Sierra Nevada Individual Species Vulnerability Assessment Briefing: Bighorn Sheep

Ovis canadensis sierra

Background and Key Terminology

This document summarizes the primary factors that influence the vulnerability of a focal resource to climate change over the next century. In this context, vulnerability is a function of the sensitivity of the resource to climate change, its anticipated exposure to those changes, and its capacity to adapt to changes. Specifically, sensitivity is defined as a measure of whether and how a resource is likely to be affected by a given change in climate or factors driven by climate; exposure is defined as the degree of change in climate or climate-driven factors a resource is likely to experience; and adaptive capacity is defined as the ability of a resource to accommodate or cope with climate change impacts with minimal disruption (Glick et al. 2011). The purpose of this assessment is to inform forest planning by government, non-profit, and private sector partners in the Sierra Nevada region as they work to integrate climate change into their planning documents.

Executive Summary

The overall vulnerability of Sierra Nevada bighorn sheep subspecies is ranked as moderate-high, due to their moderate-high sensitivity to climate and non-climate stressors, low-moderate adaptive capacity, and high exposure.

Sierra Nevada bighorn sheep are indirectly sensitive to climate-driven changes such as:

- temperature,
- precipitation, and
- fire.

Temperature is predicted to increase over the next century, and is likely to contribute to reductions in alpine habitat extent for bighorn sheep. Although snow water equivalent at high elevations in central and southern Sierra Nevada is expected to increase through the end of the century, spring and summer precipitation, important for growth of forage plants, is predicted to decrease over the next century.

Sierra Nevada bighorn sheep are also sensitive to non-climate stressors including:

- disease, and
- predation pressure.

These non-climate stressors can cause direct mortality, reduced fitness, and amplify the effects of climate-driven changes. For example, pulmonary pathogens, contracted from domestic sheep, may more readily develop into pneumonia by Sierra Nevada bighorn sheep suffering from stress resulting from reduced forage quality and quantity. The capacity of Sierra Nevada bighorn sheep to adapt to changes in climate however, will likely be facilitated by their use of a range of systems, from alpine to pinyon-juniper and sagebrush steppe at lower elevations.

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Sensitivity & Exposure

Sensitivity to climate and climate-driven changes

Sensitivity of the Sierra Nevada bighorn sheep subspecies (hereafter 'bighorn sheep') to climate change will be driven largely by the effect of temperature on alpine habitats, and precipitation (snow and rain) and fire on forage quality and availability. Bighorn sheep use forage areas such as alpine meadows with an abundance of forbs, as well as sagebrush-scrub communities (Schroeder et al. 2010). Increased temperatures are projected to lead to declines in alpine and subalpine habitat extent by 75-90% by the end of the century (Lenihan et al. 2003; Hayhoe et al. 2004), potentially resulting in large reductions of alpine forage availability near escape terrain. Annual precipitation and snowfall vary considerably in the Sierra Nevada where bighorn sheep occur (Schroeder et al. 2010). Snow can affect the timing of green-up and availability of vegetation used by mountain sheep (Rachlow and Bowyer 1991, 1994), and rain in spring and summer is important for growth of forage plants used by bighorn sheep (Wehausen 1992, Oehler et al. 2003 cited in Schroeder et al. 2010). Changes in the snow to rain ratio, and reductions in spring and summer precipitation may affect forage opportunities for Sierra Nevada bighorn sheep.

Habitat requirements differ between summer range and winter range and between sexes (Schroeder et al. 2010). For example, proximity to escape terrain appears to be associated with increased forage efficiency for females (Schroeder et al. 2010), which occur in areas of greater visibility and spend more time foraging than males, and in winter, males use ranges with more shrub and overall biomass than females (Schroder et al. 2010). Climate-driven changes to forage availability and quality may impact the sexes differently.

Sierra Nevada bighorn sheep prefer terrain that allows for visibility of predators, and thus may be negatively impacted by conifer encroachment (Latham 2010; Greene et al. 2012). Wildfire, however, may indirectly benefit bighorn sheep by increasing visibility of predators, forb availability, and forage quality (Greene et al. 2012), though due to differences in diet and habitat use, males and females may be differentially impacted by fires (Schroder et al. 2010).

Future climate exposure

Climate and climate-driven changes important to consider for Sierra Nevada bighorn sheep include increased temperatures, decreased precipitation and snowpack, and fire, and the consequent impacts on forage availability and quality.

Increased temperatures are projected to lead to declines in alpine and subalpine habitat extent by 75-90% by the end of the century (Lenihan et al. 2003; Hayhoe et al. 2004), potentially resulting in large reductions of alpine forage availability near escape terrain. However, models also predict advancement of shrubland into alpine/subalpine habitats (Lenihan et al. 2003), which may provide alternate forage sources.

Temperature: High elevation forests have seen pronounced increases in temperature over the past century (Dolanc et al. 2013). Over the next century, annual temperatures in the Sierra Nevada are expected to rise between 2.4-3.4˚C varying by season, geographic region, and elevation (Das et al. 2011; Geos Institute 2013). 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), with changes of least magnitude during both seasons anticipated in the central bioregion (Geos Institute 2013). Associated with rising temperatures will be an increase in potential evaporation (Seager et al. 2007).

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). Projections for future precipitation in the Sierra Nevada vary among models; 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), with decreases in summer and fall (Geos Institute 2013). Frequency of extreme precipitation, however, is expected to increase in the Sierra Nevada between 18-55% by the end of the century (Das et al. 2011).

Snow volume and timing: Despite modest projected changes in overall precipitation, models of the Sierra Nevada region largely project decreasing snowpack and earlier timing of runoff (Miller et al. 2003; Dettinger et al. 2004b; Hayhoe et al. 2004; 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, 2004 b; Young et al. 2009; Null et al. 2010). Annual snowpack in the Sierra Nevada is projected to decrease between 64-87% by late century (Thorne et al. 2012; Flint et al. 2013), with declines of 10-25% above 3750 m (12303 ft), and 70-90% below 2000 m (6562 ft) (Young et al. 2009). The greatest declines in snowpack are anticipated for the northern Sierra Nevada (Safford et al. 2012), with current pattern of snowpack retention in the higher-elevation southern Sierra Nevada basins expected to continue through the end of the century (Maurer 2007). The greatest losses in snowmelt volume are projected 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).

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 meal annual flow (Null et al. 2010). Mean annual flow is projected to decrease most substantially in the northern bioregion (Null et al. 2010).

Wildfire: Historically, forest fires were relatively rare in alpine and subalpine vegetation, and did not play as strong a role in structuring these ecosystems as they did in lower elevation systems (Van de Water and Safford 2011; Safford and Van de Water 2013). However, with earlier snowmelt and warmer temperatures, models and current trends suggest that fire may become a more significant ecological disturbance in high elevation forests through the 21st century (Fites-Kaufman et al. 2007; Mallek et al. 2013), especially if climate warming leads to densification of bristlecone stands (Dolanc et al. 2013). Both the frequency and annual area burned by wildfires in the western U.S. have increased strongly over the last several decades (Westerling et al. 2006). Fire severity in the Sierra Nevada also rose from 17% to 34% high-severity (i.e. stand replacing) fire, especially in middle elevation conifer forests (Miller et al. 2009). In the Sierra Nevada, increases in large fire extent have been correlated with increasing temperatures and earlier snowmelt (Westerling and Bryant 2006), as well as current year drought combined with antecedent wet years (Taylor and Beaty 2005). Occurrence of large fire and total area burned in California are predicted to continue increasing over the next century, with total area burned increasing by up to 74% by 2085 (Westerling et al. 2011). The area burned by wildfire in the Sierra Nevada is projected to increase between 35-169% by the end of the century, varying by bioregion, with the greatest increases projected at mid-elevation sites along the west side of the range (Westerling et al. 2011; Geos Institute 2013).

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). Additional material on climate trends for the system may be found through the TACCIMO website (http://www.sgcp.ncsu.edu:8090/). Downscaled climate projections available through the Data Basin website (http://databasin.org/galleries/602b58f9bbd44dffb487a04a1c5c0f52).

Sensitivity to non-climate stressors

Sierra Nevada bighorn sheep are also sensitive to a number of non-climate stressors that may interact with climate-driven stressors to increase species vulnerability, including disease and predation. Contact with domestic sheep may lead to mortality in bighorn sheep, potentially due to transmission of pulmonary pathogens that lead to pneumonia-associated mortality (Martin et al. 1996 and the references therein; Tomassini et al. 2009; Wehausen et al. 2011). In bighorn sheep species, susceptibility to pathogen related mortality may be increased by food shortage and stress, as well as periods of abnormal temperature and precipitation (Monello et al. 2001). Climate-induced reductions in forage quality and availability may increase the incidence of pneumonia and sheep mortality. Predation by cougar (*Puma concolor*) is a permanent pressure on bighorn sheep populations (USFWS 2008). Although bighorn sheep and mule deer do not strongly compete for forage, spatial proximity to deer may increase cougar predation (Johnson et al. 2013). Predator-prey dynamics may be altered if Sierra Nevada bighorn sheep foraging opportunities decline or shift away from escape terrain, or conifer encroachment reduces visibility as a result of climate-driven changes.

Adaptive Capacity

The capacity of Sierra Nevada bighorn sheep to accommodate changes in climate is likely influenced by its small population size and specialized habitat use. The Sierra Nevada bighorn sheep population has the lowest number and most restricted range of any bighorn species (Sierra Nevada Bighorn Sheep Recovery Program 2013) and is listed as endangered under the U.S. Endangered Species Act. The population is estimated at fewer than 500 individuals and distributed in herd units occupying three distinct areas along the crest of the southern Sierra Nevada. Despite their fragmentation, bighorn sheep have the ability to disperse long distances provided suitable habitat remains connected. Although Sierra Nevada bighorn sheep are dependent on alpine areas near escape terrain during portions of the year, they also occupy a range of habitats, and have considerable plasticity in relation to the other subspecies of bighorn sheep. Utilization of a range of systems, from alpine to pinyon-juniper and sagebrush steppe at lower elevations (Schroeder et al. 2010) during the seasonal upslope and downslope migration may indicate a level of plasticity that will aid Sierra Nevada bighorn sheep in adapting to climate changes.

Literature Cited

Cayan, D., 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**(3): 399-145.

Cayan, D. R., E. P. Maurer, M. D. Dettinger, M. Tyree and K. Hayhoe (2008). "Climate change scenarios for the California region." Climatic Change **87**(S1): 21-42.

Das, T., M. D. Dettinger, D. R. Cayan and H. G. Hidalgo (2011). "Potential increase in floods in California's Sierra Nevada under future climate projections." Climatic Change **109**(S1): 71-94.

Dettinger, M. D. (2005). "From climate-change spaghetti to climate-change distributions for 21st Century California." San Francisco Estuary and Watershed Science **3**(1): Article 4.

Dettinger, M. D., D. R. Cayan, N. Knowles, A. Westerling and M. K. Tyree (2004a). Recent Projections of 21st-Century Climate Change and Watershed Responses in the Sierra Nevada, USDA Forest Service. **Gen. Tech. Report PSW-GTR-193**.

Dettinger, M. D., D. R. Cayan, M. K. Meyer and A. E. Jeton (2004b). "Simulated Hydrologic Responses to Climate Variations and Change in the Merced, Carson, and American River Basins, Sierra Nevada, California, 1900–2099." Climate Change **62**: 283-317.

Dolanc, C. R., J. H. Thorne and H. D. Safford (2013). "Widespread shifts in the demographic structure of subalpine forests in the Sierra Nevada, California, 1934 to 2007." Global Ecology and Biogeography **22**(3): 264-276.

Fites-Kaufman, J. A., P. Rundel, N. Stephenson and D. A. Weixelman (2007). Montane and Subalpine Vegetation of the Sierra Nevada and Cascade Ranges. Terrestrial Vegetation of California. Berkeley, University of California Press**:** 456-501.

Flint, L. E., A. L. Flint, J. H. Thorne and R. Boynton (2013). "Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance." Ecological Processes ***2***: 25.

Geos Institute (2013). Future Climate, Wildfire, Hydrology, and Vegetation Projections for the Sierra Nevada, California: A climate change synthesis in support of the Vulnerability Assessment/Adaptation Strategy (VAAS) process, Available online at: http://www.geosinstitute.org/climatewiseservices/completed-climatewise-projects.html.

Glick, P., B. A. Stein and N. A. Edelson (2011). Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. Washington, D.C., National Wildlife Federation.

Greene, L., M. Hebblewhite and T. R. Stephenson (2012). "Short-term vegetation response to wildfire in the eastern Sierra Nevada: Implications for recovering an endangered ungulate." Journal of Arid Environments **87**: 118-128.

Hayhoe, K., D. Cayan, C. B. Field, P. C. Frumhoff, E. P. Maurer, N. L. Miller, S. C. Moser, S. H. Schneider, K. N. Cahill, E. E. Cleland, L. Dale, R. Drapek, R. M. Hanemann, L. S. Kalkstein, J. Lenihan, C. K. Lunch, R. P. Neilson, S. C. Sheridan and J. H. Verville (2004). "Emissions pathways, climate change, and impacts on California." Proceedings of the National Academy of Sciences **101**(34): 12422-12427.

Johnson, H. E., M. Hebblewhite, T. R. Stephenson, D. W. German, B. M. Pierce and V. C. Bleich (2013). "Evaluating apparent competition in limiting the recovery of an endangered ungulate." Oecologia **171**(1): 295-307.

Knowles, N. and D. Cayan (2004). "Elevational dependence of projected hydrologic changes in the San Francisco Estuary and Watershed." Climate Change **62**: 319-336.

Latham, E. L. S. (2010). Changes in Bighorn Sheep Habitat in the Sierra Nevada Mountains. Master of GIS, University of Calgary.

Lenihan, J., R. Drapek, D. Bachelet and R. P. Neilson (2003). "Climate change effects on vegetation distribution, carbon, and fire in California." Ecological Applications **13**(6): 1667-1681.

Mallek, C. R., H. D. Safford, J. H. Viers and J. Miller (2013). "Modern departures in fire severity and area vary by forest type, Sierra Nevada and southern Cascades, California, USA." Ecosphere **4**(12): 1-28.

Martin, K. D., T. Schommer and V. L. Coggins (1996). Literature review regarding the compatibility between bighorn and domestic sheep. Proceedings of the biennial symposium of the Northern Wild Sheep and Goat Council.

Maurer, E. P. (2007). "Uncertainty in hydrologic impacts of climate change in the Sierra Nevada, California, under two emissions scenarios." Climatic Change **82**(3-4): 309-325.

Maurer, E. P., I. T. Stewart, C. Bonfils, P. B. Duffy and D. Cayan (2007). "Detection, attribution, and sensitivity of trends toward earlier streamflow in the Sierra Nevada." Journal of Geophysical Research **112**(D11).

Miller, J. D., H. D. Safford, M. Crimmins and A. E. Thode (2009). "Quantitative Evidence for Increasing Forest Fire Severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA." Ecosystems **12**: 16-32.

Miller, N. L., K. E. Bashford and E. Strem (2003). "Potential impacts of climate change on California hydrology." Journal of American Water Resources Association **39**(4): 771-784.

Monello, R. J., D. L. Murray and E. F. Cassirer (2001). "Ecological correlates of pneumonia epizootics in bighorn sheep herds." Canadian Journal of Zoology **79**: 1423-1432.

Null, S. E., J. H. Viers and J. F. Mount (2010). "Hydrologic response and watershed sensitivity to climate warming in California's Sierra Nevada." PLoS One **5**(4).

Rachlow, J. L. and R. T. Bowyer (1991). "Interannual Variation in Timing and Synchrony of Parturition in Dall's Sheep " Journal of Mammalogy **72**(3): 487-492.

Rachlow, J. L. and R. T. Bowyer (1994). "Variability in Maternal Behavior by Dall's Sheep: Environmental Tracking or Adaptive Strategy?" Journal of Mammalogy **75**(2): 328-337.

Safford, H., M. North and M. D. Meyer (2012). Chapter 3: Climate Change and the Relevance of Historical Forest Condition. Managing Sierra Nevada Forests, USDA Forest Service, Pacific Southwest Research Station. **Gen. Tech. Rep. PSW-GTR-237**.

Safford, H. D. and K. M. Van de Water (2013). Using Fire Return Interval Departure (FRID) analysis to map spatial and temporal changes in fire frequency on National Forest lands in California. Albany, CA, USDA Forest Service, Pacific Southwest Research Station. **General Technical Report PSW-GTR-247**.

Schroeder, C. A., R. T. Bowyer, V. C. Bleich and T. R. Stephenson (2010). "Sexual Segregation in Sierra Nevada Bighorn Sheep, Ovis canadensis sierrae: Ramifications for Conservation." Arctic, Antarctic, and Alpine Research **42**(4): 476-489.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. P. Huang, N. Harnik, A. Leetmaa, N. C. Lau, C. Li, J. Velez and N. Naik (2007). "Model projections of an imminent transition to a more arid climate in southwestern North America." Science **316**(5828): 1181-1184.

Sheffield, J., G. Goteti, F. Wen and E. F. Wood (2004). "A simulated soil moisture based drought analysis for the United States." Journal of Geophysical Research: Atmospheres (1984-2012) **109(D24)**.

Sierra Nevada Bighorn Sheep Recovery Program. "Sierra Nevada Bighorn Sheep Recovery Program." Retrieved August 8, 2013, 2013, from http://www.dfg.ca.gov/snbs/RecoveryHome.html.

Taylor, A. H. and R. M. Beaty (2005). "Climatic influences on fire regimes in the northern Sierra Nevada mountains, Lake Tahoe Basin, Nevada, USA." Journal of Biogeography **32**(3): 425-438.

Thorne, J. H., R. Boynton, L. Flint, A. Flint and T.-N. G. Le (2012). Development and Application of Downscaled Hydroclimatic Predictor Variables for Use in Climate Vulnerability and Assessment Studies, Prepared for California Energy Commission, Prepared by University of California, Davis. **CEC-500-2012-010**.

Tomassini, L., B. Gonzales, G. C. Weiser and W. Sischo (2009). "An ecologic study comparing distribution of Pasteurella trehalosi and Mannheimia haemolytica between Sierra Nevada bighorn sheep, White Mountain bighorn sheep, and domestic sheep." Journal of Wildlife Disease **45**(4): 930-940.

USFWS (2008). Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Sierra Nevada Bighorn Sheep (Ovis canadensis sierrae) and Taxonomic Revision. Department of the Interior USFWS. **73**.

Van de Water, K. M. and H. D. Safford (2011). "A Summary of Fire Frequency Estimates for California Vegetation before Euro-American Settlement." Fire Ecology **7**(3): 26-58.

Wehausen, J. D., S. T. Kelley and R. R. Ramey II (2011). "Domestic sheep, bighorn sheep, and respiratory disease: a review of the experimental evidence." California Fish and Game **97**(1): 7-24.

Westerling, A. L. and B. P. Bryant (2006). Climate Change and Wildfire in and around California: Fire Modeling and Loss Modeling. Prepared for California Climate Change Center. **CEC-500-2005-190-SF:** 33.

Westerling, A. L., B. P. Bryant, H. K. Preisler, T. P. Holmes, H. G. Hidalgo, T. Das and S. R. Shrestha (2011). "Climate change and growth scenarios for California wildfire." Climatic Change **109**(S1): 445-463.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan and T. W. Swetnam (2006). "Warming and earlier spring increase western U.S. forest wildfire activity." Science **313**: 940-943.

Young, C. A., M. I. Escobar-Arias, M. Fernandes, B. Joyce, M. Kiparsky, J. F. Mount, V. K. Mehta, D. Purkey, J. H. Viers and D. Yates (2009). "Modeling The Hydrology Of Climate Change In California's Sierra Nevada For Subwatershed Scale Adaptation." Journal of American Water Resources Association **45**(6): 1409-1423.

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