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Natural Resource Stewardship and Science

A Natural Resource Condition Assessment for Sequoia and Kings Canyon National Parks

Appendix 8 – Alpine Environm*ents*

Natural Resource Report NPS/SEKI/ NRR—2013/665.8

ON THE COVER

Giant Forest, Sequoia National Park

Photography by: Brent Paull

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This document contains subject matter expert interpretation of the data. The authors of this document are responsible for the technical accuracy of the information provided. The parks refrained from providing substantive administrative review to encourage the experts to offer their opinions and ideas on management implications based on their assessments of conditions. Some authors accepted the offer to cross the science/management divide while others preferred to stay firmly grounded in the presentation of only science-based results. While the authors' interpretations of the data and ideas/opinions on management implications were desired, the results and opinions provided do not represent the policies or positions of the parks, the NPS, or the U.S. Government.

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Scope of Analysis

Sequoia and Kings Canyon National Parks protect most of the subalpine and alpine environment of the southern Sierra Nevada of California. With over 48% of the parks occurring above 3,048 meters (10,000 feet), they are dominated by high elevation habitats. This rugged, remote wilderness is also one of the most scenic landscapes in the world, drawing over 100,000 visitors, largely travelling by foot, each year.

Crowning the tops of mountain systems worldwide, the alpine ecosystem is considered quite rare from a global perspective (Heywood 1995) making the protected status of the Sierra Nevada alpine critical to the protection of alpine ecosystems worldwide. In these environmentally extreme and biogeographically isolated highlands, life is tightly constrained by harsh growing conditions. But the alpine is rich in biodiversity. Although at first glance the high peaks and tablelands may appear nearly devoid of life, the alpine flora of the Sierra Nevada includes approximately 600 species of vascular plants (Major and Taylor 1988), with at least 200 of those restricted to the alpine zone (Sharsmith 1940). The Sierra Nevada is in a hotspot of global biodiversity (Myers et al. 2000), so it follows that the Sierra Nevada alpine zone is the most botanically species-rich of the continental alpine environments (Billings 2000).

The alpine provides primary habitat for a significant number of sensitive organisms in the two parks, including six of nine recognized at risk or locally extinct animal taxa (American pika, *Ochotona princeps;* Sierra Nevada red fox, *Vulpes vulpes necator*; wolverine *Gulo gulo;* Sierra Nevada bighorn sheep *Ovis canadensis sierra*; Yosemite toad, *Bufo canorus*, and mountain yellow-legged frogs, *Rana muscosa*, *R. sierra*) and thirty-two of the 150 special status plants (see Sensitive Animal and Sensitive Plants appendices of this report for detailed discussion of these taxa). Dominated by slow-growing perennial plants which are adapted to the extreme climatic conditions that characterize the high elevations, alpine vegetation is thought to be particularly vulnerable to the shifts in temperature and snowpack dynamics predicted under anticipated climate change scenarios.

This report provides an overview of the characteristics and extent of the alpine environment in Sequoia and Kings Canyon National Parks, followed by a discussion of the known and potential impacts of each of the key stressors on alpine communities. Because many of the focal resources addressed in this report contain components of, or overlap with the alpine, this section is not meant to be comprehensive, and the reader is frequently directed to other sections for additional detail.

Here the term alpine refers to the environment occurring above the treeline at the highest elevations of the Sierra Nevada. The term treeline is used conservatively to include only those high elevation habitats that do not support tree species, regardless of stature. Stands of low-growing krummholz pine (which include whitebark, foxtail, and lodgepole pine in the southern Sierra) are thus excluded from this definition.

Critical Questions

- What is the distribution of alpine habitats in Sequoia and Kings Canyon National Parks?
- How are the primary stressors expected to impact the alpine?
- How have past management actions impacted the alpine?
- What critical gaps in understanding exist?

Analyses

Methods

Delineating a boundary between the alpine and subalpine poses an ecological and cartographic challenge. Although at the landscape scale it may appear that the transition between the subalpine and the alpine occurs at a distinct elevation, alpine species are found not only above the treeline, but also in openings in subalpine woodlands (Major and Taylor 1988). It is also difficult to use vegetation data to distinguish between a climatically driven treeline, above which low temperatures and a short growing season prohibit tree growth, and a substrate driven treeline, where local environmental conditions, such as the presence of bedrock, limit growth of vegetation. Tree species also can form windswept mats (krummholz) well above the timberline. Subalpine and alpine communities thus intermix and create a mosaic of types over a range of elevations and environments.

To describe the distribution of the alpine in Sequoia and Kings Canyon National Parks, vegetation associations and mapping units from the current vegetation map of the two parks were used (USGS-NPS Vegetation mapping program 2007). Two categories of associations were recognized: those that are exclusively alpine, and those that could be considered conditionally alpine (occurring both in the alpine and subalpine). Mesic rock outcrops, for example, occur well below the alpine throughout the two parks, but are also found in the high elevations. For these types a lower elevation limit of 3,048 meters (10,000 feet) was used to constrain the inclusion of these treeless types to those most likely to qualify as alpine. Although this may result in including some vegetation polygons that are technically subalpine, the 3,048 meter elevation represents the approximate treeline in much of the two parks and thus serves our general purpose. Note, however, that treeline can be found as high as 3,300 meters (10,827 feet) in the Mt. Whitney region of Sequoia National Park. The vegetation types and mapping units used to define the alpine of the two parks are listed in Table 1.

Table 1. Vegetation associations and mapping units recognized in the alpine of Sequoia and Kings Canyon National Parks (USGS-NPS Vegetation mapping program 2007).

Exclusively alpine mapping units	Conditionally alpine vegetation types and mapping units (if occurring above 3,048 m)
Alpine Talus Slope	Boulder Field
Alpine Scree Slope	Dome
Alpine Snow Patch Communities	Intermittently to Seasonally Flooded Meadow
Alpine Fell-field	Mesic Rock Outcrop
Alpine Permanent Snowfield/Glacier	Oceanspray Shrubland Alliance
	Semi-permanent to Permanently Flooded Meadow
	Shorthair Sedge Herbaceous Alliance
	Sierra Willow/Swamp Onion Seasonally Flooded Shrubland Alliance
	Sparsely Vegetated Riverine Flat
	Sparsely Vegetated Rocky Streambed
	Sparsely Vegetated to Non-vegetated Exposed Rock
	Sparsely Vegetated Undifferentiated
	Upland Herbaceous
	Water
	Willow spp. Riparian Shrubland Mapping Unit
	Willow spp. Talus Shrubland Mapping Unit
	Willow spp./Meadow Shrubland Mapping Unit

Results

Using the classification rules described above, 111,659 ha (275,915 acres) of Sequoia and Kings Canyon National Parks are mapped as alpine habitat (Figure 1). This is comparable to the 112,262 ha (277,406 acres) mapped as 'barren' using the California Wildlife Habitat Relationship system, which is relied upon by several of the related sections of this report. Of this total, approximately 45 percent (50,241 ha, or 124,147 acres) is mapped as exclusively alpine, while the remaining 55 percent is derived from "conditionally alpine" mapping units (treeless types occurring above 3,048 m, or 10,000 feet). Taken together, the alpine habitats defined here account for approximately 32 percent of the area encompassed by the two parks.

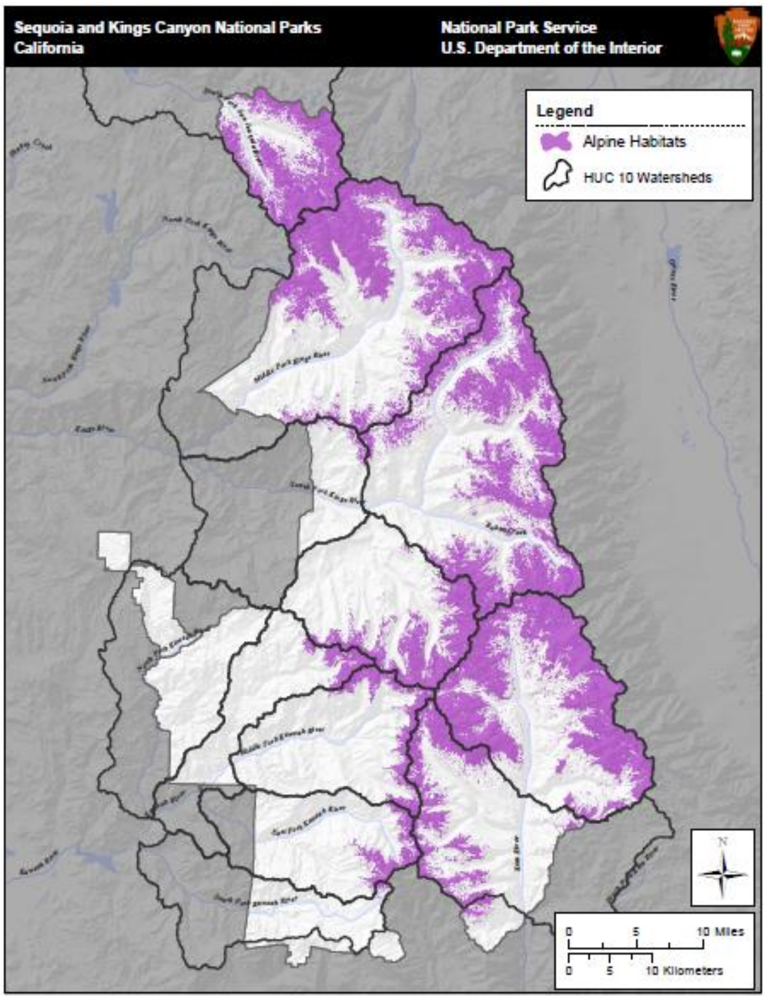

Figure 1. Distribution of alpine habitats in Sequoia and Kings Canyon National Parks.

Stressors

Climate

Once thought to be relatively protected from the primary anthropogenic stressors facing Sierra Nevada wild lands, the highest elevations are now considered some of the most vulnerable to the effects of a changing climate (Krajik 2004, Parmesan 2006). In the Sierra Nevada, at least 7,400 hectares of alpine habitat and another 47,700 hectares of subalpine forest (Davis *et al.* 1998) are threatened with increasing fragmentation, invasion by both native and non-native species, and subsequent loss of biodiversity.

Although all of the high elevation land area encompassed by Sequoia and Kings Canyon National Parks enjoys designated or proposed wilderness status, it is not protected from the effects of a changing climate. Worldwide, alpine areas belong to those regions expected to experience above average warming with continued global climate change (Theurillat and Guisan 2001; Krajick 2004). Hypothesized (and in some cases realized) shifts include an expansion of subalpine taxa into alpine environments, an increase of native ruderal taxa into subalpine and alpine sites, expansion in the ranges of woody taxa (both shrubs and trees), and the increased potential for non-native taxa to establish in these previously un-invaded environments (Pauchard *et al.* 2008). Because alpine communities are essentially “sky islands” of habitat, we expect that narrowly restricted alpine taxa are vulnerable to being displaced by those subalpine species that may be able to move upward in response to warming temperatures.

Recent changes in climate in the mountains of western North America and the relationship of those changes to anthropogenic causes are well documented (Barnett *et al.* 2008). In these western mountains, we are already seeing an increase in mean temperature (Bonfils *et al.* 2008), a shift in precipitation from falling primarily as snow towards rain (Das *et al.* 2009, Knowles *et al.* 2006), and an earlier onset of spring snowmelt (Stewart *et al.* 2005, Cayan *et al.* 2001). These changes in climate have in turn been linked to earlier green-up dates (Schwartz *et al.* 2006), increased forest tree mortality (van Mantgem *et al.* 2007), and changes in the latitudes and timing of faunal observations (Rosensweig *et al.* 2008). Whether or not alpine species in the parks have already reacted to rapid climate change is uncertain, as such studies have yet to be reported. Note, however, that evidence of vertebrate range expansions and contractions has been documented from Yosemite National Park as a result of the resurvey of the historic Grinnell transects (Moritz *et al.* 2008), and similar work is in progress in the southern portion of the Sierra Nevada.

Changes in climatic conditions and evidence of subsequent changes in alpine vegetation have been reported from the mountains of Europe. For example, results from Trivedi *et al.* (2008) support predictions of fragmentation and habitat loss for alpine plant species due to increases in mean annual temperature. In the Scandinavian alpine, shrub expansion has been correlated with warm summers and decreasing winter snow cover (Hallinger *et al.* 2010). Pauli *et al.* (2007) reported early evidence of warming-induced species declines in the high European Alps. Kullman (2010) used historic floristic census data from four summits in the southern Swedish Scandes to document changes in species richness and elevational shifts in alpine plants over the past 50 to 60 years.

Anthropogenically forced changes in alpine vegetation may also lead to secondary ecosystem effects. In the Rocky Mountains of Colorado, Forrest *et al.* (2010) demonstrate that changes in the alpine climate may lead to changes in the competitive relationships of alpine plants. In the central Chilean Andes, results from Muňoz and Cavieres (2008) suggest that at high densities the non-native dandelion (*Taraxacum officinale*, which is also naturalized and abundant in the mountains of California and the intermountain west) alters pollinator visitation and seed output in nearby native members of the Asteraceae. Consensus is thus emerging that climate change is likely to bring about complex changes in the alpine ecosystem that go beyond a simple model of invasion by low elevation species.

Non-native invasive species

Plants

Coupled with changes in recreational use patterns, changes in temperature and precipitation have the potential to contribute to the successful introduction and establishment of potentially invasive non-native plants. In the 1980s and 1990s the Natural Resource Inventory documented few non-native plants in the alpine and subalpine, and managers have largely relied on that remaining the case in subsequent years (Graber et al. 1993). Recent trends in visitor use patterns, however, suggest the danger of complacency in this regard. In the ten year period between 2000 and 2009, overnight visits to the wilderness areas of Sequoia and Kings Canyon National Parks increased 49%, from approximately 72,500 to 108,300 visitor use nights (Gregg Fauth *pers. comm.*). Similarly, in 1999 490 'through hikers' left Yosemite National Park and walked the length of the John Muir Trail to the summit of Mt. Whitney in Sequoia National Park. In 2008, 1309 people made the same walk- an increase of 167% (Mark Fincher, *pers. comm.*).

What might this mean for the introduction of invasive plants? Increased visitation is likely to lead to increased propagule pressure, as humans carry seeds from around the world on their gear and clothing and at the same time create conditions favorable for their establishment (Morgan and Carnegie 2009). The suite of species being transported is likely to change over time, as the lower elevations of the western states become successfully colonized by a wide variety of taxa from diverse sources. So while high elevation environmental conditions are being disrupted due to changes in temperature and precipitation, new propagules are likely being introduced, suggesting that it is only a matter of time before new plants that can take advantage of those conditions arrive and become established.

Animals

In contrast to the relatively intact native plant communities of the high elevations, alpine aquatic ecosystems have been profoundly altered by the establishment of non-native animals. Specifically, the introduction of non-native fish into historically fishless high elevation lakes has resulted in dramatic declines in mountain yellow-legged frog populations (see Sensitive Animals: Supplement appendix, this document). The cascading effect of nonnative fish establishment can be seen when fish are removed from the aquatic system, not only in the recovery of frog populations, but in the dramatic increase in invertebrate diversity and abundance. Fish eradication has also set the stage for recovery of mountain garter snakes (*Thamnophis elegans elegans*) (Knapp 2005) and gray crowned rosy finches (*Leucosticte* *tephrocotis dawsoni)* (Epancin *et al.* 2010) who are known to prey on young amphibians and invertebrates, respectively.

Although not yet detected in the parks waterways, both the highly invasive zebra mussel (*Dreissena polymorpha)* and the New Zealand mud snail *(Potamopyrgus antipodarum)* also have the potential to establish in Sierran alpine lakes and streams.

Two non-native birds (willow ptarmigan, *Lagopus lagopus*; and chukar, *Alectoris chukar)*, occur in the alpine, but little is known about their ecosystem effects. No non-native mammals, amphibians or reptiles have been reported from the alpine of the two parks.

Pathogens

The spread of *Batrachochytrium dendrobatidis*, an introduced chytrid fungus that causes the disease chytridiomycosis, has contributed to the widespread collapse of mountain yellow-legged frogs throughout the Sierra Nevada alpine. It is discussed in Sensitive Animals: Supplement appendix.

White pine blister rust (*Cronartium ribicola*), which is well-established in the montane forests and threatens the two dominant subalpine tree species in the southern Sierra (whitebark pine, *Pinus albicaulis*, and foxtail pine, *P. balfouriana*), is discussed in detail in the Intact Forest appendix and Five-needle Pines appendix of this report. It is mentioned here because any disruption of the subalpine woodland is likely to interact with other stressors and result in significant consequences for the alpine.

Diseases carried by domestic sheep are thought to have played a role in the decline of native Sierra Nevada bighorn populations. The long-term viability of the federally endangered species remains threatened by the potential spread of respiratory diseases transmitted through contact with domestic herds.

Air Quality/Water Quality

Proximity to the agricultural industry in the Central Valley of California coupled with prevailing weather patterns is known to lead to the delivery of nitrogen and phosphorus, acidic precipitation, pesticides and other contaminants to the alpine. The resulting effects on air quality and water quality--including the potential for significant deposition of these pollutants into high elevation ecosystems--are discussed in the Air Quality appendix and the Water Quality appendix of this report.

The Western Airborne Contaminants Assessment Project (WACAP) evaluated and addressed concerns regarding the persistence, toxicity, and bioaccumulative properties of airborne contaminants such as mercury and pesticides in national park ecosystems. Of the twenty western national parks studied, Sequoia and Kings Canyon National Parks were found to have the highest level of current use pesticides, with measurable levels of both current use and and banned pesticides in snow, lake sediment, fish tissue, vegetation and/or in the air (Landers et al. 2008).

The Sierra Nevada contains thousands of dilute, oligotrophic lakes that are sensitive to changes in climate and atmospheric deposition of acids, nutrients and toxic substances. Recent results suggest that lakes throughout the Sierra are undergoing mild eutrophication. Currently the high elevations of the Sierra Nevada receive an average of 3-4 kg/ha/yr of inorganic nitrogen, with maximum rates of about 6-7 kg/ha/yr (Sickman et al. 2001). Locally, Sickman *et al.* (2003) report that Emerald Lake in Sequoia National Park has experienced eutrophication by P and N during the last 10-15 years. Synoptic lake surveys suggest that trophic changes occurring at Emerald Lake are part of a regional alteration of planktonic communities in high-elevation lakes in the Sierra Nevada.

Fire

Historically fire has played a limited role in the highest elevations. Although ignition potential is high during dry summer months, the lack of fuel restricts high elevation fires to occasional lightning ignited trees at the lower elevations of the alpine, resulting in highly localized effects. How future changes in climate may impact fire regimes in the alpine is uncertain due to the interaction of ignitions, fuel loads, and fuel moisture.

Land Use Fragmentation

Relative to the roaded areas of the lower elevations, the alpine represents some of the least fragmented habitat of the two parks. It is, however, traversed by a network of trails that are used by hikers and pack stock. The ecological impact of this fragmentation on alpine communities has received little attention. At the local scale, work by Holmquist *et al.* (2008) in subalpine wetlands of Yosemite National Park suggests that human use of trails through high elevation meadows influences the composition and dynamics of invertebrate communities in the surrounding vegetation.

Past Management Actions

The most significant management influences on the alpine of Sequoia and Kings Canyon National Parks stem from severe overgrazing by livestock in the mid to late nineteenth century, and widespread stocking of non-native fish in historically fishless lakes and streams beginning in the same period and continuing through the early 1988.

Cattle were first introduced to lowland California in 1769. The use of the Sierra Nevada for summer pasture, first by cattle and then sheep, was triggered by severe drought events of the 1860s and 70s. Although livestock grazing within the newly-created national parks (Sequoia National Park was established in 1890, Kings Canyon National Park in 1940) was prohibited, cattle trespass persisted and was only gradually curtailed during the decades that followed. Widespread overgrazing and its impacts in the Sierra Nevada was well-documented by managers and scientists during the early and mid 1900s (Ratliff 1985). Meadows in particular were a subject of concern, and subsequently significant resources were dedicated to stabilizing those systems. Beginning in the 1950s and continuing through the 1980s, the parks Soil and Moisture Crews focused their efforts on constructing check dams to control erosion in deeply gullied meadows, and also on removing young lodgepole pine (*Pinus contorta* var. *murrayana*) and corn lily (*Veratrum californicum*) which were thought to reflect the effects of past overgrazing (Neuman 1990). Willows (*Salix* spp.) were both actively planted and removed from wetlands. Although these restoration activities took place largely in the montane and subalpine, work was also done in alpine meadows and should be taken into account when evaluating the condition of alpine meadows. During the same period, NPS trail maintenance crews began to reroute backcountry trails from within wet meadows to drier upland terrain and to attempt to restore the adjacent vegetation.

Fish stocking began in the Sierra Nevada in the mid-nineteenth century and by the 1940s was fully established as a state sponsored program. Consequently, non-native trout are well established in alpine water bodies. In the 1970s the NPS began to limit fish stocking in the Sierran parks; by 1988 the introduction of non-native fish into park waters had been stopped entirely in Sequoia and Kings Canyon National Parks, with Yosemite National Park following suit in 1991 (Knapp 1996). The history, extent, and ecological ramifications of fish stocking in the two parks is well-documented in the literature and is discussed in detail in the Sensitive Animals appendix of this assessment.

Overharvest of wildlife, prior to enforcement of hunting and trapping regulations by state and federal authorities, also played a role in impacting wildlife species in the alpine. While diseases contracted from domestic sheep probably were the most important cause of Sierra Nevada bighorn sheep population declines from the 1860s to the early 1900s, market hunting in mining towns probably played a role as well (USFWS 2007). With the wolverine, trapping and control programs were undoubtedly important contributors to the species' decline and extirpation during the same time period (Dixon 1925, Grinnel et al. 1937). While overharvesting played a historical role in impacting wildlife species, it is not a current stressor.

Assessment

To some degree, the alpine environment and the communities it supports is influenced by each of the stressors considered in this assessment. Of the known stressors, it is likely that invasive animals (non-native fish) and non-native pathogens (chytrid fungus, and diseases transmitted by domestic sheep) have historically had the greatest impact on the alpine communities that are evident today. As a result, alpine aquatic systems have been profoundly altered and may be considered among the most compromised systems in Sequoia and Kings Canyon National Parks. The widespread establishment of non-native trout, coupled with the relatively recent emergence of chytrid fungus, is directly linked to the precipitous decline of the mountain yellow-legged frog, which today occupies a fraction of its historical range. Remaining populations of the federally endangered Sierra Nevada bighorn sheep remain at risk from diseases carried by domestic sheep.

It is assumed that historic livestock grazing, particularly by sheep, has shaped the alpine communities we see today. As it is difficult, however, to reconstruct the historic structure, composition and function of these systems (although see Dull 1999), we are unable to say with certainty what the long term ecosystem effects have been.

Positioned 'downwind' of the primary agricultural and urban centers of California, the Sierra Nevada mountains are known to receive a stream of pollutants and contaminants. The long-term effect of these inputs on alpine organisms is the subject of ongoing investigation, but it is likely that the deposition of agricultural contaminants and elevated concentrations of airborne pollutants will interact with other stressors and rise in importance as our understanding increases. For example, simulation models of a Rocky Mountain alpine environment suggest that while vegetation shifts in response to either warming or increased airborne nitrogen deposition, it is the interaction of temperature and nitrogen that will cause the most profound changes (Porter et al. 2011).

We expect that a changing climate will have dramatic effects on the distribution of plants and animals in the Sierra Nevada, with many organisms moving upward in latitude and/or altitude in response to warming temperatures and changing precipitation regimes. Because alpine habitats are found at the extreme end of the temperature gradient in the Sierra, the life forms that are narrowly adapted to those conditions essentially have "nowhere to go", making them uniquely vulnerable to the effects of climate change.

Gaps in Understanding

The remoteness and inaccessibility of the alpine wilderness sets the stage for gaps in what otherwise might be considered basic biogeographic and ecological knowledge. Despite these disadvantages, the alpine has long drawn the attention of scientists, naturalists, and wilderness managers and this has led to the development of a significant body of knowledge regarding the Sierra Nevada alpine.

Remote and rugged terrain has led to a paucity of temperature and precipitation data from the high elevations of the two parks. Addressing this lack will rise in importance as the need for detailed information about the alpine climate, how it is changing, and how plants and animals are responding to those changes increases.

A comprehensive description of alpine plant communities and association-level floristic classification is lacking for the southern Sierra Nevada. This limits our ability to compare the characteristics of the Sierran alpine with alpine systems elsewhere in the world, and to use results from research in similar systems to generate hypotheses regarding local impacts and stressors.

Little is known about the alpine aquatic flora (both vascular and non-vascular) and fauna (specifically, aquatic macroinvertebrates). These water dependent organisms are potentially key indicators of changes in water quality. Due to their sensitivity to contaminants, documenting their distribution and abundance is critical to establishing a baseline against which changes can be measured. Although restoration of high elevation aquatic systems through the removal of non-native fish appears results in recovery of invertebrate populations, we lack information on how the changes in these systems may have impacted other predators, such as the Clark’s nutcracker (*Nucifraga columbiana*).

Limited demographic data are available for the dominant subalpine tree species of the Sierra Nevada. As the climate changes, fluctuations in treeline are hypothesized to pose a unique threat to alpine plant communities. Understanding the population dynamics of these ecotones will be required to anticipate, interpret, and potentially mitigate such shifts.

Recommendations for management and future study/research

Many of the recommendations included in the detailed focal resource chapters of this assessment apply to the alpine environment. The following list is thus not intended to be exhaustive, but rather to serve as a starting point to frame discussion, management, and research.

To better understand the potential and realized effects of environmental stressors on the alpine environment:

- Continue to solicit and encourage research on the potential impacts of climate change on individual species and assemblages, as well as physical and biotic interactions
- Continue to solicit and encourage the study of snowpack dynamics
- Continue to solicit and encourage investigations into the effects of contaminants and airborne pollutants on alpine ecosystems
- Maintain support for implementation of Inventory & Monitoring protocols in the subalpine and alpine: lakes, birds, wetland ecological integrity, and subalpine forests
- Maintain support for the USGS Long-term forest demography studies in the subalpine and upper montane woodlands of Sequoia and Yosemite National Parks
- Revisit high elevation Natural Resource Inventory plots to detect early shifts in the distribution of alpine plant species and to establish a second data point for long term monitoring of alpine communities

- Maintain support for monitoring trends in alpine vegetation and temperature at the Mt. Langley GLORIA site
- Evaluate the potential for expanding the Yosemite Sky Islands monitoring protocol to the unglaciated alpine plateaus of the Kern Canyon, which have the potential to provide complementary data from the southern Sierra Nevada
- Expand phenological monitoring to include key subalpine and alpine species
- Expand current climate and weather monitoring to include deployment of low-cost temperature sensors
- Develop methodology for detecting changes in the extent of alpine communities at the landscape scale

To maintain the integrity of and increase the resiliency of the alpine ecosystem:

- Continue to restore high elevation aquatic ecosystems through removal of non-native fish
- Enhance early-detection efforts for non-native plants and animals, concentrating on areas both subject to disturbance and with a high likelihood of propagule or organism introduction
- Eradicate non-native species when population numbers are low and likelihood of successful control is high
- Expand the range of the Sierra Nevada bighorn sheep through reintroduction into historic range within the parks

- Continue and enhance monitoring of the impact of recreational pack stock on alpine meadows

To increase understanding of alpine ecosystems:

- Continue to document the distribution and abundance of alpine plants, with an emphasis on expanding existing inventories of bryophytes, lichens, and aquatic plants
- Continue to document the distribution and abundance of alpine fauna, with an emphasis on invertebrates and cryptic amphibians
- Continue and enhance monitoring of the effects of restoration efforts on alpine aquatic ecosystems
- Describe the plant communities found in the alpine of the Southern Sierra Nevada and their relationship to environmental variables

Literature Cited

Barnett, T. P., D. W. Pierce, H. G. Hidalgo, C. Bonfils, B. D. Santer, T. Das, G. Bala, A. W. Wood, T. Nozawa, A. A. Mirin, D. R. Cayan, and M. D. Dettinger. 2008. Human-induced changes in the hydrology of the western United States. Science 319:1080-1083.

Billings, W. D. 2000. Alpine vegetation. Pages 537-572 *in* M. G. Barbour and W. D. Billings, editors. North American Terrestrial Vegetation. Cambridge University Press, New York.

Bonfils, C., B. D. Sante, D. W. Pierce, H. G. Hidalgo, G. Bala, T. Das, T. P. Barnett, D. R. Cayan, C. Doutriaux, A. W. Wood, A. Mirin, and T. Nozawa. 2008. Detection and attribution of temperature changes in the mountainous western United States. J Clim 21:6404–6424.

Cayan, D. R., S. A. Kammerdiener, M. D. Dettinger, J. M. Caprio, and D. H. Peterson. 2001. Changes in the onset of spring in the western United States. Bulletin of the American Meteorological Society 82:399-415.

Das, T., H. G. Hidalgo, M. D. Dettinger, D. R. Cayan, D. W. Pierce, C. Bonfils, T. P. Barnett, G. Bala, and A. Mirin. 2009. Structure and detectability of trends in hydrological measures over the western United States. Journal of Hydrometeorology 10:871-892.

Davis, F. W., D. M. Stoms, A. D. Hollander, K. A. Thomas, P. A. Stine, D. Odion, M. I. Borchert, J. H. Thorne, M. V. Gray, R. E. Walker, K. Warner, and J. Graae. 1998. *The California Gap Analysis Project--Final Report*. University of California, Santa Barbara, CA. [http://www.biogeog.ucsb.edu/projects/gap/gap_rep.html]

Dixon, J. S. 1925. Closed season needed for fisher, marten, and wolverine in California. California Department of Fish and Game 11:23-25.

Dull, R. A. 1999. Palynological evidence for 19th century grazing-induced vegetation change in the southern Sierra Nevada, California. Journal of Biogeography 26:899–912.

Epanchin, P.N., R.A. Knapp, and S.P. Lawler. 2010. Nonnative trout impact an alpine-nesting bird by altering aquatic insect subsidies. Ecology 91:2406–2415.

Forrest, J., D. W. Inouye, and J. D. Thomson. 2010. Flowering phenology in subalpine meadows: Does climate variation influence community co-flowering patterns? Ecology, 91(2), 2010, pp. 431–440.

Graber, D. M., S. A. Haultain, and J. E. Fessenden. 1993. Conducting a biological survey: a case study from Sequoia and Kings Canyon National Parks. In: Proceedings of the Symposium on Research in California's National Parks, National Park Service.

Grinnell, J., J. S. Dixon, and J. M. Linsdale. 1937. Fur-Bearing Mammals of California, University of California Press, Berkeley.

Hallinger, M., M. Manthey and M. Wilmking. 2010. Establishing a missing link: warm summers and winter snow cover promote shrub expansion into alpine tundra in Scandinavia. New Phytologist Volume 186, Issue 4: 890–899.

Heywood, V. H. 1995. Global Biodiversity Assessment. Cambridge University Press, Cambridge, U.K.

Holmquist, JG, Schmidt-Gengenbach, J. 2008. Effects of experimental trampling addition and reduction on vegetation, soils, and invertebrates and assessment of current conditions in Tuolumne Meadows. Final Report, Yosemite National Park, El Portal, CA. 87pp.

Knapp, R. A. 1996. Non-native trout in natural lakes of the Sierra Nevada: an analysis of their distribution and impacts on native aquatic biota. Pages 363-407 in Sierra Nevada Ecosystem Project: Final Report to Congress. Volume III: Assessments, Commissioned Reports, and Background Information. Davis: University of California, Centers for Water and Wildland Resources.

Knapp, R. A. 2005. Effects of nonnative fish and habitat characteristics on lentil herpetofauna in Yosemite National Park, USA. Biological Conservation 121:265-279

Knowles, N., M. D. Dettinger, and D. R. Cayan. 2006. Trends in snowfall versus rainfall in the Western United States. Journal of Climate 19:4545-4559.

Krajik, K. 2004. All downhill from here? Science 303:1600-1602.

Kullman, L. 2010. Alpine flora dynamics - a critical review of responses to climate change in the Swedish Scandes since the early 1950s. Nordic Journal of Botany 28: 398-408.

Landers, D. H., S. L. Simonich, D. A. Jaffe, L. H. Geiser, D. H. Campbell, A. R. Schwindt, C. B. Schreck, M. L. Kent, W. D. Hafner, H. E. Taylor, K. J. Hageman, S. Usenko, L. K. Ackerman, J. E. Schrlau, N. L. Rose, T. F. Blett and M. M. Erway. 2008. The Fate, Transport and Ecological Impacts of Airborne Contaminants in Western National Parks (USA). EPA/600/R-07/138. U.S. Environmental Protection Agency, Office of Research and Development, NHEERL, Western Ecology Division, Corvallis, Oregon.

Major, J. and Taylor, D.W., 1988: Alpine. In Barbour, MG and Major, J. (eds.), Terrestrial Vegetation of California. California Native Plant Society Special Publication 9. Sacramento, Calif., 601-677.

Morgan, J. W. and V. Carnegie. 2009. Backcountry huts as introduction points for invasion by non-native species into subalpine vegetation. Arctic, Antarctic, and Alpine Research, Vol. 41, No. 2, pp. 238–245.

Moritz, C, J. Patton, C. Conroy, J. Parra, G. White, S. Beissinger 2008. Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA Science.

Muñoz, A. A. and L. A. Cavieres. 2008. The presence of a showy invasive plant disrupts pollinator service and reproductive output in native alpine species only at high densities. *Journal of Ecology* 2008, 96, 459–467.

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. da Fonseca and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853-858.

Neuman, M.J. 1990. Past and present conditions of backcountry meadows in Sequoia and Kings Canyon National Parks, 2nd ed. December 21, 1990. National Park Service file report, Sequoia and Kings Canyon National Parks. 722 p.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology and Systematics 37:637-669.

Pauchard, A., C. Kueffer, H. Dietz, C. C. Daehler, J. Alexander, P. J. Edwards, J. R. Arévalo, L. A. Cavieres, A. Guisan, S. Haider, G. Jakobs, K. McDougall, C. I. Millar, B. J. Naylor, C. G. Parks, L. J. Rew, and T. Seipel. 2009. Ain't no mountain high enough: plant invasions reaching new elevations. Frontiers in Ecology and the Environment 7:479–486.

Pauli, H., M. Gottfried, K. Reiter, C. Klettner and G. Grabherr. 2007. Signals of range expansions and contractions of vascular plants in the high Alps: observations (1994–2004) at the GLORIA*master site Schrankogel, Tyrol, Austria. Global Change Biology (2007) 13, 147–156.

Porter, E., H. Sverdrup, and T. J. Sullivan. 2011. Estimating and mitigating the impacts of climate change and air pollution on alpine plant communities in national parks. Park Science 28(2):58-64.

Ratliff. R. D. 1985. Meadows in the Sierra Nevada of California: state of knowledge. U.S. Forest Service General Technical Report PSW-84.

Rosenzweig, Cynthia, David Karoly, Marta Vicarelli, Peter Neofotis, Qigang Wu, Gino Casassa, Annette Menzel, Terry L. Root, Nicole Estrella, Bernard Seguin, Piotr Tryjanowski, Chunzhen Liu, Samuel Rawlins and Anton Imeson 2008. Attributing physical and biological impacts to anthropogenic climate change. Nature 453, 353-357

Schwartz, M. D., Ahas, R. and A. Aasa. (2006), Onset of spring starting earlier across the Northern Hemisphere. Global Change Biology, 12: 343–351.

Sharsmith, C. 1940. A contribution to the history of the alpine flora of the Sierra Nevada. Ph.D. thesis, University of California, Berkeley. 273 p.

Sickman, J. O., A. Leydecker, and J. M. Melack. 2001. Nitrogen mass balances and abiotic controls on N retention and yield in high-elevation catchments of the Sierra Nevada, California, United States. Water Resources Research 37:1445-1461.

Sickman, J. O., J. M. Melack, and D. W. Clow. 2003. Evidence for nutrient enrichment of high-elevation lakes in the Sierra Nevada, California. Limnology and Oceanography 48:1885-1892.

Stewart, I. T., D. R. Cayan, and M. D. Dettinger. 2005. Changes toward earlier streamflow timing across western North America. Journal of Climate 18:1136-1155.

Theurillat, J.P. & A. Guisan. 2001. Potential impact of climate change on vegetation in the European Alps: A review. *Clim. Change* 50: 77-109.

Tomback, D. F. and P. Achuff. 2010. Blister rust and western forest biodiversity: ecology, values and outlook for white pines. Forest Pathology 40:186-225.

Trivedi, M.R., Morecroft, M.D., Berry, P.M., Dawson, T.P., 2008b. Potential effects of climate change on plant communities in three montane nature reserves in Scotland, UK, Biol. cons., (141) 6: 1665-1675.

(USFWS) US Fish and Wildlife Service. 2007. Recovery Plan for the Sierra Nevada Bighorn Sheep. Sacramento, California.

USGS-NPS. Vegetation Mapping Program. 2007. Sequoia and Kings Canyon National Parks photo interpretation report. Three Rivers, California.

van Mantgem P.J., Stephenson N.L. 2007. Apparent climatically induced increase of tree mortality rates in a temperate forest. Ecol Lett 10:909–916.

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