Sierra Nevada Ecosystem Vulnerability Assessment Briefing: Wet Meadows and Fens

CWHR types[1]**: WTM**: Sedge species (*Carex spp*.), rush species (*Juncus spp*.), tufted hairgrass (*Deschampsia cespitosa*)

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 the wet meadow and fen systems is ranked moderate-high, due to its moderate-high sensitivity to climate and non-climate stressors, low-moderate adaptive capacity, and moderate-high exposure.

Wet meadow and fen systems are sensitive to climate-driven changes such as:

- altered precipitation,
- decreased snowpack, and
- altered hydrology.

Meadow distribution, type and vegetation density are primarily determined by hydrology; hence meadows are particularly sensitive to drying caused by reduced snowpack, erosion resulting from shifts from snow to rain, and extreme rain events.

Wet meadow and fen systems are also sensitive to several non-climate stressors including:

- water diversions,
- grazing,
- recreational activities, and
- fire suppression.

Several non-climate factors can degrade the state of meadows and compound the climate-driven changes on meadow hydrology, including grazing animals and recreational activities that

---

[1] Following the California Wildlife Habitat Relationship (CWHR) System found at: http://www.dfg.ca.gov/biogeodata/cwhr/wildlife_habitats.asp

compact soils and reduce infiltration. The capacity of wet meadow and fen systems to adapt to changes in climate is strongly limited by its fragmented distribution and dependence on water.

Recommended Citation

Hauptfeld, R.S. and J.M. Kershner. 2014. Sierra Nevada Ecosystem Vulnerability Assessment Briefing: Wet Meadows and Fens. Version 1.0. EcoAdapt, Bainbridge Island, WA.

This document is available online at EcoAdapt (http://ecoadapt.org/programs/adaptation-consultations/calcc).

Sensitivity & Exposure

Sensitivity to climate and climate-driven changes

Meadow distribution, type and vegetation density are primarily determined by hydrology (Ratliff 1985; Weixelman et al. 2011; Viers et al. 2013), indicating that wet meadows are highly sensitive to climate-driven changes that impact hydrology. This includes changes in snowmelt (Stillwater Sciences 2012), precipitation and groundwater (Cooper and Wolf 2006; Loheide et al. 2009; Howard and Merrifield 2010; Viers et al. 2013), and particularly changes in the amplitude, duration, and timing of surface and subsurface flows (Viers et al. 2013). A high groundwater table is essential for meadow plants, which often have elevated rates of transpiration (Elmore et al. 2006; Loheide and Gorelick 2007). Wet meadows, for example, are found where the groundwater table depth during the growing season is approximately 0-40 cm deep; mesic meadows at 40-100 cm; and dry meadows where the water table is below 100 cm (Chambers et al. 2011; Lord et al. 2011). 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). Greatest losses in snowmelt volume are expected between 1750 to 2750 m (5741 ft to 9022 ft) (Miller et al. 2003; Knowles and Cayan 2004; Maurer 2007; Young et al. 2009), largely corresponding with the elevation where montane meadows occur.

Shifts from rain to snow are also largely expected between 1500 to 3000 m (4921 ft to 9843 ft) (Viers et al. 2013; Young et al. 2009), where the majority of montane meadows occur (Viers et al. 2013). Shifts from snow to rain are anticipated to contribute to flashy runoff caused by extreme precipitation events, leading to erosion of moist peat and topsoil (Micheli and Kirchner 2002; Weixelman et al. 2011) and channel incision (Viers et al. 2013). Channel incision and erosion lead to drying of meadows (Viers et al. 2013) and diminished water storage within watersheds, potentially decreasing mean annual flow (Null et al. 2010). (Please refer to Null et al. 2010 for a discussion on differential watershed responses across the Sierra Nevada).

Increased evapotranspiration rates in meadows are expected to further contribute to a reduction of soil moisture (Stillwater Sciences 2012), altering meadow dynamics. Prolonged drought and altered hydrology may enable tree and shrub encroachment (Millar et al. 2004).

However, wet meadows in which hydrologic inputs are mainly from spring sources or where stream incision has not occurred are likely less sensitive to climate change.

Future climate exposure

It will be important to consider climate and climate-driven factors that impact the hydrology of wet meadow and fen systems, including changes in snow volume and timing, precipitation, runoff, and soil moisture (i.e. climatic water deficit).

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).

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). 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).

Runoff: A shift from snowfall to rainfall is also expected to result in flashier runoff with higher flow magnitudes, which may lead to erosion of topsoil (Weixelman et al. 2011; Viers et al. 2013), channel incision, drying of meadows (Viers et al. 2013), and less water stored within watersheds. Mean annual flow is projected to decrease most substantially in the northern bioregion (Null et al. 2010).). As storage capacity is reduced in the mountains (Null et al. 2010), significant challenges to groundwater recharge and surface flows will be faced in the Sacramento and San Joaquin valleys (Medellín-Azuara et al. 2008; Hanak and Lund 2012). Mean annual flow is projected to decrease most substantially in the northern bioregion (Null et al. 2010).

Climatic water deficit: 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. 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). In the Sierra Nevada, climatic water deficit has increased slightly (~4%) in the past 30 years compared with the 1951-1980 baseline (Flint et al. 2013). Future downscaled water deficit modeling using the Basin Characterization Model predicts increased water deficits (i.e., decreased soil moisture) by up to 44%, with the greatest increases in the northern Sierra Nevada (Thorne et al. 2012; Flint et al. 2013; 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

Sensitivity of wet meadow and fen systems to climate change may be exacerbated by their current impacted state (Loheide et al. 2009), fragmented distribution, and ownership patterns, in which a high percentage of meadows occur on private land. Non-climatic factors which have contributed to the degraded state of meadows include water diversions and storage (particularly in the northern Sierra Nevada), feedstock and packstock grazing (e.g. cattle, sheep and horses), recreational activities, and fire suppression (Cole et al. 2004; Stillwater Sciences 2012; Viers et al. 2013). Grazing causes soil compaction and channel incision, lowering streambeds and groundwater tables (Stillwater Sciences 2012), and potentially exacerbating the hydrologic changes anticipated with climate change. At higher elevation meadows, packstock associated with recreational activities may have greater impact than feedstock due in part to soil compaction, along with campgrounds (Menke et al. 1996 cited in Stillwater Sciences 2012), and off-road vehicle use. A list of primary research on grazing impacts in meadows can be found in Stillwater Sciences (2012). Fire suppression during the 20th century may contribute to conifer encroachment in meadows (Stillwater Sciences 2012), compounding the changes in meadow habitat features resulting from climate-driven alterations in hydrology.

Adaptive Capacity

The capacity of the wet meadow and fen systems to accommodate changes in climate is greatly limited by their dependence on water availability, as well as their fragmented distribution and degraded state. Meadows are well distributed across the Sierra Nevada at different elevations (Whitney 1979) but are among the rarest and most isolated habitat types in the region, representing approximately 1% of the land base (Davis and Stoms 1996; Viers et al. 2013). Although meadows occur within a diverse range of elevations (Whitney 1979) and soil types, permeability across the landscape is limited by topography and geologic features, including soil type, basin shape and depth, and slope (Weixelman et al. 2011). The non-uniform distribution and lack of connectivity may exacerbate the effects of altered hydrology (Viers et al. 2013) on meadows. Watersheds that have experienced a lower degree of hydrologic alteration may support meadows with a higher capacity to adapt to future climatic conditions. Similarly, meadows within cold sinks and fed by northerly exposed watersheds may be more resilient to projected climatic conditions.

Literature Cited

Chambers, J. C. and J. R. e. Miller (2011). Geomorphology, hydrology, and ecology of Great Basin meadow complexes - implications for management and restoration. General Technical Report, RMRS-GTR-258. Fort Collins, Colorado, USDA Forest Service, Rocky Mountain Research Station.

Cole, D. N., J. W. Van Wagtendonk, M. P. McClaran, P. E. Moore and N. K. McDougald (2004). "Response of mountain meadows to grazing by recreational pack stock." Rangeland Ecology and Management **57**(2): 153-160.

Cooper, D. J. and E. C. Wolf (2006). Fens of the Sierra Nevada, California. Final Report to the USDA Forest Service. **47**.

Davis, F. W. and D. M. Stoms (1996). Sierran vegetation: A gap analysis. Chap. 23. Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, Davis: University of California, Centers for Water and Wildland Resources. .

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.

Elmore, A. J., S. J. Manning, J. F. Mustard and J. M. Craine (2006). "Decline in alkali meadow vegetation cover in California: the effects of groundwater extraction and drought." Journal of Applied Ecology **43**(4): 770-779.

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.

Hanak, E. and J. R. Lund (2012). "Adapting California’s water management to climate change." Climatic Change **111**(1): 17-44.

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.

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

Loheide, S. P., R. S. Deitchman, D. J. Cooper, E. C. Wolf, C. T. Hammersmark and J. D. Lundquist (2009). "A framework for understanding the hydroecology of impacted wet meadows in the Sierra Nevada and Cascade Ranges, California, USA." Hydrogeology Journal **17**(1): 229-246.

Loheide, S. P. and S. M. Gorelick (2007). "Riparian hydroecology: A coupled model of the observed interactions between groundwater flow and meadow vegetation patterning." Water Resources Research **43**(7): n/a-n/a.

Lord, M., D. Jewett, J. R. Miller, D. Germanoski and J. C. Chambers (2011). Hydrologic processes influencing meadow ecosystems. Great Basin Riparian Ecosystems: Ecology, Management, and Restoration (Chp 4]. Geomorphology, hydrology, and ecology of Great Basin meadow complexes - implications for management and restoration. J. C. Chambers and J. R. Miller. Fort Collins, CO, USCA Forest Service Rocky Mountain Research Station. **Gen. Tech. Rep. RMRS-GTR-258:** 44-67.

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).

Medellín-Azuara, J., J. J. Harou, M. A. Olivares, K. Madani, J. R. Lund, R. E. Howitt, S. K. Tanaka, M. W. Jenkins and T. Zhu (2008). "Adaptability and adaptations of California’s water supply system to dry climate warming." Climatic Change **87**(S1): 75-90.

Micheli, E. R. and J. W. Kirchner (2002). "Effects of wet meadow riparian vegetation on streambank erosion. 2. Measurements of vegetated bank strength and consequences for failure mechanics." Earth Surface Processes and Landforms **27**(7): 687-697.

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.

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).

Ratliff, R. D. (1985). Meadows in the Sierra Nevada of California: state of knowledge. Berkeley, CA, USDA Forest Service. **Gen. Tech. Rep. PSW 84:** 52.

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**.

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)**.

Stillwater Sciences (2012). A Guide for Restoring Functionality to Mountain Meadows of the Sierra Nevada. Technical Memorandum, Prepared by Stillwater Sciences, Berkeley, CA, for American Rivers, Nevada City, CA.

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**.

Viers, J. H., S. E. Purdy, R. A. Peek, A. Fryjoff- Hung, N. R. Santos, J. V. E. Katz, J. D. Emmons, D. V. Dolan and S. M. Yarnell (2013). Montane Meadows In The Sierra Nevada: Changing Hydroclimatic Conditions And Concepts For Vulnerability Assessment, Center for Watershed Sciences Technical Report. **CWS-2013-01**.

Weixelman, D. A., B. Hill, D. J. Cooper, E. L. Berlow, J. H. Viers, S. Purdy, A. G. Merril and S. Gross (2011). Meadow Hydrogeomorphic Types for the Sierra Nevada and Southern Cascade Ranges in California, US Department of Agriculture, Forest Service, Pacific Southwest Region. **Gen. Tech. Rep. R5-TP-034:** 34.

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.

Whitney, S. (1979). A Sierra Club naturalist's guide to the Sierra Nevada. San Francisco, Sierra Club Books.

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.

EcoAdapt™
Meeting the challenges of climate change

EcoAdapt, founded by a team of some of the earliest adaptation thinkers and practitioners in the field, has one goal - creating a robust future in the face of climate change. We bring together diverse players to reshape planning and management in response to rapid climate change.

P.O. Box 11195
Bainbridge Island, WA 98110

EcoAdapt.org
+1 (206) 201 3834