Chapter 1.4—Synopsis of Climate Change

Angela Jardine[1] and Jonathan Long[2]

Introduction

Changes in climate can interact with other stressors to transform ecosystems and alter the services those ecosystems provide. This synopsis presents themes that run through the synthesis report regarding the impacts of a changing climate on the forests and waters of the synthesis area as well as long-term, broad-scale, science-based strategies to promote system resilience to those impacts. Scientific observations of climate variations in air temperatures and precipitation (type and quantity) and their interactions have been directly linked to changes in stream flows (amount and timing), fires (frequency and severity), and ecosystem structure and function over the past several decades. Future climate scenarios suggest a strong likelihood for increased exposure of socioecological systems in the synthesis area to wildfire, droughts, intense storms, and other natural disturbances. Many of the social, economic, and cultural impacts of climate change are expected to be disproportionately greater on rural communities, natural resource-based communities, Native American communities, and groups with less financial resources to facilitate adaptation (see chapter 9.3, "Sociocultural Perspectives on Threats, Risks, and Health," and Wear and Joyce [2012]). Well-synthesized information about strategic responses to climate change is available in the chapter on climate change in PSW-GTR-237 (Safford et al. 2012) and the recent report *Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector* (Vose et al. 2012).

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Observed and Predicted Climate Change in the Synthesis Area

Climate refers to the long-term weather patterns (i.e., precipitation, temperature, humidity, sunshine, wind velocity, fog, frost, and hail storms) for a given region. Climate dynamics are the products of a complex system that entails large natural variability on different temporal and spatial scales (Lucarini 2002). There is important climatic variation from north to south within the synthesis area, as well as east-west variation. Despite this complexity, there are several recent trends and projections that appear to be relatively consistent across climate change scenarios

[1] Field research engineer and Ph.D. candidate, Programa Clima e Ambiente, Instituto Nacional de Pesquisas da Amazônia e Universidade do Estado do Amazonas, Manaus, Amazonas, Brazil.

[2] Research ecologist, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 1731 Research Park Dr., Davis, CA 95618.

and most parts of the synthesis area, including increased average annual and seasonal temperatures, increased length of freeze-free season and fire season, increased droughts, and increased storm severity (Das et al. 2011, Overpeck et al. 2013, Safford et al. 2012).

Across the Southwestern United States (California, Nevada, Utah, Arizona, Colorado, and New Mexico), temperatures since 1950 are reported to be the warmest in the past 600 years, with average daily temperatures in the most recent decade (2001–2010) being higher than any other decade since 1901 (the period of record used for a standardized comparison of the first decade of the 21st century to the entire record of the 20th century using the PRISM monthly gridded analysis dataset) (Hoerling 2013). Likewise, the spatial extent of drought from 2001 through 2010 covered the second largest area observed for any decade since 1901, and total streamflows in the four major drainages of the Southwest (Sacramento/San Joaquin, Upper Colorado, Rio Grande, and Great Basin) fell 5 percent to 37 percent below the 20th-century averages during the 2001–2010 decade (Overpeck et al. 2013).

In the Sierra Nevada, warming temperatures since the 1980s are generally attributed to increasing nighttime minimum temperatures across the region; however, different elevations have experienced a range of temperature changes (Safford et al. 2012). For example, the annual number of days with below-freezing temperatures in higher elevations is decreasing, whereas the number of extreme heat days at lower elevations is increasing (Safford et al. 2012). Changing temperatures combined with elevation differences influence the type of precipitation received in the Sierra Nevada, which in turn greatly impacts regional hydrology and fire vulnerability.

Observations show an increase in the proportion of precipitation falling as rain instead of snow since the 1980s (Harpold et al. 2012, Safford et al. 2012). This change has manifested in spring snowpack decreases of at least 70 percent across the lower elevations of the northern Sierra Nevada, a trend that has not yet been observed in the higher elevation southern Sierra Nevada. By 2002, spring thaw and peak streamflows were occurring 1 to 4 weeks earlier than they had 50 years earlier in the central Sierra Nevada (Stewart et al. 2005). Such changes have extended the fire season in the Sierra Nevada, particularly in low- to mid-elevation conifer forests (Safford et al. 2012). A longer fire season, associated with earlier drying and more cured fuels, has been linked to increases in the size or intensity of wildfires across the Western United States in general and the Sierra Nevada and southern Cascade Range specifically (Miller and Safford 2012, Miller et al. 2012, Safford et al. 2012, Westerling et al. 2006). These changes are a primary concern for forest and water resource managers across the synthesis region.

One of the most significant projected changes in climate for the synthesis area over the next century is an increase in average temperature by 2 to 4 °F (1.1 to 2.2 °C) in the winter and double that amount in the summer (Safford et al. 2012). Changes in precipitation are less clear and may differ within the synthesis area (Safford et al. 2012). In the Sierra Nevada, models project a decrease in mountain snowpack of at least 20 percent and up to 90 percent over the next century (Safford et al. 2012). This prediction is a major concern for water resource managers, who are already trying to balance various demands for water during periods of low flows. These changes are associated with projected reductions in streamflow, especially during the spring, on the western slopes of the Sierra Nevada, with greater impacts expected in the south (San Joaquin basin) than in the north (Sacramento basin) (VanRheenen et al. 2004). Flood potential is predicted to increase for high-elevation, snow-fed streams owing to shifts toward earlier peak daily flows (driven by increasing temperatures), increases in the frequency and magnitude of storms, and an increased proportion of precipitation falling as rain instead of snow (Das et al. 2011, Overpeck et al. 2013, Safford et al. 2012). For the western slopes of the Sierra Nevada, wintertime "wet" floods are expected to become more frequent and intense, while spring and summer snowmelt floods are expected to become smaller (Das et al. 2011, Overpeck et al. 2013).

Despite uncertainty about changes in annual precipitation, many models suggest increases in area burned in the Sierra Nevada, particularly on the drier eastern side, even in scenarios when precipitation increases (Hayhoe et al. 2004, Krawchuk et al. 2009, Lenihan et al. 2008). Simulations also point to widespread conversion of conifer-dominated forest to mixed evergreen forest as broadleaved trees, especially oaks, and shrubs increase at lower elevations, extensive expansion of grassland vegetation (primarily via fire-driven conversion of woody vegetation), and to loss of alpine and subalpine vegetation at high elevations (Lenihan et al. 2008). Crimmins et al. (2011) noted that water balance, rather than temperature, drives changes in plant distributions, and that increases in precipitation in recent decades may be resulting in downhill as well as uphill expansion of some plant species. Their findings have resulted in some scientific debate (Dobrowski et al. 2011, Stephenson and Das 2011).

Although many of the datasets discussed above focus on measurements of climate over the past 100 years or so, it is important to consider longer term perspectives when considering potential impacts to ecosystems. Taking a long-term view allows distributions of plants and animals to be seen as constantly shifting along complex and variable gradients (Stine 2004). The ranges of species will tend to contract into refugia during unfavorable periods and expand outward under more favorable conditions. In response, scientists have proposed using soft boundaries and corridors for long-term management plans (Stine 2004). This approach was a driving force behind setting guidelines for conservation of the California spotted owl rather than adoption of reserves (Verner 1997). As an alternative to a reserve approach for conserving biodiversity in the face of environmental change, Davis et al. (1996) considered establishment of biodiversity management areas that would have multiple uses but maintain an emphasis on species conservation. Another finding from studies with long-term perspective is that aquatic ecosystems may be particularly affected by climate change, with the indigenous fauna being survivors from past droughts that strained those habitats (Stine 2004). However, key challenges facing the broader socioecological systems are how well those species, as well as human systems, can tolerate the impacts of climate change in combination with other stressors that have been introduced within the past two centuries.

Marc Meyer

Figure 1—This red fir stand in the Illilouette Valley of Yosemite National Park has experienced multiple fires in recent decades.

Approaches to Promote Resilience to Climate Change

Chapter 1.2 summarizes strategic approaches to meet the challenges of promoting socioecological resilience. Current climate change impacts and those predicted to occur in the near and distant future challenge the ability to manage natural resources now and especially in the long term. The following points highlight concerns, strategic approaches, and research needs from various chapters of this science synthesis that focus on climate change. Readers are encouraged to review the chapters listed at the end of each example (and the references therein) for greater detail.

- **Recognize and address scale mismatches—**The temporal, spatial, and functional scales of management systems may not be well matched to the scales of environmental variation.

Forest ecology research has concentrated on narrow spatial and temporal scales; however, effective planning for climate change should consider long temporal periods and large spatial scales to account for widespread changes in disturbance regimes. Designing treatments at larger scales allows strategies to better account for landscape-scale processes, such as wildfires and insect outbreaks, as well as species that have large ranges. (See chapter 1.2.)

- **Consider long-term (>50 years) risks** in addition to short-term (<10 years) expected outcomes.

Large old-forest structures, which provide vital habitat for a variety of fauna in the synthesis area, take decades or centuries to develop; landscape plans should promote recruitment of these habitat features and promote forest resilience by increasing growing space and reducing the risk of uncharacteristic high-intensity fire. (See chapters 2.1, "Forest Ecology;" 7.1, "The Forest Carnivores: Marten and Fisher;" and 7.2, "California Spotted Owl: Scientific Considerations for Forest Planning.")

Many of the ecological services afforded by mountain meadows are threatened by a warming climate, and these vulnerabilities appear to be particularly high in several central Sierra Nevada watersheds, including the American, Mokelumne, Tuolumne, and Merced. Restoration efforts in these systems may help to delay runoff and increase summertime low flows. (See chapter 6.3, "Wet Meadows.")

Post-wildfire flooding and debris flows can have significant downstream impacts, including accelerated filling of reservoirs and other effects on water supplies, as well as significant and lasting impacts on vulnerable and isolated aquatic populations (see chapter 6.1, "Watershed and Stream Ecosystems"). Because climate change is expected to increase the incidence of severe wildfire and possibly rainstorms, and because human populations are increasing, the threat posed by post-wildfire debris flows is expected to increase. Debris flows can be difficult to mitigate, and few options exist beyond reducing the potential for severe fires. (See chapter 4.3, "Post-Wildfire Management.")

- **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.

Eighty-five percent of known California spotted owl sites occur in moderate- or high-risk fire areas in the Sierra Nevada. Uncertainty exists regarding how increasing trends in the amounts and patch sizes of high-severity fire will affect California spotted owl occupancy, demographics, and habitat over longer timeframes. Barred owls have replaced or displaced northern spotted owls over large areas of their range. Management needs to consider effects of multiple stressors on at-risk species, especially because conditions may change which options are prudent or feasible over time. (See chapter 7.2.)

Given expectations for climate change, increased use of prescribed fire and managed wildfire at large scales would help to restore resilience in many forests. (See chapter 1.3, "Synopsis of Emergent Approaches.")

In the face of climate change, proactive conservation strategies for trout and amphibians should consider not only direct effects of climate, such as ameliorating high temperatures or low flows, but also reducing interactions with introduced species and other stressors. In some situations, there may be enhanced opportunities to deal with introduced species as climate change or wildfires alter conditions. (See chapters 6.1 and 6.4, "Lakes: Recent Research and Restoration Strategies.")

Although climate change may be a chronic stressor, the catalyst through which its effects will be expressed is likely to be wildfire.

Approaches to promote resilience following severe wildfires should consider landscape context and the changing climate to help to identify desired conditions, target treatments, and associated monitoring, and to identify species and genotypes appropriate for postfire planting efforts. (See chapters 3.1, "Genetics of Forest Trees," and 4.3.)

- **Rely more on process-based indicators than static indicators of structure and composition, while recognizing that restoration of structure and process must be integrated.**

Sierra Nevada managers have been experimenting with PSW-GTR-220 principles, using topography as a template to vary treatments while meeting fire hazard reduction, wildlife habitat, and forest restoration objectives. Although climate change may be a chronic stressor, the catalyst through which its effects will likely be expressed is wildfire. (See chapter 1.3, "Synopsis of Emergent Approaches.")

Manipulation of current forests to resemble historical forest conditions may not be the best long-term approach when considering future climates. In many places, such an approach may represent a useful short-term goal, but climates and climate-driven processes are heading in unprecedented directions. Given the likely novelty of future climates, a prudent approach for maintaining forest ecosystems is to restore key processes such as wildfire that have shaped forest ecosystems for millennia, and associated structure and composition that are resilient to those processes and aid in their restoration. (See chapter 4.1, "Fire and Fuels.")

Climate patterns strongly influence soil development and nutrient cycling processes. As elevation and precipitation increase, soil pH and base saturation tend to decrease as a result of greater leaching and decreased evapotranspiration. (See chapter 5.1, "Soils.")

Climate change effects on flood regimes could alter sediment storage in floodplains, terraces, and colluvial hollows, which would in turn influence channel stability. Climate change is also expected to diminish summer low flows that could threaten aquatic life, especially cold water species. (See chapter 6.1.)

Because foundational ecological processes, such as soil water storage and vegetation evapotranspiration, may not have explicit targets, there may be a tendency to undervalue—or even ignore—them in decisionmaking. Forest treatments have the potential to enhance system resilience to multiple stresses by reducing evapotranspiration and increasing soil water availability. In addition, such treatments have the potential to enhance the yield, quality, and timing of downstream water flows and resulting ecosystem services. (See chapter 6.1.)

- **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.

Climate change may become a chronic stressor in red fir forests in the lower parts of their present distribution; reductions in the extent of true fir forests could be particularly detrimental to martens; consequently, the potential influence on terrestrial and aquatic ecosystem processes in the fir zone constitute an important cross-cutting research gap. (See chapters 1.5, "Research Gaps: Adaptive Management to Cross-Cutting Issues," 2.1, and 7.1.)

Post-wildfire management increasingly involves evaluating impacts of wildfire and potential benefits of treatment using decision support tools, developing broadscale and long-term restoration strategies to influence ecological trajectories and promote desired conditions; and to design and implement programs that feed back into adaptive management frameworks. (See chapter 4.3.)

There is broad consensus for using common garden experiments or provenance tests to prepare for projected conditions by better understanding how genetic variability can improve ecological restoration. (See chapter 3.1, "Genetics of Forest Trees.")

Rigorous assessment of the effects of future climate change on spotted owls will require dynamic models that incorporate vegetation dynamics and effects of competitor species. (See chapter 7.2.)

Further research is needed to evaluate how nitrogen deposition and ozone affect carbon sequestration both aboveground and in the soil. This information will be critical to climate change mitigation efforts in the region. During severe fires, accumulated nitrogen in vegetation, litter, and surface soils will be released, and both thinning and prescribed fire can be used to proactively reduce the amount of plant matter available for combustion. However, long-term ecosystem protection and sustainability will ultimately depend on reductions in nitrogen deposition, and this is the only strategy that will protect epiphytic lichen communities. (See chapter 8.1, “Air Quality.”)

- **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.

Addressing diverse viewpoints and perceptual divides regarding climate change by focusing on more immediate and local issues and potential impacts to public health and socioeconomic well-being, is important for generating support for mitigation and adaptation. (See chapter 9.3.)

Anticipated shifts in the hydrologic cycle are expected to detract from spring and summer water-based recreation and tourism, may reduce water supplies, and may increase risks of floods. These projections highlight the importance of advance planning as well as efforts to restore degraded systems so they will be less vulnerable. (See chapters 6.1; 6.3; 9.1, “Broader Context for Social, Economic and Cultural Components;” and 9.3, “Sociocultural Perspectives on Threats, Risks, and Health.”)

Adjusting management approaches based upon long-term monitoring and feedback loops becomes increasingly important as climate change induces effects on systems. (See chapters 9.1 and 9.6, “Collaboration in National Forest Management.”)

An important opportunity to mitigate climate change while promoting broader objectives lies in utilizing biomass generated from restorative forest treatments for energy production, especially in lieu of pile burning. (See chapter 9.5, “Managing Forest Products for Community Benefit.”)

- **Use participatory and collaborative approaches to facilitate adaptive responses and social learning.**

Rural communities in the United States tend to be more vulnerable to climate change than urban communities, and people residing in the wildland-urban interface are particularly vulnerable to fire, making the concept of community resilience especially relevant in these contexts because of its focus on a community’s ability to cope with change. (See chapter 9.4, “Strategies for Job Creation Through National Forest Management.”)

Interactions with holders of traditional and local ecological knowledge could be particularly valuable in understanding impacts of climate change. (See chapters 4.2, “Fire and Tribal Cultural Resources,” and 9.6.)

Science-management partnerships can facilitate dissemination of scientific information to help confront the challenges associated with climate change (see chapter 1.2, "Integrative Approaches: Promoting Socioecological Resilience"). The California Landscape Conservation Cooperative (CA LCC) is an example of a partnership that aims to address impacts of climate change and has held recent workshops for the synthesis area.

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