack influences growth and ecophysiological traits (traits of adaptation of an organism's physiology to environmental conditions) of woody sagebrush steppe species.

Various studies have manipulated how much moisture is available for plants by changing snow depth, temperature, and rain fall capture. These manipulation studies have been useful for understanding the response of ecophysiological traits to changes in water availability. There were no differences in stem water relations and photosynthetic gas exchange in big sagebrush (*Artemisia tridentata*) and bitterbrush (*Purshia tridentata*) among snow depth treatments within a year (Loik et al. 2015) but much difference associated with year-to-year precipitation (Loik et al. 2015). These results may be different at higher elevations. In a long-term heating experiment on an alpine meadow in Colorado, Perfors et al. (2003) found that big sagebrush had increased growth rates in heated plots associated with an earlier snow melt date but Roy et al. (2004) note an increase in herbivory of big sagebrush associated with the earlier snow melt date. In a study in Oregon, Bates et al. (2006) manipulated patterns of seasonal precipitation in a natural sagebrush ecosystem. They changed when plants received the most water—winter, spring, or fixed (receiving the same as the average rainfall in the last 50 years)—and then measured the response in the plant community. Big sagebrush did not show changes in abundance across precipitation treatments, but when most of the rain fell in the spring, plants had higher reproductive success. Further, Gillespie and Loik (2004) looked at pulses of precipitation by simulating a summer rainstorm (predicted to be more common under future climate) and suggested that seedlings of big sagebrush, because of an ability to maintain higher photosynthetic rates through better use of pulse events of precipitation, may cope with climate change better than seedlings of bitterbrush. Enhanced photosynthesis would



Figure 6.1.2—The potential changes to snowpack depth and its seasonal longevity (A), monitored on the Lassen and Modoc (B), expected to occur because of changing climate may have profound effects on water availability and plant distribution (photo A by Debbie Mayer, Forest Service; photo B by Forest Service).

allow the sagebrush to allocate more carbohydrates to root production and thereby increase water and nutrient acquisition. Together, these results suggest changes in precipitation patterns under climate change will influence the fitness of sagebrush plants.

A strong relationship exists among habitat type, climate change, and snowfall. Bradford et al. (2014), with ecohydrological modeling, found that warming temperatures changed how much precipitation fell as snow in a sagebrush steppe and adjoining lodgepole pine (*Pinus contorta*) ecosystems in Colorado, and as a result,

the availability of that water to plants changed as well. There were differences among the ecosystems with climate change scenario, impacting drainage and transpiration. Under the IPCC's A2 "business as usual" future climate scenario, the ecohydrology of the lodgepole pine system more strongly resembled that of the sagebrush steppe, suggesting potential vegetation transitions. Kormos et al. (2017), looking at juniper encroachment just east of the Idaho and Oregon border, examined the relationship between the amount of snow accumulating in sagebrush habitat versus juniper habitat. Their models showed more snow accumulation in the juniper woodlands compared to open sagebrush habitat but that the additional snow melted earlier. Thus, juniper encroachment into sagebrush habitat changes the water balance and overall ecohydrology of the system, and reduces foraging and nesting resources available for greater sage-grouse (Connelly et al. 2011; Miller et al. 2011, 2017). Similar results were found by Roundy et al. (2014), with more water available for plant growth when trees were removed from sagebrush habitat.

Insect and Disease

Bark Beetles

Although damage in 2016 from drought and bark beetles on the Lassen and Modoc was extensive, given the lower amount of forested land area, these patterns of tree mortality were, in general, less when compared to Southern California. The U.S. Department of Agriculture, Forest Service, published a bark beetle forecast map for California (<https://usfs.maps.arcgis.com/apps/MapJournal/index.html?appid=7b78c5c7a67748808ce298efefceaa46>) that, for 2017, predicted tree mortality was not expected to increase on the Lassen and Modoc. The forecast also shows declines in the southern part of the State, where much more extensive damage has occurred.

Modeled projections by Bentz et al. (2010) for the Western United States suggested little change in regards to the probability of a bark beetle outbreak on the Lassen and Modoc, even under warming temperatures for the next century. The interaction of climate, insects, and tree mortality is, however, complex. Creeden et al. (2014) note that for several forests suffering bark beetle outbreaks, the climate and weather differed, which affected the reproduction and winter survival of the beetles and the drought stress of host trees. Thus, Anderegg et al. (2015) argue for a multifaceted approach to account for different responses by the insects and trees to climate drivers.

Forest management and treatments (i.e., thinning and controlled burning) can affect bark beetle populations. On the west slope of the Warner Mountains of the Modoc, Egan et al. (2010) found less tree mortality caused by fir engraver beetles (*Scolytus ventralis*) and mountain pine beetles (*Dendroctonus ponderosae*) in pre-commercially thinned plots compared to nonthinned plots. On the Klamath National Forest, while results were not significant, a trend for less mortality in thinned plots was also observed (Fettig et al. 2010). Multiple studies have, however, observed an increase in insect-related tree mortality in plots that had been burned, either with or without thinning (Fettig et al. 2010; Fettig and McKelvey 2010). For example, Fettig and McKelvey (2010) saw a dramatic increase in beetle mortality in burned plots on the Lassen, where trees in burned plots had higher mortality due to beetle attack immediately after burning. Adjacent, unburned plots had higher levels of attack 3 to 5 years after treatment, likely because beetles moved off the burned areas to the neighboring, unburned, plots. These results led Fettig and McKelvey (2010, p. 37) to note, however, that "unburned areas (split plots) were adjacent to burned areas (split plots) that likely served as an important source of beetles once the abundance of fire-injured trees that were highly susceptible to bark beetle attack declined."

While shifts in climate are expected to allow pine beetles to move uphill, and inhabit novel territory, studies in Great Basin of high-elevation bristlecone pine have shown that this species is not often chosen for oviposit by mountain pine beetles, but when eggs are laid, the resulting larvae do not develop, suggesting this pine may have resistance to the insect (Eidson et al. 2017, 2018).

Aroga Moths

Aroga moth (*Aroga websteri*), also known as the sagebrush defoliating moth, can kill sagebrush plants after a single season of defoliation. They occur in outbreaks (irruptions) throughout the Great Basin, and how the frequency of these irruptions will change under climate change is uncertain. In Utah, Bolshakova and Evans (2014) found that sagebrush growing on north-facing slopes with lower incident solar radiation made good habitat for the moths, conditions not expected to be altered under climate change. The suitability of habitat for the moths might change, however, as temperatures associated with different slopes, aspects, and elevation change. Indeed, further study showed that years with high precipitation in June and July—corresponding to late-stage larval development—

was associated with population irruptions (Bolshakova and Evans 2016).

Nursery Pathogens

Nurseries can, because they are monocultures of plants, provide ideal environments for pathogens to develop. Diseases can be spread from nurseries to natural areas. In the United States, diseases can be introduced from outside our borders (Liebhold et al. 2012), or be common, widespread, indigenous diseases found naturally in our Nation's forests and spread by windborne spores (e.g., fusiform rust in the South and Diplodia blight in the Midwest), or be ubiquitous, common nursery diseases not found in natural areas. For some diseases, infected seedlings subsequently have reduced survival and growth when outplanted on restoration sites in natural areas (Stanosz and Carlson 1996; Palmer et al. 1988; Powers et al. 1981). For other diseases, infected nursery stock that otherwise meets quality standards for outplanting survives and grows well in the forest and the disease organisms rapidly disappear (Dumroese et al. 1993, 2000; Smith 1967).

Globally, diseases caused by *Phytophthora* species are garnering more attention because of their potential to harm natural areas. For example, a *Phytophthora* introduced to Australia through nursery stock threatens one of the world's most biologically diverse areas by driving some species to extinction (Shearer et al. 2007). In California, the most well-known *Phytophthora* is *P. ramorum*, which causes sudden oak death. Since its detection 2 decades ago, the amount of worldwide research into this *Phytophthora* species has grown exponentially, and in the United States, escalated in 2004 after nurseries shipped stock contaminated with sudden oak death nationwide (Stokstad 2004).

Phytophthora species, commonly found in nurseries (Jung et al. 2016) including those in the West (Dumroese and James 2005), are commonly called "water molds" because they thrive in moist conditions and their spores are unusual in that they can swim through films of water on leaves or through water-filled pores in the soil. Thus, in nurseries that grow seedlings in containers (container nursery), use excessive irrigation and place containers on the ground, or nurseries that grow plants in soil (bareroot nursery) and use excessive irrigation or have poorly drained soils, *Phytophthora* easily moves from plant to plant. Unfortunately, infected but symptomless plants

escape detection and can spread the disease (Migliorini et al. 2015; Simamora et al. 2017). Indeed, *Phytophthora* species have been found in native plant nurseries and on restoration sites in California (Rooney-Latham et al. 2015). Once introduced into natural areas, these pathogens are most likely impossible to eradicate (Hillman et al. 2016). In nurseries, *Phytophthora* diseases, like all other root diseases, can be effectively managed by using integrated pest management techniques with an emphasis on sanitation (Dumroese 2012). The Phytophthoras in Native Habitats Work Group (www.calphytos.org) provides extensive best-management practices for nurseries and land managers to reduce threats from introductions of potentially devastating *Phytophthora* species. Fortunately, the Lassen and the Modoc are in a low risk area for sudden oak death (Koch and Smith 2012).

Tree and Shrub Range Changes

Niche modeling has provided a great deal of information about the distribution of species now, and their predicted distributions into the future. Schlaepfer et al. (2012a) developed an ecohydrological niche model (which included information on soil water availability to plants) for big sagebrush from across the Western United States, including Northeastern California, which the authors felt explained more about the biology of the species than a climate niche model alone, particularly under climate change. Given two future climate-change scenarios, Schlaepfer et al. (2012b) used species distribution models based on climate and hydrology to predict areas that will be suitable for sagebrush into the future, and found that the amount of area in Northeastern California that is appropriate for sagebrush is forecasted to decrease (fig. 6.1.3), though much will still be consistent with sagebrush habitat (see Chapter 4.3, Dumroese, this synthesis, *Sagebrush Rangelands and Greater Sage-grouse in Northeastern California*, for more discussion about sagebrush rangelands and greater sage-grouse). Still and Richardson (2015) modeled the niche of Wyoming big sagebrush (*A. tridentata wyomingensis*) and, for Northeastern California, noted that the area continues to be appropriate for Wyoming big sagebrush through anticipated climate change to 2050 and suggested that restoration efforts should focus on areas that are predicted to be appropriate for sagebrush into the future (fig. 6.1.4).

The ability for seeds to move across the landscape and germinate will be important as ranges shift under climate change. Schlaepfer et al. (2014) modeled germination in



Figure 6.1.3—Models of climate and species distribution suggest that the area suitable for mountain big sagebrush, such as these growing in Eastern Lassen County, will decrease in Northeastern California (photo by Dawn M. Davis, used with permission).

big sagebrush and concluded that Northeastern California had consistently good conditions for germination to take place. Based on that study, Schlaepfer et al. (2015) modeled regeneration at leading- and trailing-edge populations and found one-third lower probabilities of recruitment at trailing-edge sites under current climate conditions, whereas leading-edge populations are predicted to have higher recruitment. Sagebrush seeds have been found in the local seed bank in Northeastern Nevada (Barga and Leger 2018), but work in Northeastern Montana at the range edge of big sagebrush habitat showed little germination of sagebrush seedlings from the seed bank (Martyn et al. 2016). These results of Martyn et al. (2016) support other, earlier findings of the short lifespan of sagebrush seeds in the seed bank (Meyer 1994; Young and Evans 1989). In Northeastern Nevada, shrub cover was the factor most associated with the size and content of the total (not just sagebrush) local seed bank (Barga and Leger 2018).

Empirical tests of the effects of warming on plant growth and species interactions have also contributed to our understanding of plant responses to climate change. Kopp and Cleland (2015) used artificial warming chambers on the Inyo National Forest to look at species interactions with sagebrush and a native plant, fiveleaf clover (*Trifolium andersonii*), which appears to be doing poorly under sagebrush encroachment. They show this clover had earlier flowering with warmer temperatures, but

that the presence of sagebrush changed the phenological response to warming as well as the number of flowers produced, suggesting the importance of including species' interactions as climate changes and species' range shifts in response to climate. Another, less-investigated aspect includes the diversity of fungal species living inside leaf tissue (endophytes). A study in Gambel oak (*Quercus gambelii*) found that endophytic communities varied based on solar radiation and, hence, climate, suggesting that climate change could impact these community interactions as well (Koide et al. 2017). Sagebrush plants are also subject to drought stress and drought-related mortality. Karban and Pezzola (2017), on sites near Truckee, CA, examined effects of drought on sagebrush during the 2010–2015 drought. By 2016, most of the observed plants had some branch mortality, and 14 percent, growing in a more competitive environment, had died. Branches that flowered more often suffered mortality the following year, and plants with more branches were able to keep a larger proportion of them alive through the drought.

The association between sagebrush and climate is complex, though precipitation has often been found to be an important driver. Several different lines of evidence show that the distribution and range of sagebrush are closely tied to climate. Climatic envelope modeling of the entire range of sagebrush (considering seven species and subspecies of *Artemisia*) showed that a range of predicted climate change impacts on sagebrush ecosystems on the Lassen and Modoc is possible, from low to very high (Bradley 2010). Dalgleish et al. (2011) used historical data from the U.S. Sheep Experiment Station in Idaho to examine the demographic rates and climate change impacts of two grasses—bluebunch wheatgrass (*Pseudoroegneria spicata*) and needle-and-thread grass (*Hesperostipa comata*)—as well as three-tipped sagebrush (*Artemisia tripartita*). They found that precipitation could have a potential impact on plant demography, particularly February and March snow, total annual precipitation as well as summer temperature. Annual growth rings in mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) in Colorado reveal this species is water limited and a decrease in mountain sagebrush growth with increasing temperatures under climate change is predicted (Poore et al. 2009). Similar results were found by (Apodaca et al. 2017) in Nevada, where the size of annual growth rings in big sagebrush was positively influenced by total annual precipitation, and negatively influenced by the mean maximum temperature during the growing season, suggesting slowing growth in a drier, warmer climate.

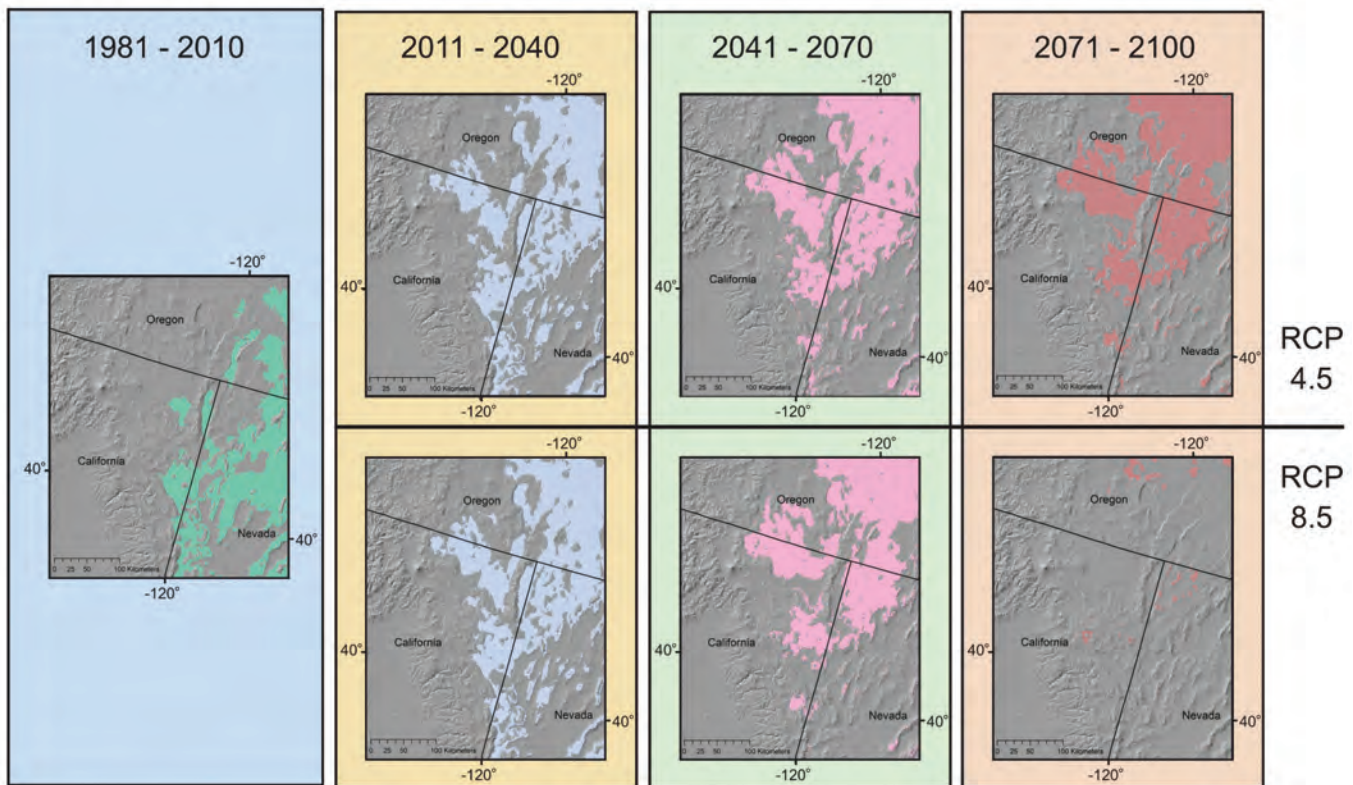


Figure 6.1.4—The climate niche for Wyoming big sagebrush under different climate projections in Northeastern California. Each panel represents a specific combination of Representative Concentration Pathway (RCP) and years. RCPs are projections of the trajectory of greenhouse gas concentrations and are expressed in terms of radiative forcing (the difference between incoming solar insolation and re-radiation of energy back into space). An RCP 8.5 scenario represents no change in the current rate of greenhouse gas emissions whereas the RCP 4.5 scenario reflects reductions in emissions from current rates. For each RCP, three 30-year increments are presented (adapted from Still and Richardson 2015).

Fire and Climate Change

The Sierra Nevada Science Synthesis (Long et al. 2014a) dedicates an entire section to fire in the Sierra Nevada, which is considered a fire-adapted system where historically fire played an important role in shaping and maintaining the ecosystem. Under predicted climate change, warmer, drier conditions are expected to lengthen the fire season and increase fire severity across the West. Not all models, however, provide the same fire predictions. While the models of Brown et al. (2004) and Stavros et al. (2014) both suggest an increase in fire activity because the fire season will start earlier and end later, they disagree on the frequency of very large wildland fires (VLWFs). Stavros et al. (2014), modeling across the West, predict more frequent VLWFs, whereas Brown et al. (2004), looking specifically at Northeastern California, predict a decline in VLWFs because of an anticipated decline in the number of extremely dry days having conditions conducive to large fires.

On the Lassen and Modoc, sagebrush habitats are also impacted by fire, but are not considered historically fire-adapted systems (Knapp 1996). The fire ecology of the region was described in detail by Riegel et al. (2006). The focus of this chapter is on the interaction between sagebrush and disturbances such as fire, invasive species, and climate change.

Fire Processes and Disturbance

In sagebrush habitats, fire cycles have changed since the introduction of cheatgrass (*Bromus tectorum*; Knapp 1996; Miller et al. 2011). Parks et al. (2015) looked at departure from the “expected” amount of fire to determine where fire deficits were occurring. The Great Basin landscape type in Northern California had a surplus of fire, that is, more acres burned than were predicted to burn. The authors showed an association between cheatgrass distribution in the Lassen and Modoc and increased fire frequency. In a review of fire effects on soils in sagebrush steppe, Sankey

et al. (2012) found that, before fire, soils under shrubs had more nutrients, and this did not change after fire. However, more intense fires caused greater soil temperatures that made soils more susceptible to erosion due to water. While herbaceous plants recovered from fire faster than shrubs, they remain easier to burn, which can result in more frequent fires. Patterns of precipitation can be used to model cheatgrass fire occurrence (Poore et al. 2009). The authors found that fire was more likely to occur in a dry year that followed several wetter years, which allowed for an accumulation of fine fuels from the cheatgrass.

Taylor et al. (2014) reviewed 18 studies to determine if cheatgrass was recruited after fire, and if the likelihood of that recruitment was associated with climate variables. Indeed, warmer and drier sites had the highest probability of a positive response by cheatgrass to fire. In Northeastern California, Coates et al. (2016) noted that increased precipitation may, in fact, result in less sagebrush, as fine-fuel densities (i.e., cheatgrass) increase with more precipitation, resulting in larger burned areas. Indeed, Wade and Loik (2017) found that cheatgrass is able to take advantage of a pulse of spring precipitation, as measured through carbon assimilation, compared to other native plant species.

Fire also shapes the distribution of species. Dodson and Root (2015) looked at postfire recovery after the Eyerly fire in Northern Oregon. They found an association with climatic moisture deficit and vegetation, with more native, perennial species in wetter locations. The authors state, “The strong pattern in the present observational study suggests that increasing temperatures and decreasing moisture availability may be key drivers of vegetation changes following wildfire in the future, but caution is warranted in extrapolating these results” (p. 672). They explain that the study area was unique, and different sites could show different results. Yang et al. (2015) modeled the distribution of quaking aspen (*Populus tremuloides*) in Northeastern Nevada and examined how the range of quaking aspen is expected change under climate change. Their models show that the land area occupied by quaking aspen is predicted to be reduced under climate change, however, when fire is included in the model, the area occupied by quaking aspen is larger. Finally, for five California tree species, Hood et al. (2010) created models for tree mortality based on extent of crown injury in response to fire: smaller sugar pine (*Pinus lambertiana*) trees were more often killed, whereas larger ponderosa

(*Pinus ponderosa*) and Jeffrey (*Pinus jeffreyi*) pines were more likely to succumb.

Managed Fire, Fuels Reduction

In some sagebrush communities, livestock grazing is an available approach to fuels management to reduce the risk or intensity of wildfire. According to Davies et al. (2009) livestock grazing started in sagebrush communities in the mid to late 1800s and is not considered a historical disturbance (see Chapter 3.1, Warren, this synthesis, *Perceptions and History of Rangeland*; Chapter 3.2, Dumroese, this synthesis, *Rangeland in Northeastern California*; and Chapter 3.3, Padgett, this synthesis, *Weeds, Wheels, Fire, and Juniper: Threats to Sagebrush Steppe*). Davies et al. (2009) compared grazing and fire disturbances on the vegetation at the Northern Great Basin Experimental Range, 56 km west of Burns, OR. Cheatgrass invaded the most in nongrazed and burned plots, while sagebrush densities decreased dramatically with burning, regardless of grazing treatment. Grazing disturbed the native plant community less than fire, the historical disturbance regime. In fact, this could be due to fuel loading resulting in more loss of native plants after fire. Davies et al. (2016) examined the relationship between winter grazing by cattle and fire intensity in Southeastern Oregon. They found it was an effective fuels reduction treatment for sagebrush, with a reduction in the amount of litter in the grazed plots, and a subsequent lower burning temperature. Diamond et al. (2009) also found an association with timing of grazing and a change in fire behavior, with lower flame lengths associated with the grazed plots.

Hurteau et al. (2014) reviewed the literature on fire in the Southwestern United States (Arizona, New Mexico, Nevada, and California). They discuss fire frequencies, suppression, climate and fire associations, vegetation, and climate change. Hurteau et al. (2014) also discuss management implications of projected increased fire frequencies under climate change, and the research that has gone into the idea to “restore fire as an ecologically beneficial process” (p. 286). They review the research behind several management practices, including forest thinning and prescribed burning, which they conclude “is the most effective means of reducing high-severity fire risk” (p. 286). Safford and Van de Water (2014) determined the Fire Return Interval Departure across California and found an average of 72 years for the Lassen and 50 years for the Modoc, noting that fewer fires are now occurring in these two national forests compared to pre-European settlement.

Postfire recovery in sagebrush habitats can require many years, or recovery to prior conditions may be impossible due to transitioning to an altered state (Knapp 1996). Moreover, different types of sagebrush habitats have different fire-return intervals, depending on sagebrush species and fire-return intervals (Miller et al. 2011). Ellsworth et al. (2016), working in Southcentral Oregon 17 years after a wildfire, found cheatgrass very common in all post-burning plots, but not in unburned controls. Shrub cover decreased dramatically after burns. However, early stages of recruitment were observed and young sagebrush plants were colonizing the plots. They felt there was “strong postfire resiliency” in their study system, and suggested fire suppression in sagebrush steppe habitats may not be “universally appropriate.” Haubensak et al. (2009) looked at salt deserts in Northern Nevada and found that 5 years after wildfire the local species, bud sagebrush (*Artemisia spinescens*, also referred to as *Picrothamnus desertorum*), was not found in the burned sites, potentially due to grazing, but that nonnative species abundance was much greater. Several guides for managing and restoring sagebrush ecosystems are listed in Chapter 3.2 (Dumroese, this synthesis, *Rangeland in Northeastern California*).

The relationship between plant species composition and fire has impacts on other species as well. MontBlanc et al. (2007) examined the association between piñon-juniper/shrublands and fire and ant species diversity in Central Nevada. They found more ants on plots that were burned than unburned, though species richness stayed the same. Elevation was the major driver of species compositional changes in ants at this site. “Our study results may indicate that burns conducted in a patchy, heterogeneous fashion can provide a variety of habitat conditions and facilitate the persistence of diversity in ant species” (p. 485).

Social Impacts of Smoke

The social impacts of smoke in California have been reviewed extensively in the Sierra Nevada Science Synthesis (Long et al. 2014a) as well as the Northwest Forest Plan Science Synthesis (Spies et al. 2018). Section 8 of the Sierra Nevada Science Synthesis addresses air quality in California and highlights research on social impacts of smoke from wildfires and prescribed fires, particularly in the Southern Sierra (fig. 6.1.5). They contrast wildfires with prescribed fires and point out that wildfires generally burn when fuels are drier, and thus produce more particulate matter, which are lofted higher into the atmosphere. Controlled fires often occur in moister, cooler conditions,



Figure 6.1.5—Smoke from wild and prescribed fires, such as this rising from Halls Flat on the Lassen, is an important issue in forest management in the Western United States. Both the Sierra Nevada Science Synthesis and the Northwest Forest Plan Science Synthesis have extensive discussions about the social aspects of smoke (photo by Deborah Mayer, Forest Service).

and their timing can be regulated to minimize impacts on local air quality, though with cooler air, smoke tends to be retained for longer periods, and controlled burns have caused high pollution days in the Tahoe Basin.

Chapter 10 of the Northwest Forest Plan Science Synthesis discusses the environmental and social justice implications of the impacts of wildfire smoke in their study area. They cite studies from the Southeastern United States that have concluded that smoke impacts all communities equally, regardless of socioeconomic status, however, they caution that more studies are needed in their study area.

Implications of Climate Change for Postfire Restoration

Chapter 4.3, *Post-Wildfire Management*, in the Sierra Nevada Science Synthesis (Long et al. 2014b) examines

different management actions after fire. Burned Area Emergency Response is the first restoration action to occur after wildfire. This initial response is designed to stabilize the soils, and “protect life, property, water quality and ecosystems” (Long et al. 2014b, p. 188). Salvage logging, replanting, and other long-term restoration practices are also considered in the Sierra Nevada Science Synthesis. The chapter discusses these different approaches in depth and concludes that balancing economic and ecological costs and benefits in the short- and long-term must be considered. Issues include impacts to native plant and shrub species. For example, Knapp and Ritchie (2016) showed that increasing the intensity of salvage logging subsequently reduced the number of native shrub species on the site and the percent cover of them.

Postfire restoration is also addressed in the Northwest Forest Plan Science Synthesis (Spies et al. 2018). Chapter 3 discusses old-growth forests, and the interaction with fire and succession. It discusses the ecological consequences of salvage logging, highlighting concerns about altered ecosystem conditions and impacts with the removal of the dead biomass.

The implications of climate change in seeding projects that often occur as part of postfire restoration are discussed below.

Climate Change Impacts on Threatened Ecosystems and Species

In each section below, research regarding the response of species within the study area to a changing climate is synthesized, with a focus on Great Basin ecosystems.

Invertebrates

The diversity of butterflies across the Great Basin has been studied in detail. Fleishman et al. (2001) looked at the potential impacts of climate change on the diversity of butterfly species across the Great Basin. They noted that while vegetation zones in general are expected to shift upslope with climate change, individual host plant species (plants consumed by larvae) may not. Moreover, butterflies also require nectar sources, specific oviposition environments, etc. and hence the distribution of host plants may not match the distribution of the butterfly species. Few butterfly species are predicted to be lost from the Great Basin as a whole. Fleishman et al. (2001) note that in the Middle Holocene, temperatures in the basin were several degrees warmer than today, so the authors predicted

that there may be some ability to withstand the current warming trends, as species that could not withstand such climatic changes have already been extirpated. Fleishman and Mac Nally (2003) examined butterfly diversity in two mountain ranges in Central Nevada and compared data collected 6 years apart. The prediction is for a change in temperature in the Great Basin of 1.1 to 1.6 °F (2 to 3 °C), and a 10- percent decrease in summer precipitation, and a 15- to 40-percent increase in precipitation in other seasons. With 6 years of sampling, they found very similar results and concluded there may be a time lag in response to a changing climate. They speculate that fauna that live in “the Great Basin are ‘tough-tested’—species with low tolerance for environmental variability probably were extirpated long ago” (p. 400).

Butterfly diversity is indeed tied to vegetation, and management activities have the potential to impact that diversity. McIver and Macke (2014) examine the effects of fire and fuels treatments on butterfly diversity and found that any treatments that resulted in the removal of trees (e.g., junipers) tended to increase the amount of soil moisture available. This increased the amount of herbaceous food plants available for butterfly larvae, and hence the number of butterflies. Because of differences in butterfly abundances between years and the time lags involved, they suggest that any butterfly monitoring program needs to be intensive and long-term in order to be informative.

Two studies suggest that the local invertebrate populations in the Lassen and Modoc are unique compared to other parts of the Great Basin. Miller et al. (2014) examined the phylogenetic relationship between populations of the northern scorpion (*Paruroctonus boreus*) in the Intermountain West and found the Lassen population to be genetically different from those in other parts of the range. Based on their modeling, they conclude that suitable habitat for these scorpions in Northeastern California has persisted from the Last Interglacial Maximum through the Last Glacial Maximum to the present day. Schultheis et al. (2012) examined the current and Last Glacial Maximum distribution of stoneflies (*Doroneuria baumanni*) across the Great Basin. Using molecular genetic approaches, they showed that the stoneflies in Northeastern California and Nevada were genetically distinct from other stoneflies. They conclude that changes in historic climate have shaped current patterns of genetic diversity.

Birds

A number of bird species found within the study area have been studied with regards to responses to climate change. Siegel et al. (2014) used the Climate Change Vulnerability Index to look at predicted climate change impacts in a number of bird species in the Sierra Nevada. Northern goshawks (*Accipiter gentilis*) were listed as “moderately vulnerable” under two different climate scenarios. Spotted owls (*Strix occidentalis*) and black-backed woodpeckers (*Picoides arcticus*) were “presumed stable” (see Chapter 4.2, Hanberry and Dumroese, this synthesis, *Biodiversity and Representative Species in Dry Pine Forests* for more discussion about black-backed woodpeckers).

The northern goshawk has a circumpolar distribution, so global studies are relevant to a discussion of climate change impacts on the species. De Volo et al. (2013) studied the population genetics of northern goshawks from Southeastern Alaska to the Appalachians (including samples from the Lassen and Modoc) and found four genetic variants (haplotypes) in the Sierra-Cascade region and evidence that this population was isolated from other populations during the most recent period of glaciation, with a glacial maximum approximately 21,000 years ago, and ending 11,000 years ago.

Two studies have shown interesting changes in nest and body size in northern goshawks. Møller and Nielsen (2015) examined northern goshawks in Denmark and found a strong positive relationship between nest size and temperature, with larger nests occurring where temperatures are warmer. Tornberg et al. (2014) studied bird size from 200 museum specimens in Finland and observed a decrease in body size from 1962 to 2008, possibly relating to changes in prey type and availability. They commented that this was consistent with what is expected under climate change. This seems to contrast with the larger nest sizes observed in Denmark, as larger nests were correlated with larger bodies.

Northern spotted owls (*Strix occidentalis caurina*) have been the focus of a great deal of research (empirical and modeling) in regards to their response to predicted climate change; however, studies have yielded varying results. Glenn et al. (2011) looked at weather patterns and the northern spotted owl from Oregon and Washington and concluded that climate change, in the form of hotter, drier summers along with wetter winters, could have a negative impact on their populations.

Climate-based niche modeling focusing on Oregon, Washington, and Northern California showed changes in the probability of occurrence of owls under different climate change scenarios, but the model predictions were quite variable (Carroll 2010). Focusing on the Tahoe and Eldorado National Forests, Jones et al. (2016) modeled California spotted owl (*S. o. occidentalis*) distributions and found that rising summer temperatures resulted in a decline in predicted owl occurrence. Fledgling counts of California spotted owls on the Lassen were associated with climate: warmer early nesting temperatures and less precipitation resulted in higher fledgling counts (Cade et al. 2017). Unexpectedly, these authors did not find an association with previous-year precipitation and fledgling number.

Cicero and Koo (2012) looked at divergence in the sage sparrow (*Amphispiza belli*) species complex (including samples from the Lassen and Modoc), by examining variation in several morphological traits as well as sequence variation at an mtDNA marker, and climate niche modeling. They found strong evidence for divergence between the taxonomic groups (at the time of publication, there were three subspecies). Further, they showed that during the last 120,000 years, the distribution of the climate niche for sage sparrows has changed dramatically across the West. While they did not hypothesize about the birds’ distribution in the future under climate change, a strong association exists between climate and local distribution of these taxa.

All sage-grouse are considered sagebrush obligates, relying on intact sagebrush habitats during all life stages (Schroeder et al. 1999) and that habitat is under threat from a number of factors (Knick and Connelly 2011). Among climate-related variables, precipitation and the availability of water are the key factors for sage-grouse survival and reproduction in arid and semiarid regions. Donnelly et al. (2016) found that greater sage-grouse lek distribution was structured by the proximity to mesic (wetlands, etc.) resources with an observed average distance of 3.3 miles (5.3 km). Gibson et al. (2017) looked at nest site selection of greater sage-grouse in Nevada and found an association between weather and drought patterns and nest site selection. They found that drought reduced fitness, but that females were able to select the most productive nest sites among those available, thus mitigating, but not eliminating the impacts of drought on fitness. Blomberg et al. (2014) studying greater sage-

grouse in Nevada, found an association with climate and probability of post-fledgling survival, with a positive correlation with precipitation (fig. 6.1.6). An earlier study in Nevada by Nisbet et al. (1983) found positive associations between lek locations and water sources (less than 1.25 miles [2 km]) and precipitation (more than 10 inches [25 cm]).

Other approaches have been used to look at the relationship between climate, habitat, and sage-grouse success. Homer et al. (2015), focusing on Southwestern Wyoming, used remote sensing data to project trends in sagebrush habitat to 2050 based on changes in precipitation using IPCC climate models. Their models “predicted losses of -12 percent of greater sage-grouse nesting habitat and -4 percent of summer habitat from 2006 to 2050 due to climate alone” (p. 143). They considered these losses to be substantial.

Because sage-grouse rely almost exclusively on sagebrush habitats, encroachment by trees into sagebrush communities presents a major threat to population persistence, as it can severely reduce the amount and quality of available habitat (Miller et al. 2011, 2017; see *Juniper Woodlands* in Chapter 2.1 [Moser, this synthesis, *Understanding and Managing the Dry, Conifer Forests of Northeastern California*] and *Impacts of Conifer Encroachment* in Chapter 4.3 [Dumroese, this



Figure 6.1.6—Ongoing research on greater sage-grouse informs land managers about critical habitat needs of this species and how predicted increases in drought brought by climate change may affect the resilience of this species on the landscape (photo by Dawn M. Davis, used with permission).

synthesis, *Sagebrush Rangelands and Greater Sage-grouse in Northeastern California*] for more information). Falkowski et al. (2017) mapped where woody plants, mostly conifers and mesquite (*Prosopis* species), were found within the established range of greater sage-grouse. In Northeastern California, about half of the range had conifers at levels that could represent habitat loss for the sage-grouse. The authors discuss efforts to remove conifers from areas where there is encroachment to increase greater sage-grouse habitat. Pennington et al. (2016) conducted a literature review of the relationship between greater sage-grouse and forb species. They found a number of studies documenting the greater sage-grouse use of forbs for food and nesting habitat. However, they also found a lack of information on the relationship between climate and forbs, suggesting that their ability to understand how forbs important to sage-grouse will respond to climate change is limited, and they identified this as an information gap.

Other stressors impact greater sage-grouse populations and habitat including disease and human development. Walker et al. (2007) worked in Montana and Wyoming and presented the first data documenting the West Nile virus infection rate for wild greater sage-grouse. They also found the first documented occurrence of West Nile virus antibodies in greater sage-grouse, suggesting the birds had survived infection. Taylor et al. (2013), also working in Wyoming and Montana, studied energy development and West Nile virus occurrence in relation to the number of males on greater sage-grouse leks. They found that in non-disease-outbreak years, their models predicted drilling alone reduced the number of leks by 61 percent. In the absence of energy development, in an outbreak year, they predicted a reduction in the number of leks by 55 percent. Indeed, coal bed methane extraction results in the construction of ponds, which increases the amount of available mosquito habitat (Zou et al. 2006).

Reptiles

Jezkova et al. (2016) looked at range shifts in the desert horned lizard (*Phrynosoma platyrhinos*) species complex, and concluded the species expanded rapidly into the Great Basin after glaciation. Moreover, their results suggest that the niche of the species itself has shifted as the climate continued to change after the Last Glacial Maximum, with the species moving into warmer and drier climates (fig. 6.1.7).



Figure 6.1.7—After the last glaciation, the desert horned lizard moved rapidly into the Great Basin and its habitat niche has continued to shift with changes in climate since then (Jezkova et al. 2016; photo by Tony Kurz, used with permission).

Mammals

Carnivores

The black bear (*Ursus americanus*) population range in Western Nevada, just south and east of the Lassen and Modoc, has rebounded from its low observed around 1940. The genetic consequences of that recent range expansion were studied by Malaney et al. (2018), who concluded that the levels of connectivity between populations were insufficient to avoid a genetic bottleneck and to maintain a single genetic metapopulation. The authors argue that, given these results, it is important to maintain the connectivity between populations as temperatures rise with climate change, and more fragmentation occurs with spreading urbanization (Malaney et al. 2018).

Mesocarnivores

Barton and Wisely (2012) examined the population genetics of skunks and found that California striped skunk (*Mephitis mephitis*) populations are genetically distinct from all other striped skunk populations. They posited this was the result of post-and interglacial migration and isolation. This, along with the studies described earlier about scorpions (Miller et al. 2014) and stoneflies (Schultheis et al. 2012) suggest this isolation was not limited to skunks.

Rodents and Lagomorphs

Studies focused on rodents have found associations between the number of prey and the numbers of

predators—results that link predator and prey abundance with specific management approaches. Holbrook et al. (2016) studied Piute ground squirrels (*Urocitellus mollis*) and American badgers (*Taxidea taxus*) in Southwestern Idaho and examined the relationship between climate and disturbance on the occupancy of these mammals. Specifically, they looked at the cheatgrass/fire cycle in relation to mammal distribution. Badger occupancy was directly related to squirrel (prey) occupancy. Increasing abundance of cheatgrass was associated with decreasing abundance of ground squirrels. Moreover, increasing frequency of fire was also associated with a decreased abundance of ground squirrels. If the cycle of cheatgrass/fire continues or increases, the data here suggest there could be a negative impact on both prey and predator species. They also showed that successful reseeded projects after fire have a strong positive effect on ground squirrel abundance, compared to untreated plots.

An important question in rodent and lagomorph (rabbits, hares, and pikas) diversity and abundance is the question of how ranges are shifting under climate change. Some, but not all, rodent species show evidence for shifting ranges. Rowe et al. (2015) looked at the ranges of 34 species of small mammals (rodents, shrews, and lagomorphs) in three regions of California (Lassen National Park, Yosemite National Park, and Sequoia Kings Canyon National Park) and found widespread evidence for range shifts in many of these species. However, the direction and patterns of these range shifts was not consistent across the different regions of the State. Local temperature was the best predictor of range shifts. Larrucea and Brussard (2008) looked at the presence of pygmy rabbit (*Brachylagus idahoensis*) at sites last surveyed in the 1950s, including sites in Modoc and Lassen Counties in California. They found rabbits at only 36 percent of the historic sites, with evidence for a shift uphill of about 500 feet (150 m). Of the historic sites, 16 percent had been burned, and the authors concluded that wildfires are “probably the greatest threat to pygmy rabbit habitat today.” Morelli et al. (2012) used historical data to look at changes in the distribution of Belding’s ground squirrel (*Urocitellus beldingi*), including Northeastern California. They found that 42 percent of historical sites are now unoccupied. Species distribution models show that under climate change, much of the current range of this squirrel will be extirpated. This is particularly alarming as this species is an important food source for raptors and other predators. Rodents have been shown to respond to climate change through tracking changing habitat. Through

occupancy modeling, the piñon mouse (*Peromyscus truei*) was shown to be associated with its namesake, piñon pine (*Pinus monophylla*), which are expanding into sagebrush habitat. Thus, the range of the piñon mouse is also hypothesized to expand (Massey et al. 2017).

Other evidence has suggested, however, that some species are expanding their niche, and remaining in the same locations. Hornsby and Matocq (2012) focused on the bushy-tailed woodrat (*Neotoma cinerea*) and found that the woodrats in the study area are part of the intermountain clade that includes woodrats from Nevada, Utah, and Idaho. “The genetic pattern of recent demographic expansion is supported by the clade-specific ecological niche model, which emphasizes the notion that distinct evolutionary lineages within species may have different niche associations, and thus, unique responses to past and future climatic shifts” (p. 300). Jezkova et al. (2011) examined niche shifts in the chisel-toothed kangaroo rat (*Dipodomys microps*) and found that, “On the other hand, species that persisted in place throughout the climatic fluctuation of the late Pleistocene (such as *D. microps*) might respond differently to future climate changes as they might be capable of tolerating conditions beyond their current limits through either ‘niche drifting’ or ‘niche evolution’” (p. 3500). This idea of a more flexible niche is supported by the findings of Terry et al. (2017) who showed, using carbon and nitrogen isotopes collected from bones in cave deposits as well as modern populations, that the diet of kangaroo rats was (and is) much more diverse than previously thought, and the species was (and is) not a dietary specialist.

Smith et al. (1995) showed that in woodrats, body size is closely tied to fecal pellet size. They then analyzed samples collected from paleo-middens in the Great Basin dating from 20,000 years ago to present. Body size fluctuated with temperature, with larger body sizes at times when the temperature was cooler. These results suggest that woodrat body size may continue to decrease with increasing temperatures under climate change.

Pika

Pikas (*Ochotona princeps*) are lagomorphs, small montane mammals related to rabbits. They occur throughout mountains of Western North America (Smith and Weston 1990), including the Sierra Nevada and adjacent Great Basin ranges. They have received a great deal of research attention for their potential vulnerability to warming

climates (Beever et al. 2011). The species has come to serve as a model for climate change in mountain environments (fig. 6.1.8). They are best known for inhabiting high-elevation talus slopes, although they extend to lower elevations when habitat is available (Beever et al. 2008; Jeffress et al. 2017; Manning and Hagar 2011; Millar et al. 2013; Ray et al. 2016), and have a low tolerance for heat stress (Smith and Weston 1990). With climate change, a question is whether or not pika populations will move uphill, and what will happen when there is no more room for them to move uphill. This question has merit because studies have shown that the pattern of uphill movement of pikas in the Great Basin portion of the species range is not new, and has been occurring for thousands of years. Grayson (2005) reviewed evidence for the paleohistory dynamics of pikas in the Great Basin. Grayson argued that current pattern of local extinction at low and warm margins of the range follows a trend discernible throughout the past thousands of years. The Middle Holocene (7,500 to 4,000 years ago) in the Great Basin was warm and dry, and pika populations moved uphill about 1,430 feet (435 m) on average. Calkins et al. (2012) modeled future distribution of pikas across the Western United States and showed that with each degree of increased temperature, the distribution of pikas decreased. At about a 13-°F (7-°C) increase in temperature, pikas were nearly gone. Models by Mathewson et al. (2017) with a climate change component also predicted a reduced distribution of pika in the near future.



Figure 6.1.8—Perceived to be a species vulnerable to changes in climate, the pika, and its distribution in response to past changes in climate, is helping scientists predict where pikas may thrive in the future (photo by Ken Hickman, used with permission).

Multiple repeat-survey studies have compared historic (20th century) observational records of pika occupancy in the Great Basin to current occupancy. Most of these sites were at low and ecological margins of the species range. For such sites, these studies are in general agreement that pikas have shifted their distribution uphill and that warmer temperatures as well as cold winters are associated with pika extirpation. Beever et al. (2011) found that the minimum elevation of pika at 10 sites in the Great Basin Ecoregion has moved uphill at least 475 feet to a mean elevation of 1,194 feet (145 m to 364 m) between 1999 and 2008. Studies comparing historical records (generally 1890s to 2000s) have found a trend for pika populations to be extirpated from lower-elevation sites (Beever et al. 2016; Stewart et al. 2015; Wilkening et al. 2011). However, Beever et al. (2010) found an association between temperature and extirpation of pika populations in the Great Basin including both chronic heat stress and acute cold stress.

Although temperature is a significant driver of pika distribution, precipitation may also be an important variable. In general, studies have shown that pikas are less likely to be found in drier places (Henry et al. 2012; Jeffress et al. 2013). Beever et al. (2013) found an association with precipitation (positive) and temperature (negative) and occurrence of pika in the Great Basin (including the Lassen and Modoc). In Colorado and Montana, Bhattacharyya and Ray (2015) found evidence that several direct and/or indirect effects of climate change, such as warming summers, loss of preferred winter forage, reduced snow cover, and changing cache composition may adversely affect pika.

Despite this evidence, when more typical upland habitat in the Great Basin (as well as elsewhere) has been surveyed, pika populations occur widespread across the region as well as in previously unexpected locations (e.g., Jeffress et al. 2017; Millar and Westfall 2010; Millar et al. 2018). Beever et al. (2008) published the first records of pikas in Hays Canyon Mountain Range (just east of the Lassen and Modoc), and many other marginal locations have been similarly reported. In the Hayes Canyon Range, pikas were using cheatgrass as a food resource, interesting because cheatgrass does not normally grow at elevations where pikas live. Millar et al. (2013) and Millar and Westfall (2010) documented newly observed low-elevation and montane pika sites in the Great Basin including two low-elevation, dry-climate populations of pikas in the Madeline Uplands on MacDonald and Observation Peaks of Lassen

County (Millar et al. 2013). This area is much drier and warmer than might be expected to support pikas, although pikas were documented in the region in the early 20th century by Howell (1924). Pikas have been found living in lava-talus slopes and caves within the Lava Beds National Monument of Northeastern California, a site on the edge of their range (Ray et al. 2016). The microenvironments of these slopes and caves are relatively cooler and the authors hypothesize these conditions are more similar to those at the center of the pikas' range, and that perhaps local adaptation has occurred in response to the warmer summer temperatures of the area.

In general, pikas appear able to persist under what might appear to be marginal conditions due to the unique microclimate processes generated within taluses (Millar et al. 2014; Rodhouse et al. 2017). In summer, convection circulates cool air in the talus interior to the bases where pikas live, with the result that mean temperatures are lower than external ambient air and diurnal fluctuations greatly attenuated. In winter, the opposite happens, where snow cover adds thermal insulation to the open talus matrix, keeping these habitats stably warmer than external conditions.

However, as pika distributions are moving, often uphill, in response to a warming climate, so are other rodent species, and with those species come new disease threats that pikas have not been exposed to previously. Foley et al. (2017) have shown that in high-elevation sites in Colorado and Montana, the diversity of flea species found on pikas includes species that specialize on pikas as well as species that specialize on other rodent species, presumably from contact with those other rodent species.

Genetic approaches have also been used to determine patterns of movement among pika populations. Castillo et al. (2016) looked at gene flow and connectivity among sites and determined that gene flow was likely, and consistently, influenced by climate-related variables (especially the relative potential for heat stress) across multiple landscapes. Across the entire range of the pika, genetic variation is highly structured with five primary groups; the Lassen and Modoc pika are genetically similar to those from all of California, parts of Nevada, Western Utah, and Oregon (Galbreath et al. 2010).

Finally, given the increasing frequency and intensity of fire, it appears pikas have considerable resiliency to this disturbance. Varner et al. (2015) looked at the response of a

pika population to a wildfire on the north face of Mt. Hood in Oregon and found that pika were returning to even the most severely burned patches 2 years after burning. In the Madeleine Plains of Lassen County, pika occupancy was greatest in taluses where fires had burned, renewing forb and graminoid vegetation around the taluses that pikas use for foraging and caching (Millar et al. 2013).

Risks of Climate Change to Riparian, Meadows, and Other Aquatic Systems

Vernal pools have received a great deal of research attention, as they harbor a large number of native plant and animal species (see Chapter 4.2, Padgett, this synthesis, *Aquatic Ecosystems, Vernal Pools, and Other Unique Wetlands* for more information about vernal pools as well as redband trout [*Oncorhynchus mykiss* ssp.]). Grazing is an issue for some of these native plant species.

Merriam et al. (2016) looked at fenced and unfenced vernal pools in Northeastern California and found that while livestock grazing late in the season increased the occurrence of the threatened grass species, slender Orcutt grass (*Orcuttia tenuis*), variation in annual precipitation patterns had a greater effect on *O. tenuis*. Looking at the broader vernal pool plant community, Bovee et al. (2018) found that excluding cattle for up to 20 years resulted in fewer annual vernal pool specialists, but promoted perennial vernal pool species. They concluded that “livestock grazing may contribute more to plant community structure than inter-annual or between-pool variation in precipitation in montane vernal pools” (p. 17).

Climate change is expected to impact vernal pools through changes in temperature and hydrology. Gosejohan et al. (2017) looked at vernal pools on the Modoc Plateau, and found a strong association between-pool hydrology (maximum depth and inundation period) and plant community organization. They point out that understanding the relationship between-pool hydrology and plant species is the first step in understanding how climate change will impact plant distribution in vernal pool habitats. Pyke (2005) studied the relationship between climate change and brachiopods (small aquatic crustaceans) found in vernal pools in the Central Valley of California. While this is a very different ecosystem than found in the Lassen and Modoc, his findings are still relevant. He examined effects of climate change on different scales of vernal pools and found that changes in precipitation (inundation) and temperature (evaporation) will impact individual pools.

Across a local landscape, the availability of reproductive habitat and the movement of predators such as dragonflies will influence branchiopod distributions (fig. 6.1.9).

Amphibians in the Western United States face increasing threats, including introduced species and climate change. For example, in their review, Ryan et al. (2014) discuss studies showing the return of amphibian populations after fish removals in montane ponds, and point out that this is the one management approach that can be done in the short term by local managers. The impacts of a changing climate are, however, complex. O'Regan et al. (2014) show that for the Great Basin spadefoot toad (*Spea intermontana*), the anticipated faster drying of temporary ponds under climate change accompanied by higher temperatures, which reduced the amount of time for metamorphosis, resulted in faster growth and no reduction in toad size.

As the Great Basin becomes drier and temperatures increase, native fish habitat is a concern. Warren et al. (2014) examined limits to upstream migration of native and nonnative trout species. They found more limits on upstream migration in northern species of trout in the Great Basin, compared to southern ones. “Our assessment of potential upstream shifts in the bioclimatic envelope (with both moving and static upper limits) supports the overall conclusion that even slight shifts in stream conditions could substantially reduce available habitat for trout in the northwestern Great Basin.” Howard and Nobel (2018) looked at hydrology and phytoplankton in Butte Lake in



Figure 6.1.9—Aquatic habitats support a variety of wildlife, including this four-spotted skimmer (*Libellula quadrimaculata*). Dragonflies can also affect the populations and distributions of other fauna inhabiting vernal pools (photo by Tony Kurz, used with permission).

Lassen Volcanic National Park and found a dramatic shift in diatom communities during a drought year, and suggested that this community shift could influence fish communities as well. Schultz et al. (2017) looked at stream temperatures associated with both drought and fire at a location directly north of the Lassen and Modoc and noted that many streams listed as perennial lacked water during drought years. In addition, they found temperatures increased 7.2 °F (4 °C) immediately after a fire. They conclude that, “Combined drought and postfire conditions appeared to greatly restrict thermally-suitable habitat for Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*)” (p. 60).

Climate Change Impacts on Seeding Projects

Similar to conifer trees, different species of rangeland forbs have different germination strategies and populations within a species have been shown to have variation in germination requirements, often associated with variability in the climate where the seeds originate (Barga et al. 2017). Thus, national forest restoration projects, for which native plants are the first choice (Johnson et al. 2010)—whether they be trees, shrubs, grasses, or forbs—require managers to decide what sources of seeds to use. Several guidelines exist. For example, Buck et al. (1970) describe a set of tree seed zones for California that are currently used by the Forest Service to guide their reforestation projects. Seeds are transferred within a 500-foot (152-m) elevation band within a given seed zone. However, these seed zones are geographically based, and as such, their use under a changing climate is being questioned. Moreover, the seed zones focus only on trees, and not other native plant species. To address this gap, Johnson et al. (2010) suggest using seeds from similar ecosystems and to sample a seeds from parents from different locations within that ecosystem. This will result in a set of genetically diverse, locally adapted seeds for seeding projects. Bower et al. (2014) further refined these recommendations by proposing seed zones for native plants based on temperature and precipitation variables, paired with Level III Ecoregions (Omernik 1987). These zones are designed to be discrete units to maximize their usefulness for managers while providing flexibility for moving seeds across the landscape and ensuring the resulting plants are adapted to their new location. Another approach has been released recently; the Seedlot Selection Tool (<https://seedlotselectiontool.org/sst/>) uses climate models to determine the best seed source for a restoration project, based on climate-matching between the seed source and

the planting site. The user can define several variables in the tool, including which climate variables to include in the model. The user can also select a climate change scenario and determine which seed sources have the best climate-matching in future climates as well as current ones.

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