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| **Ecosystem Service: RECREATION** |

**General Overview of Process**

EcoAdapt, in collaboration with the U.S. Forest Service and California Landscape Conservation Cooperative (CA LCC), convened a 2.5-day workshop entitled *A Vulnerability Assessment Workshop for Focal Resources of the Sierra Nevada* on March 5-7, 2013 in Sacramento, California. Over 30 participants representing federal and state agencies, non-governmental organizations, universities, and others participated in the workshop[[1]](#footnote-1). The following document represents the vulnerability assessment results for **RECREATION**, which is comprised of evaluations and comments from a participant breakout group during this workshop, peer-review comments following the workshop from at least one additional expert in the subject area, and relevant references from the literature. The resulting document is not comprehensive; rather it is an initial evaluation of vulnerability based on existing information and expert input. This synthesis is intended to be a living document that can be revised and expanded upon as new information becomes available.



**Geographic Scope**

The project centers on the Sierra Nevada region of California, from foothills to crests, encompassing ten national forests and two national parks. Three geographic sub-regions were identified: north, central, and south. The north sub-region inclues Modoc, Lassen, and Plumas National Forests; the central sub-region includes Tahoe, Eldorado, and Stanislaus National Forests, the Lake Tahoe Basin Management Unit, and Yosemite National Park; and the south sub-region includes Humodlt-Toiyabe, Sierra, Sequioa, and Inyo National Forests, and Kings Canyon/Sequoia National Park.



**Key Definitions**

Vulnerability: Susceptibility of a resource to the adverse effects of climate change; a function of its sensitivity to climate and non-climate stressors, its exposure to those stressors, and its ability to cope with impacts with minimal disruption[[2]](#footnote-2).

Sensitivity: A measure of whether and how an ecosystem service is likely to be affected by a given change in climate or factors driven by climate.

Adaptive Capacity: The degree to which an ecosystem service can change or respond to address climate impacts.

Exposure: The magnitude of the change in climate or climate driven factors that the ecosystem service will likely experience.



**Methodology**

The vulnerability assessment comprises three vulnerability components (i.e., sensitivity, adaptive capacity, and exposure), averaged rankings for those components, and confidence scores for those rankings (see tables below). The sensitivity, adaptive capacity, and exposure components each include multiple finer resolution elements that were addressed individually. For example, sensitivity elements include: direct sensitivity of the ecosystem service to temperature and precipitation, sensitivity of different service components, ecosystem service sensitivity to disturbance regimes (e.g., wind, drought, flooding), sensitivity to other climate and climate-driven changes (e.g., snowpack, altered hydrology, wildfire), and sensitivity to non-climate stressors (e.g., grazing, recreation, infrastructure). Adaptive capacity elements include: intrinsic value of the ecosystem service and management potential. To assess exposure, participants were asked to identify the climate and climate-driven changes most relevant to consider for the ecosystem service and to evaluate exposure to those changes for each of the three Sierra Nevada geographic sub-regions. Climate change projections were provided to participants to facilitate this evaluation[[3]](#footnote-3). For more information on each of these elements of sensitivity, adaptive capacity, and exposure, including how and why they were selected, please refer to the final methodology report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada*[[4]](#footnote-4).

During the workshop, participants assigned one of three rankings (High (>70%), Moderate, or Low (<30%)) to each finer resolution element and provided a corresponding confidence score (e.g., High, Moderate, or Low) to the ranking. These individual rankings and confidence scores were then averaged (mean) to generate rankings and confidence scores for each vulnerability component (i.e., sensitivity, adaptive capacity, exposure score) (see table below). Results presented in a range (e.g. from moderate to high) reflect variability assessed by participants. Additional information on ranking and overall scoring can be found in the final methodology report *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada*4.



**Recommended Citation**

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**Overview of Vulnerability Component Evaluations**

**SENSITIVITY**

|  |  |  |
| --- | --- | --- |
| **Sensitivity Factor** | **Sensitivity Evaluation** | **Confidence** |
| Direct Sensitivities – Temperature | **2.5 Moderate-High** | **3 High** |
| Direct Sensitivities – Precipitation | **2.5 Moderate-High** | **3 High** |
| Sensitivity of Service Components | **No answer** | **No answer** |
| Disturbance Regimes | **3 High** | **3 High** |
| Climate-Driven Changes | **No answer** | **No answer** |
| Non-Climatic Stressors – Current Impact | **2 Moderate** | **2 Moderate** |
| Non-Climatic Stressors – Influence Overall Sensitivity to Climate | **1 Low** | **2 Moderate** |
| Other Sensitivities | **No answer** | **No answer** |

**Overall Averaged Confidence (Sensitivity)[[5]](#footnote-5): Moderate-High**

**Overall User Perceived Ranking (Sensitivity)[[6]](#footnote-6): Low-Moderate**

**Overall Averaged Ranking (Sensitivity)[[7]](#footnote-7): Moderate**



**ADAPTIVE CAPACITY**

|  |  |  |
| --- | --- | --- |
| **Adaptive Capacity Factor** | **Adaptive Capacity Evaluation** | **Confidence** |
| Service Value | **3 High** | **3 High** |
| Willingness to Change Behavior | **2 Moderate** | **2 Moderate** |
| Specificity of Management Rules | **1 Low[[8]](#footnote-8)** | **No answer** |
| Other Adaptive Capacities | **2 Moderate** | **2 Moderate** |

**Overall Averaged Confidence (Adaptive Capacity)5: Moderate-High**

**Overall User Perceived Ranking (Adaptive Capacity)6: Moderate**

**Overall Averaged Ranking (Adaptive Capacity)7: Moderate**



**EXPOSURE**

|  |  |  |
| --- | --- | --- |
| **Exposure Factor** | **Exposure Evaluation** | **Confidence** |
| *No factors chosen* | **Not assessed** | **N/A** |

|  |  |  |
| --- | --- | --- |
| **Exposure Region** | **Exposure Evaluation (2010-2080)** | **Confidence** |
| Northern Sierra Nevada | **Not assessed** | **N/A** |
| Central Sierra Nevada | **Not assessed** | **N/A** |
| Southern Sierra Nevada | **Not assessed** | **N/A** |

**Overall Averaged Confidence (Exposure)5: N/A**

**Overall User Perceived Ranking (Exposure)6:**  **N/A**

**Overall Averaged Ranking (Exposure)7: N/A**



**Description of Ecosystem Service**

Recreation is a cultural ecosystem service (Smith et al. 2011), and represents a major component of the lifestyle and culture of the Sierra Nevada (Sierra Nevada Conservancy 2011a), as well as a major economic contributor to Sierra Nevada communities (Roberts et al. 2009). National forests provide recreational settings, opportunities, and access, as well as manage for scenic character; they also partner with a variety of private entities to provide recreational opportunities through special use permits, as well as partner with other federal and state agencies to provide and regulate recreation (U.S. Forest Service (USFS) 2015). Common recreational activities in the Sierra Nevada include: hiking, camping, water activities (e.g., rafting, fishing), natural feature and wildlife viewing, hunting, and snow activities (e.g., skiing, snowmobiling), among others.



**Sensitivity**

1. **Direct sensitivities to changes in temperature and precipitation.**
   1. Sensitivity to temperature (means & extremes): Moderate-High
      1. Participant confidence: High
   2. Sensitivity to precipitation (means & extremes): Moderate-High
      1. Participant confidence: High

**Additional comments:** Water-oriented recreation, winter sports, and hunting and wildlife viewing are affected.

**References:**

Temperature: Minimum and maximum air temperatures in the Sierra Nevada have increased (0.9°C and 0.3°C, respectively) over the past 30 years relative to a mid-20th century baseline (1951-80) (Flint et al. 2013). Mirroring increases in air temperature, stream temperatures have increased as well (Hari et al. 2006, Webb and Nobilis 2007, Kaushal et al. 2010 cited in Null et al. 2012). Increasing temperatures can directly affect recreation by altering the duration of recreation seasons (e.g., summer vs. winter) and demand for associated activities (e.g., water-based activities during warm months) (Loomis and Crespi 1999 cited in Irland et al. 2001). For example, warmer temperatures at lower elevations could drive increased visitation and demand for higher elevation (i.e., cooler) recreation opportunities (Irland et al. 2001; USFS 2013). Warming temperatures can also indirectly affect recreation opportunities by driving shifts in a variety of other climate-driven factors, including wildfire regimes, snowpack depth and melt timing, and stream temperature, subsequently impacting various recreational activities. These impacts are discussed further below.

Precipitation: Precipitation has increased slightly (~2%) in the Sierra Nevada over the past 30 years compared with a mid-twentieth century baseline (1951-1980) (Flint et al. 2013). However, temperature increases are driving shifts from snow to rain (Mote et al. 2005; Knowles et al. 2006). Higher precipitation is often associated with El Niño years (North et al. 2005; Hallet and Anderson 2010). Changes in precipitation can directly affect recreation by altering seasonality and demand (Loomis and Crespi 1999 cited in Irland et al. 2001), and indirectly impact recreation by affecting other climate-driven factors, including snowpack, flow regimes (Meyers et al. 2010; Das et al. 2011), and fire risk. These impacts are discussed further below.



1. **Sensitivity of components of the ecosystem service.**
   1. Sensitivity of service components to climate change: No answer
      1. Participant confidence: No answer

**Additional comments:** Campfires in late season may be curtailed (even in campsites). Insect pests such as mosquitos might be increased. More fires will lead to more smoke, affecting OHV recreation.

**References:**

From 2005-2009, the most popular recreational activities were: viewing natural features, downhill skiing, hiking/walking, relaxing, and wildlife viewing (USFS 2015); these activities are projected to retain their popularity in the future (USFS 2015).

Forests: Forested landscapes in the Sierra Nevada provide a variety of recreational opportunities including camping, hiking, wildlife and natural feature viewing, horseback riding, hunting, and off highway vehicle (OHV) use. As of 2011, the Sierra Nevada hosted over 9700 miles of National Forest Service trails, ranging from minimally to fully developed and including trails in both wilderness and non-wilderness areas (USFS 2015). Although they are a key recreational resource, high demand and financial constraints may challenge trail management in the future (USFS 2015).

Hunting: A variety of species are hunted on national forests in the Sierra Nevada, including big game, small game and upland birds, and migratory game birds (USFS 2013). The Forest Service manages wildlife habitat, while the California Department of Fish and Game manages individual species and issues hunting permits (USFS 2013). Habitat alterations as a result of climate change and management practices (i.e., fire suppression) may affect game populations and hunting access (USFS 2013). From 2003-2008, over 14.4 million visits to national forests in the U.S. were hunting-related (Mockrin et al. 2012).

Water: The Sierra Nevada hosts eight Wild and Scenic Rivers, constituting 345.5 river miles, though an additional 467 river miles are proposed for listing (Boston et al. 2013 cited in USFS 2015). Both Wild and Scenic and other rivers, as well as lakes, streams, and ponds, are used for a variety of recreational purposes (e.g., whitewater rafting, kayaking, canoeing, fishing, water sources for hikers) (USFS 2015). A majority of whitewater recreation is found on the western slopes of the Sierra Nevada, which hosts more than 128 whitewater runs of varying degrees of difficulty (Ligare et al. 2011). Key rivers for whitewater recreation include the American, Tuolumne, and Kern Rivers, which are regulated by dams (Ligare et al. 2011). Peak season for whitewater recreation is related to snowmelt (April-June), though winter rain and summer/late fall reservoir releases can also maintain sufficient water levels for boating (Ligare et al. 2011).

Fish: Both native and introduced fish species are utilized by fishermen in the Sierra Nevada. Unfortunately, fish stocking has reduced populations of native fish and amphibians (USFS 2015). California salmonid populations are at the southern boundary of their range, and small thermal increases in summer temperatures can result in suboptimal or lethal conditions (Katz et al. 2013). It is possible that a majority of California’s endemic salmon, trout and steelhead could become extinct within the next 50 to 100 years, particularly pink salmon (*Onchorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta*) (Katz et al. 2013; for more information, see Aquatic System synthesis).

Snow: The national forests of the Sierra Nevada host roughly 1700 miles of snow trails and 34 winter trailheads, supporting a variety of winter activities (cross-country skiing, snowmobiling, snowshoeing) (USFS 2015). The Sierra Nevada also has many ski resorts that operate on Forest Service lands under special use permits.



1. **Sensitivity to changes in disturbance regimes.**
   1. Sensitivity to disturbance regimes including: Wildfire, wind, drought, flooding, other: smoke
   2. Sensitivity to these disturbance regimes: High
      1. Participant confidence: High

**Additional comments:** More wildfires, extended droughts, and floods will restrict recreation. Floods also wash out roads and facilities.

**References:**

Wildfire: Warming temperatures have been linked with increasing forest fire frequency, severity, and size in the western United States (Westerling et al. 2006; Miller et al. 2009; Dillon et al. 2011; Taylor and Scholl 2012). Warmer air temperatures increase wildfire risk by drying fuels and creating or extending periods of fire weather (Fried et al. 2004; Chang 1999, Swetnam 1993, Swetnam and Baisan 2003 cited in Skinner and Stephens 2004; Collins 2014). Precipitation also affects fire frequency, severity, and extent by affecting fuel production and moisture (Chang 1999, Swetnam 1993, Swetnam and Baisan 2003 cited in Skinner and Stephens 2004). For example, fire in the majority of California is more probable during La Niña years, which are characterized by drier than average conditions and drought (North et al. 2005). Higher than average precipitation, often associated with El Niño phases (Hallet and Anderson 2010), can stimulate plant growth and increase available fuel and fire risk in subsequent years (Skinner and Stephens 2004). This process has been documented in the Southwest, where current year drought preceded by years with above-average precipitation led to the largest fire years in ponderosa pine forests (Strom and Fule 2007). Historically, fire activity has been correlated with positive phases of the Pacific North America Pattern (PNA), Pacific Decadal Oscillation (PDO), and warm periods (Trouet et al. 2009; Taylor and Scholl 2012).

Since the 1980s, however, the Sierra Nevada has experienced an increase in large fires (>1,000 ac), tracking trends of increasing temperatures and earlier snowmelt (Westerling and Bryant 2006; Westerling et al. 2006). Fire severity also rose from 17% to 34% high severity (i.e. stand replacing) fire from 1984-2007, especially in middle elevation conifer forests (Miller et al. 2009). Fire frequency is usually higher on south-facing slopes (Taylor 2000) and at mid- to upper-slope positions, due to higher winds, lower canopy cover, and fuel characteristics (Rothermel 1983), though in Yosemite National Park mixed conifer forests, no spatial trend in fire frequency was found (Scholl and Taylor 2010).

Wildfire likely has variable impacts on recreational opportunities (Winter et al. 2014a). Fire impacts can range from altered visitation rates (Loomis et al. 2001; Englin et al. 2008) and travel plans (Thapa et al. 2008; Winter and Knap 2008; Winter et al. 2014a) to minimal impacts on visitor experience (Loomis et al. 2001; Winter and Knap 2008). Large, severe fires likely pose the greatest threat to recreation, potentially leading to area closures and/or degraded viewsheds and scenic quality (Morris and Walls 2009). For example, smoke from wildfires during June 2008 forced the cancellation of several recreation events in the Sierra Nevada due to reduced visibility and hazardous levels of air pollution (Bytnerowicz et al. 2014).

Flooding: Flooding can cause extensive damage to infrastructure, endanger human lives (Dettinger et al. 2011), and/or result in recreational closures. Historically, large floods in California occur between February and March (Das et al. 2011) as a result of winter storms or in conjunction with spring/early summer snowmelt (Roos 1997 cited in Das et al. 2011). Floods are also linked with winter-spring atmospheric circulations and atmospheric rivers (Cayan and Riddle 1992, Ralph et al. 2006, Naiman et al. 2008 cited In Das et al. 2011).

Insects and disease: From 1999-2001, insect and disease mortality increasingly contributed to national forest timberland acres requiring regeneration (Mills and Zhou 2003). A 2006 model estimated that 1.4 million acres of Sierra Nevada forest is susceptible to high levels of mortality due to insects and disease, where ‘susceptible’ is defined as the expectation that 25% or more of the standing tree volume would die over the next 15 years (Living Assessment 2003). Habitat for sudden oak death *(Phytophthora ramorum*; hereafter SOD)is projected to extend from Los Angeles, California to the Puget Sound area in Washington by 2050, with limited inland expansion (Kliejunas 2011). Models predict the risk for SODwill increase in California (Sturrock et al. 2011) and spread to the northern foothills of the Sierra Nevada (Kelly et al. 2007), though it currently only exists in coastal California (Rizzo et al. 2002; Kelly et al. 2007). Mountain pine beetles (*Dedroctonus ponderosae* Hopkins; hereafter, MPB) attack a variety of tree species, including lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), limber pine (*Pinus flexilis*), western white pine (*Pinus monticola*), and whitebark pine (*Pinus albicaulis*) (Gibson et al. 2009). Recent and projected increases in MPB outbreak frequency and severity are attributed to a combination of climate change (Bentz et al. 2010; Logan et al. 2010) and altered forest structure (Sibold et al. 2006; Baker 2009). Dead trees pose a safety risk, endangering recreational users in a variety of settings (e.g., campgrounds, trails, roads, picnic areas, etc.) (Morris and Walls 2009). Large-scale mortality events, and resultant high numbers of standing dead trees, have prompted closures of recreational sites in other states (Robbins 2008 cited in Morris and Walls 2009). Deceased trees also increase fuel loads and wildfire risk (Morris and Walls 2009).

Wind: Prevailing winds in the Sierra Nevada are typically from the southwest, though eastern winds can occur as well (Hilimire et al. 2013). Wind from other directions, such as the extreme northern wind event that occurred in the central Sierra Nevada in 2011, can cause significant tree blow-down (Hilimire et al. 2013), affecting recreational safety.

Drought: Drought conditions can increase fire risk (Fettig et al. 2013) and the likelihood of disease and insect outbreaks (Bentz et al. 2010), affecting recreational opportunities, safety, and scenic character (USFS 2013). La Niña years typically bring drier than average conditions and drought (North et al. 2005). Drought can also affect water-reliant recreation (e.g., fishing, boating, water sources for hikers, equestrians, etc.) and exacerbate conflicts among water users (USFS 2013; USFS 2015).



1. **Sensitivity to other types of climate and climate-driven changes.**
   1. Sensitivity to climate and climate-driven changes including[[9]](#footnote-9): Snowpack and snowmelt timing, altered hydrology, water temperature, altered fire regimes, extreme temperature or precipitation events, storms, vegetation shifts
   2. Sensitivity to these climate and climate-driven changes: No answer
      1. Participant confidence: No answer

**Additional comments:** More wildfires, extended droughts and/or floods will restrict recreation. Floods also wash out roads and facilities. Loss of snowpack limits winter recreational season. Trout streams closed during high water temperatures.

**References:**

Snowpack and snowmelt timing: Overall, April 1st snowpack in the Sierra Nevada, calculated as snow water equivalent (SWE), has seen a reduction of 11% in the last 30 years (Flint et al. 2013), as a consequence of earlier snowmelt (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007), increased frequency of melt events (Mote et al. 2005), and increased rain:snow ratio (Knowles et al. 2006). However, trends in snowpack in the Sierra Nevada have displayed a high degree of inter-annual variability and spatial heterogeneity (Mote et al. 2005; Safford 2010). SWE in the highest elevation central and southern Sierra Nevada has actually increased during the last half-century, likely due to increases in precipitation (Mote et al. 2005; Mote 2006; Moser et al. 2009; Flint et al. 2013). In addition, snowmelt is occurring earlier in the spring (Cayan et al. 2001; Stewart et al. 2005; Hamlet et al. 2007).

Shifts in snowpack and snowmelt timing can affect a variety of recreational activities. For example, snowpack reductions and earlier snowmelt can lead to a shortened winter recreation season with altered access opportunities and visitation (Burakowski and Magnusson 2012). Between 1999-2010, lower snowfall years resulted in a 5% reduction in visitation to California ski resorts with over $100 million in lost revenue and staffing cuts within the ski industry (Burakowski and Magnusson 2012). Snowpack changes also affect spring and summer recreation (e.g., rafting; Ligare et al. 2011), as the Sierra Nevada snowpack traps winter precipitation and releases it via snowmelt in spring and summer (Westerling et al. 2006), when precipitation is typically lower. Earlier snowmelt can effectively lengthen the dry season, affecting fire risk (Westerling et al. 2006), flow regimes (Maurer 2007; Young et al. 2009; Null et al. 2010), and both land- and water-based recreation (Ligare et al. 2011).

Altered hydrology: Shifts in precipitation, snowpack, and evaporation drive changes in hydrology. A 2010 assessment using the Forest Service Watershed Condition Framework found that 63% of Sierra Nevada watersheds were functioning properly, while 36% were classified as “functioning at risk” (USFS 2015). Compared to 1948, peak streamflow in 2002 occurred 5-15 days earlier, largely as a result of earlier snowmelt (Safford et al. 2012). Earlier snowmelt and smaller peak flows may shift the timing of water-based recreation, increasing boating access for some rivers in the spring while decreasing the duration of summer season access as flows decline below boatable levels (Ligare et al. 2011). Low streamflow volumes are common during summer and fall (Stewart et al. 2005), but shifts to intermittent flows (Perry et al. 2012) in some stream reaches could impact coldwater species (Blaustein et al. 2010; Null et al. 2012) and recreational access (Ligare et al. 2011). Flood magnitudes associated with extreme precipitation events have increased compared to historical conditions (Das et al. 2011); flood periods may increase boating access on regulated rivers, but shift typical boating season from summer to winter and early spring (Ligare et al. 2011). Climatic water deficit, which combines the effects of temperature and rainfall to estimate site-specific soil moisture, has increased slightly (~4%) in the Sierra Nevada in the past 30 years compared with the 1951-1980 baseline (Flint et al. 2013). Shifts in the hydrologic cycle may impact water-based recreation in the spring and summer (Jardine and Long 2014).

Water temperature: Stream temperatures have increased in recent decades as air temperatures have increased (Hari et al. 2006, Webb and Nobilis 2007, Kaushal et al. 2010 cited in Null et al. 2012). However, riparian vegetation species, height, density and location, as well as stream orientation (LeBlanc and Brown 2000) and topographic shading (Null et al. 2012) also influence stream temperatures. Warming water temperatures can have a variety of impacts on aquatic habitats (see Aquatic System synthesis), including reduced habitat for coldwater species (Blaustein et al. 2010; Null et al. 2012). In lakes, increased temperatures decrease the solubility of gases, and processes such as denitrification and nitrogen fixation are accelerated. Such changes can lead to water quality problems in Lake Tahoe and other lakes (Coats 2010), with implications for recreation.

Extreme events (temperature & precipitation): More heat waves occurred between 2001-2010 in the Southwestern United States (including California) than compared to average decadal records of the 20th century (Overpeck et al. 2013). Heat waves typically reduce soil moisture (Gershunov et al. 2013), which can affect fire risk and subsequently, recreation. In addition, heat waves could alter demand for certain recreational activities (e.g., water-based or high elevation activities) (Irland et al. 2001; USFS 2013). Extreme precipitation events can lead to flooding (Das et al. 2011), potentially increasing boating access for short periods (Ligare et al. 2011).

Storms: Warmer temperatures may cause a greater number of extreme convective storms, including enhanced occurrence of lightning strikes (Hallett and Anderson 2010), affecting fire risk and recreational safety. Large storms in California, which bring significant 3-day rainfall totals and affect flood risk (Das et al. 2011), are associated with landfalling atmospheric rivers (Dettinger et al. 2011).

Vegetation shifts: Hardwood-dominated forests have increased in the Sierra Nevada over the past 80 years, a pattern that is likely linked with climate warming (Safford et al. 2012 and citations therein). Simultaneously, yellow pine-dominated forests, blue oak woodlands, and subalpine/alpine vegetation have declined, while shade-tolerant conifers have experienced increased dominance in forest canopies, largely as a result of management practices (Safford et al. 2012 and citations therein). Shifts in habitat and vegetation type may affect hunting opportunities and/or access if game species are forced to shift their range in response to climate change (Morris and Walls 2009). In addition, vegetation shifts can affect fire regimes (Lyderson and North 2012) and/or scenic quality (USFS 2013), with potential impacts on recreational use and experience (Juarez et al. 2013 cited in USFS 2015)

Altered wildfire regimes: See wildfire discussion (above).



1. **Sensitivity to impacts of other non-climate stressors.** 
   1. Sensitivity to other non-climate stressors including: Residential and commercial development, energy production and mining, invasive and other problematic species, pollution and poisons, geologic events: landslides, other: population growth
   2. Current effects of these identified stressors on system: Moderate
      1. Participant confidence: Moderate
   3. Degree stressors increase sensitivity to climate change: Low
      1. Participant confidence: Moderate

**Additional comments:** Residential and commercial development supports recreation and detracts from some forms. Use conflicts are big issues: houses and mountain bikes, ORV and solitude seekers, hikers and hunters. Air pollution from valley in the south.

**References:**

Residential and commercial development: Increasing urbanization in California (CA Department of Parks and Recreation (CA DPR) 2009) and the U.S. (USFS 2012) may increase the proportion of urban recreationists in the Sierra Nevada (USFS 2015), which could alter recreation demand (USFS 2012). In addition, development can compete with available recreational acreage (CA Department of Forestry and Fire Protection (CALFIRE) 2010) and/or degrade scenic character, affecting subsequent recreational experiences (Juarez et al. 2013 cited in USFS 2015).

Population growth: California’s population is expected to increase 33% by 2050, growing to roughly 50 million people (California Department of Finance 2014). Population increases will likely drive increases in recreation demand in the Sierra Nevada, as roughly 79% of visitors to the Sierra Nevada come from California (USFS 2015). Elevated demand can lead to crowding issues, which is one of the main sources of dissatisfaction in current national forest recreational users (USFS 2015). Elevated demand and use can also lead to other high-use problems (e.g., sanitation issues) (USFS 2013). The Central Valley, in particular, is projected to see significant population growth, but lacks substantial recreation opportunities (CA DPR 2009), which may drive increased use of Sierra Nevada recreational opportunities (USFS 2015). In addition, amenity migration[[10]](#footnote-10) to the Sierra Nevada will likely continue to drive demand for consistent or enhanced recreational opportunities (Winter et al. 2014b). Changes in population and visitor demographics may also affect recreation demand and/or require shifts in recreation management (Winter et al. 2014b), as different cultural groups prefer varying forms of recreation and/or have variable access to and engagement with current recreational opportunities (Roberts et al. 2009; Winter et al. 2014b). Population growth can also affect water-based recreation by increasing competition for water among agriculture, urban areas, special use permittees, natural resource maintenance, and hydropower (USFS 2015).

Energy production and mining: Alternative energy production can compete with recreational acreage and opportunities (CALFIRE 2010), as well as degrade the scenic character of recreational areas (Juarez et al. 2013 cited in USFS 2015). Alternatively, energy development can shape or create new recreational opportunities. For example, hydroelectric dams have created 11 different reservoirs on the Sierra National Forest, and these reservoirs are used by a variety of visitors for different recreational activities (USFS 2013).

Invasive and other problematic species: Recreation can be an avenue for invasive species introductions, but has also benefited from some introductions (Knapp 1996; USFS 2015). For example, aquatic watercraft and fishing equipment facilitate the spread of invasive aquatic species, such as the Asian clam (*Corbicula fluminea*) in Lake Tahoe (Wittmann et al. 2012). However, the introduction of non-native trout to many water bodies in the Sierra Nevada during the mid-1800s to enhance recreational fishing resulted in elevated, lasting fishing opportunities that are maintained to this day (Knapp 1996).

Pollution and poisons: Air pollution may be degrading recreational opportunities on the western slopes of the southwest Sierra Nevada (Cisneros et al. 2010; Bytnerowicz et al. 2014) and in localized areas (e.g., Truckee, Mammoth Lakes) (Sierra Business Council 1997). Industrial and automobile air pollution from the Central Valley affects visibility and may exceed public health standards along the western Sierra Nevada slopes (Cahill et al. 1996; Winter et al. 2014a), while particulate pollution from woodfires in localized areas (e.g., Truckee, Mammoth Lakes) may pose a public health concern (Sierra Business Council 1997). Air pollution (e.g., ozone and nitrogen deposition) can also impair tree health (USFS 2013; Bytnerowicz et al. 2014), affecting the scenic character of recreation areas.

Dams and water diversions: Dams regulate streamflow to meet hydropower, water storage, recreational, and ecological needs (Ligare et al. 2011). For example, some dams coordinate water releases to sustain recreational water levels during the high-demand summer season (Ligare et al. 2011). However, flow timing requirements for recreation can be at odds with other water use groups (e.g., ecosystem functioning, fisheries, hydropower) (McGurk and Paulson 2000 cited in Ligare et al. 2011), and these conflicts may escalate under shifting hydrological regimes (Ligare et al. 2011). A majority of whitewater runs on regulated rivers exist in the bypass section between the dam and where water is discharged from the facility; boatable periods occur as a result of intentional water release or spills as a result of high water levels (Ligare et al. 2011). Spill events may increase with climate warming (Madani and Lund 2010), but reductions in summer water may limit recreational water releases, contributing to shifts in whitewater recreation timing from summer to late winter-early spring (Ligare et al. 2011).

Geologic events (landslides): Landslides are natural processes, but can affect public safety (Dale et al. 2001) and recreational opportunities. Landslides are associated with intense precipitation and snowmelt, and are also moderated by slope, vegetative cover, land use, and wildfire regimes (Dale et al. 2001).

Natural system modifications: Landscapes outside of their natural range of variability are more vulnerable to large-scale disturbance (e.g., fire, insect and disease outbreaks; Safford et al. 2013a cited in USFS 2015), which can degrade scenic quality and affect recreational experiences (Juarez et al. 2013 cited in USFS 2015). In addition, altered landscapes can affect wildlife forage and habitat range, with implications for recreation (USFS 2013).



1. **Other sensitivities.**
   1. Other critical sensitivities not addressed: No answer
      1. Participant confidence: No answer
   2. Collective degree these factors increase system sensitivity to climate change: No answer

**Additional comments:** Price of gas/recreation/public services (closure of campgrounds).

**References:** None identified

Certain areas of the Sierra Nevada may see higher recreational use than other areas. For example, 19 million people visited national forests in the Sierra Nevada between 2005-2009, with the Sequoia, Inyo, and Sierra National Forests accounting for 45% of all recreation visitor days (USFS 2015 and citations therein). Disproportionate use of recreational opportunities may impact recreational quality and availability.

Social, cultural, and economic factors also drive recreational use and demand. For example, visitation rates to remote areas within Sierra National Forest were largely driven by visitor economics, while recreational preferences varied by family (i.e., culture) (USFS 2013). Economic conditions and gas prices will likely moderate future demand and recreational participation (USFS 2013; USFS 2015), as will development of recreational opportunities in other areas in and adjacent to the Sierra Nevada (USFS 2013).



1. **Overall user ranking.**
   1. Overall (perceived) sensitivity of this service to climate change: Low-Moderate
      1. Participant confidence: No answer

**Additional comments:** No answer

**References:** None identified



**Adaptive Capacity**

1. **Intrinsic Value.**
   1. Degree to which service is valued: High
      1. Participant confidence: High
   2. Degree people are willing to change their behavior to maintain access to the service: Moderate
      1. Participant confidence: Moderate
   3. Economic drivers that play a role in the management access of value of this service: Federal agency budgets, and state and local price of gas / discretionary income facilities being open
   4. Describe whether the service can be accessed elsewhere, and whether it is important to continue to provide this service in its current location: Yes and no; skiing limited to where there are facilities

**Additional comments:** No answer

**References:**

Recreation is a major historical and contemporary component of the lifestyle and culture of the Sierra Nevada (Sierra Nevada Conservancy 2011a).

Economic considerations: Recreational tourism has helped many previously timber-dependent communities in the Sierra Nevada grow and prosper (Charnley 2014) through a combination of employment and sales of goods and services (USFS 2015). However, recreation trends are influenced by the national economy and shifting gas prices; high gas prices and a recovering economy stimulate local travel and recreation, which may drive increased recreational demand in the Sierra Nevada (USFS 2015).

Limited economic resources may affect the management and quality of recreational opportunities on public lands both now and in the future (Juarez et al. 2013 cited in USFS 2015). For example, many national forests in the Sierra Nevada provide more recreational opportunities than they can completely maintain (USFS 2015). As of 2006, national forests in the Sierra Nevada had a recreational site maintenance backlog equivalent to roughly $49 million and road maintenance backlogs varied from $29-129 million (USFS 2015). Reduced staffing capacity and funding will likely continue to limit the ability of national forests to manage and meet recreational demand (Juarez et al. 2013 cited in USFS 2015).

Service access and location: Climate change may cause shifts in recreational season lengths and opportunities, such as a reduction in winter recreation opportunities and/or shifts in water-based recreation timing (see Sensitivity section). Maintaining existing recreational quality, as well as meeting enhanced recreational demand is critical, for degraded recreational quality or opportunities could cause the population to recreate elsewhere (Juarez et al. 2013 cited in USFS 2015).



1. **Management potential.**
   1. Specificity of rules governing management of the service or the areas that provide the service: High
      1. Participant confidence: No answer
   2. Description of use conflicts and/or mutual benefits with other services: Water supply (cities, agriculture, downstream); biodiversity; timber harvest; grazing (quality of meadows); energy (hydro and wind)
   3. Potential for managing or alleviating climate impacts: The ability to manage or alleviate impacts depends on the type of recreation; could manage watersheds to reduce impacts

**Additional comments:** No answer

**References:**

The Forest Service has recently identified sustainable recreation as one of its priority areas, and aspires to have sustainable recreation programs operating in all national forests by 2019 (USFS 2015). However, the Forest Service must also manage for a variety of different objectives, which may limit or bolster the extent of recreational development (Smith et al. 2011; USFS 2015). For example, recreational opportunities must be balanced with preserving the quality and integrity of important historical and cultural sites (USFS 2015 and citations therein). In addition, certain Sierra Nevada landscapes have special designations and management requirements related to recreation (e.g., Pacific Crest Trail, Wild and Scenic Rivers, wilderness), and are of high value to the public (USFS 2015). National Visitor Use Monitoring (NVUM) surveys help analyze recreation trends on national forest lands, which are otherwise difficult to track (Smith et al. 2011), and will likely be an important tool for monitoring recreation use in the future and informing decision-making. In addition, design and maintenance of recreational areas will likely play a large role in meeting public demand and multiple use requirements in the future (CA DPR 2002), as well as mitigating safety hazards (e.g., landslides) (Dale et al. 2001) and adapting to changing climate conditions (e.g., climate-informed facility placement) (Dettinger et al. 2011).

The Forest Service manages recreation through a variety of avenues. Recreational settings are categorized into six types following the Recreation Opportunity Spectrum (ROS[[11]](#footnote-11)): primitive, semi-primitive non-motorized, semi-primitive motorized, roaded natural, rural, and urban (U.S. Department of Agriculture (USDA) 2012). These categories are used in forest planning to achieve myriad recreational goals (USDA 2012; USFS 2015), and determine what sort of development, management, and recreational activities are permitted and encouraged within each sector (USFS 1982). In addition, as a result of Recreation Facility Analyses started in 2007, each national forest also has a program niche statement that describes its general recreational theme (e.g., Sequoia National Forest – Giant Sequoias and Whitewater), as well as subsequent niche settings that outline geographic areas that support particular recreational activities (e.g., scenic routes, backcountry, river corridors)(USFS 2015). The Forest Service attempts to provide a variety of recreation opportunities related to their niche, including non-motorized, motorized, developed, and dispersed (land, water, air) options (USDA 2012; USFS 2015); these activities can be provided by the Forest Service or by another entity via special-use permit (USFS 2015). In the Pacific Southwest region, over 50% of special use permits issued are for recreation, with a majority located in the Sierra Nevada (USFS 2015). Recreational residences (private, non-commercial) constitute the most recreational special use permits, followed by outfitting and guiding (commercial and non-commercial) (USFS 2015). Utilization of special use permitting is projected to increase to meet increasing recreational demand amidst declining federal budgets (USFS 2015). However, special use permits may have undesired environmental impacts (Juarez et al. 2013 cited in USFS 2015).

Continued and/or expanded use of partnerships to maintain recreational opportunities will likely also be an important tool in the future (USFS 2015). The Forest Service already relies on extensive partner engagement to maintain trails and facilities (CA DPR Off-Highway Motor Vehicle Recreation Division 2011; USFS 2015), and demand shifts, staffing, and financial issues are likely to increase reliance on these partnerships (USFS 2015). In addition, increased collaboration with communities via community-based stewardship, volunteerism, and special use permits can help maintain and improve recreational opportunities despite declining federal budgets (Juarez et al. 2013 cited in USFS 2015).

Some recreational activities are affected by external management frameworks; for example, river regulation and scheduled releases are undergoing licensing revisions by the Federal Energy Regulatory Commission (FERC) in order to meet a variety of ecological and social objectives (Ligare et al. 2011). New licensing agreements emphasize maintenance of natural flow regimes (e.g., high spring flows, low summer flows; Yarnell et al. 2010), which may prohibit recreational water releases and result in reduced boating opportunities during the summer months (Ligare et al. 2011). However, better integration of flood and water resources management could help maximize water storage and release benefits for multiple uses (Dettinger et al. 2011).



1. **Other adaptive capacity factors.**
   1. Additional factors affecting adaptive capacity: No answer
      1. Participant confidence: Moderate
   2. Collective degree these factors affect the adaptive capacity of the service: Moderate

**Additional comments:** Regulations that manage recreation in climate-changed world.

**References:** None identified



1. **Overall user ranking.**
   1. Overall (perceived) adaptive capacity of the service: Moderate
      1. Participant confidence: Moderate

**Additional comments:** No answer

**References:** None identified



**Exposure**

1. **Exposure factors[[12]](#footnote-12).**
   1. Factors likely to be most relevant or important to consider for the service: Temperature (air and water), precipitation, snow volume and timing, hydrology (e.g., low/high flows, runoff timing and volume), climatic water deficit, wildfire, vegetation shifts
      1. Participant confidence: No answer



1. **Exposure region.** 
   1. Overall exposure for different Sierra Nevada regions: North – No answer; Central – No answer; South – No answer
      1. Participant confidence: No answer



1. **Overall user ranking.**
   1. Overall (perceived) exposure of the service to climate changes: Moderate
      1. Participant confidence: No answer

**Additional comments:** No answer

**References:**

Temperature: Over the next century, temperatures in California are expected to rise (Hayhoe et al. 2004; Cayan et al. 2008), with the lower range of warming projected between 1.7-3.0°C, 3.1-4.3°C in the medium range, and 4.4-5.8°C in the high range (Cayan et al. 2008). Temperatures along the western slope of the Sierra Nevada are forecast to increase between 0.5-1°C by 2049, and 2-3°C by 2099 (Das et al. 2011). On average, summer temperatures are expected to rise more than winter temperatures throughout the Sierra Nevada region (Hayhoe et al. 2004; Cayan et al. 2008; Geos Institute 2013). Temperature projections using global coupled ocean-atmospheric models (GDFL[[13]](#footnote-13) and PCM[[14]](#footnote-14)) predict summer temperatures to increase 1.6-2.4°C by mid- century (2049), with the least increases expected in the northern bioregion, and greatest increases expected in the southern bioregion (Geos Institute 2013). By late century (2079), summer temperatures are forecast to increase 2.5-4.0°C, with changes of least magnitude occurring in the central bioregion (Geos Institute 2013). Winter temperatures are forecast to increase 2.2-2.9°C by late century (2079), with changes of least magnitude occurring in the central bioregion (Geos Institute 2013). In addition, heat wave conditions (3 or more days with temperatures above 32°C) are projected occur more frequently in California by the end of the century (Hayhoe et al. 2004), and are expected to last longer, feature higher temperatures (Gershunov et al. 2013; Overpeck et al. 2013), and affect larger geographic areas (Gershunov et al. 2013). California heat waves are projected to increase most significantly in nighttime, rather than daytime, as a result of increased humidity (Gershunov and Guirguis 2012; Gershunov et al. 2013), though daytime heat wave incidence is also projected to increase (Gershunov and Guirguis 2012). Associated with rising temperatures will be an increase in potential evaporation (Seager et al. 2007).

Increasing atmospheric temperatures, coupled with reductions in summer flows, will increase water temperatures and potential suitability of stream reaches for temperature-sensitive aquatic species (Myrick and Cech 2004). Consequently, an elevational shift in the distribution of cold- and warm-water fish species will occur as cold-water species are limited to higher elevations (Yarnell et al. 2010). In a modeling exercise by Null et al. (2012), average annual stream temperatures warmed approximately 1.6˚C for each 2˚C rise in average annual air temperature. The greatest rise in stream temperatures occurred at mid elevation (1500-2500 m; 4921-8202 ft), where climate warming shifted precipitation from snowmelt to rainfall. The largest thermal change occurred during spring in the models, when stream warming could exceed 5˚C for each 2˚C rise in air temperature (Null et al. 2012). For more information on projected climate impacts on salmonid species and aquatic systems, please see the Aquatic System synthesis.

Precipitation: In general, annual precipitation is projected to exhibit only modest changes by the end of the century (Hayhoe et al. 2004; Dettinger 2005; Maurer 2007; Cayan et al. 2008; Geos Institute 2013), with some precipitation decreases in spring and summer (Cayan et al. 2008; Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 11-49% by 2049 and 18-55% by 2099 (Das et al. 2011). In addition, average fractions of total precipitation falling as rain in the Sierra Nevada can be expected to increase by approximately 10% under a scenario of 2.5˚C warming (Dettinger et al. 2004b).

Snow volume and timing: Despite modest projected changes in overall precipitation, models of the Sierra Nevada region largely project decreasing snowpack (Miller et al. 2003; Dettinger et al. 2004b; Hayhoe et al. 2004; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009) and earlier timing of runoff center of mass (Miller et al. 2003; Knowles and Cayan 2004; Maurer 2007; Maurer et al. 2007; Young et al. 2009), as a consequence of early snowmelt events and a greater percentage of precipitation falling as rain rather than snow (Dettinger et al. 2004a, 2004b; Young et al. 2009; Null et al. 2010).

Annual snowpack in the Sierra Nevada is projected to decrease between 64-87% by late century (2060-2079) (Thorne et al. 2012; Flint et al. 2013; Geos Institute 2013). Under scenarios of 2-6˚C warming, snowpack is projected to decline 10-25% at elevations above 3750 m (12303 ft), and 70-90% below 2000 m (6562 ft) (Young et al. 2009). Several models project greatest losses in snowmelt volume between 1750 m to 2750 m (5741 ft to 9022 ft) (Miller et al. 2003; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009), because snowfall is comparatively light below that elevation, and above that elevation, snowpack is projected to be largely retained. The greatest declines in snowpack are anticipated for the northern Sierra Nevada (Safford et al. 2012), with the current patterns of snowpack retention in higher- elevation southern Sierra Nevada basins expected to continue through the end of the century (Maurer 2007).

Hydrology: Increased rain:snow ratio and advanced timing of snowmelt initiation are expected to advance the runoff center of mass by 1-7 weeks by 2100 (Maurer 2007), although advances will likely be non-uniformly distributed in the Sierra Nevada (Young et al. 2009). Snow provides an important contribution to spring and summer soil moisture in the western U.S. (Sheffield et al. 2004), and earlier snowmelt can lead to an earlier, longer dry season (Westerling et al. 2006). A shift from snowfall to rainfall is also expected to result in flashier runoff with higher flow magnitudes, and may result in less water stored within watersheds, decreasing mean annual flow (Null et al. 2010). Flood magnitudes are projected to increase across the Sierra Nevada, even with declines in overall precipitation (Das et al. 2011). Winter rainfall floods are likely to increase in frequency, while snowmelt floods may decrease in frequency (Das et al. 2011). Scenarios modeling increased atmospheric temperatures at 2°C, 4°C, and 6°C run by Null et al. (2010) forecast that, overall, watersheds in the northern Sierra Nevada are most vulnerable to decreased mean annual flow, southern-central watersheds are most susceptible to runoff timing changes, and the central portion of the range is most affected by longer periods with low flow conditions. Changes in stream flow and temperature are expected to be most significant in streams fed by the relatively lower elevation northern Sierra Nevada and southern Cascades, while the southern Sierra Nevada with its much higher elevations is predicted to retain a higher proportion of its snowpack (Mote et al. 2005; Katz et al. 2013).

Climatic water deficit: Increases in potential evapotranspiration will likely be the dominant influence in future hydrologic cycles in the Sierra Nevada, decreasing runoff even under forecasts of increased precipitation, and driving increased climatic water deficits (Thorne et al. 2012). Climatic water deficit, which combines the effects of temperature and rainfall to estimate site-specific soil moisture, is a function of actual evapotranspiration and potential evapotranspiration. Future downscaled water deficit projections using the Basin Characterization Model (Thorne et al. 2012; Flint et al. 2013) and IPCC A2 emissions scenario predict increased water deficits (i.e., decreased soil moisture) by up to 44% in the northern Sierra Nevada, 38% in the central Sierra Nevada, and 33% in the southern Sierra Nevada (Geos Institute 2013).

Wildfire: Large fire occurrence and total area burned in California are predicted to continue increasing over the next century, with total area burned increasing 7-41% by 2050, and 12-74% by 2085 (Westerling et al. 2011). Models by Westerling et al. (2011) project annual area burned in the northern, central and southern Sierra Nevada to increase by 67-117%, 59-169%, and 35-88%, respectively (Geos Institute 2013). Greatest increases in area burned in the Sierra Nevada are projected to occur at mid-elevation sites along the west side of the range (Westerling et al. 2011).

Vegetation shifts: Changes in temperature, precipitation, and evapotranspiration will likely drive dominant vegetation shifts in the Sierra Nevada (Lenihan et al. 2003, 2008; Safford et al. 2012; Geos Institute 2013). Various MC1 vegetation modeling efforts predict an expansion of mixed forests, mixed woodlands (at lower- to mid-elevations), and grasslands; reductions in subalpine vegetation and evergreen conifer forests; and a migration of woody vegetation (including shrublands and evergreen conifers) to higher elevational limits as colonization opportunities increase (Lenihan et al. 2003, 2008; Geos Institute 2013). Additionally, increased fire frequency and severity could cause vegetation conversion and a corresponding decrease in old growth forest (Lenihan et al. 2008).

More information on downscaled projected climate changes for the Sierra Nevada region is available in a separate report entitled *Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy process* (Geos Institute 2013).



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5. Overall confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure, respectively. [↑](#footnote-ref-5)
6. Overall user ranking is based upon participant opinion given their knowledge and expertise in the subject area. [↑](#footnote-ref-6)
7. Overall sensitivity, adaptive capacity, and exposure are an average of the sensitivity, adaptive capacity, or exposure evaluation columns above, respectively. No weightings were applied to any of the factors considered; users are encouraged to develop their own weighting schemes. [↑](#footnote-ref-7)
8. This score was inversed for consistency with other scoring structures (i.e., high rule specificity confers low adaptive capacity). [↑](#footnote-ref-8)
9. Factors listed include those identified by workshop participants and those identified in the scientific literature. [↑](#footnote-ref-9)
10. The movement of people to rural communities for actual or perceived environmental or social benefits (Winter et al. 2014b). [↑](#footnote-ref-10)
11. <http://www.fs.fed.us/cdt/carrying_capacity/rosfieldguide/ros_primer_and_field_guide.htm> [↑](#footnote-ref-11)
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