Sierra Nevada Individual Species Vulnerability Assessment Briefing: Mountain Yellow-Legged Frogs

Sierra Nevada Yellow-Legged Frog and Northern Distinct Population Segment of Southern Mountain Yellow-Legged Frog

Rana sierrae and *Rana muscosa*

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

Sierra Nevada yellow-legged frog and northern distinct population segment of southern mountain yellow-legged frog are collectively referred to as mountain yellow-legged frogs.

Mountain yellow-legged frogs are indirectly sensitive to climate and climate-driven changes such as:

- altered precipitation (e.g. volume and timing),
- altered snowmelt (e.g. volume and timing),
- altered flows, and
- increased temperature.

Mountain yellow-legged frogs are sensitive to climate and climate-driven changes that influence stream hydrology, water temperature, and water quality, including precipitation type, timing and volume, and air temperature. Mountain yellow-legged frogs are dependent on perennial water for reproduction and prolonged metamorphosis, and changes in precipitation timing and volume can result in desiccation, potentially increasing mortality.

Mountain yellow-legged frog species are also sensitive to several non-climate stressors including:

- fish stocking,
- agrochemical contamination, and

- fungal infections.

Non-climate stressors can decrease habitat quality, increase mortality and sublethal effects, and exacerbate climate-driven impacts. Stocked trout have contributed to the decline of mountain yellow-legged frogs, and may severely limit breeding habitat, compounding possible mortality from habitat desiccation. The adaptive capacity of mountain yellow-legged frogs is strongly limited by dependence on perennial water in high elevation habitat, the same habitat that supports self-sustaining populations of non-native trout, and sensitivity to non-climate stressors.

Recommended Citation

Hauptfeld, R.S. and J.M. Kershner. 2014. Sierra Nevada Individual Species Vulnerability Assessment Briefing: Mountain Yellow-Legged Frogs. 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

The sensitivity of mountain yellow-legged frogs to climate change will likely be driven by the frogs' habitat specialization in high-elevation (i.e. 1370 m to 3660 m / 4495 ft to 12008 ft) lakes, seeps and springs, slow-moving streams (Lacan et al. 2008), and meadows. Both species of mountain yellow-legged frog are dependent on perennial water for breeding and prolonged larval development (Lacan et al. 2008), and are sensitive to changes that flood or prematurely dry habitat, alter water quality, and change predator-prey relationships. Breeding occurs primarily in smaller lakes, which are more susceptible to drying (Lacan et al. 2008). Full metamorphosis for the Sierra Nevada population segments requires two to four years (Knapp and Matthews 2000; Lacan et al. 2008), suggesting sensitivity to changes that wash away or desiccate eggs and tadpoles, including altered temperature, precipitation timing and volume. Highest egg mass counts have been recorded in summers following high snowpack, and snowpack reductions predicted in the northern Sierra Nevada (Safford et al. 2012) may reduce Sierra Nevada yellow-legged frog recruitment success as the frequency of summer drying of small lakes increases (Lacan et al. 2008). Drying even once in 10 years yielded a significantly lower abundance of metamorphs than lakes and ponds that remained wet (Lacan et al. 2008).

In addition, warming water temperatures may exert both positive and negative influence on mountain yellow-legged frogs. 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). Water temperatures influence the biological, physical, and chemical properties of aquatic ecosystems, including dissolved oxygen levels, nutrient cycling, productivity, metabolic rates and life histories (Vannote and Sweeney 1980; Poole and Berman 2001). Warming may benefit mountain yellow-legged frogs if it results in decreased time to metamorphosis, as occurs with some species (e.g. Pacific tree frog) (Paull et al. 2012). Warming may also alter susceptibility to infection and infection rates, although the relationship in North American amphibians is often nonlinear. Warming may increase the ability of a pathogen to penetration the host, but also decrease a tadpole's period of sensitivity (Paull et al. 2012). Furthermore, pathogen outbreaks in foothill yellow-legged frogs in Northern California associated with warm temperatures (e.g. *Lernaea cyprinacea*) may be aided by reduced water levels, resulting in higher densities of larvae and easier transmission of the pathogen (Kupferberg et al. 2009).

Future climate exposure

Mountain yellow-legged frogs are highly sensitive to climatic and non-climatic stressors that may desiccate or flood habitat, alter water quality, and change predator-prey relationships. Exposure factors important to consider for both mountain yellow-legged frog species include increasing temperature and changes in precipitation, snowpack, runoff and timing that affect the hydroperiod of lentic habitat, and the frequency and duration of flows of lotic habitat (Coats 2010; Null et al. 2010; Yarnell et al. 2010; Kiernan and Moyle 2012).

Temperature: 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). Projected increases of 2°C, 4°C and 6°C reduced cold water habitat (with stress threshold 21°C) on the South Fork American River in the Sierra Nevada by 57%, 91% and 99.3%, respectively (Null et al. 2012).

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). Increased rain:snow ratio and advanced timing of snowmelt initiation are expected to shift the runoff center of mass forward by 1-7 weeks by 2100 (Maurer 2007). 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).

Runoff and flows: The impacts of shifts in the spring hydrograph on stream ecology vary according to stream elevation, latitude, and degree of overall temperature increase (Young et al. 2010). Mean annual flow is projected to decrease most substantially in the northern bioregion (Null et al. 2010). 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 (see Null et al. 2010 for watershed sensitivities to anticipated changes).

In addition, reduced snowpack is expected to produce longer warm, low flow and zero-flow periods, with shorter duration of cold water within the system (Seavy et al. 2009; Yarnell et al. 2010). Rising water temperatures in summer and fall will be exacerbated by lower base flows resulting from reduced snowpack (Stewart et al. 2004; Hamlet et al. 2005; Stewart et al. 2005). Changes in stream flow and temperature are expected to be most significant in streams fed by the relatively lower elevation Cascades and northern Sierra Nevada, while the southern Sierra Nevada with its much higher elevations is predicted to retain a higher proportion of its snowpack (Katz et al. 2012; Mote et al. 2005), which may moderate stream temperatures.

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

Mountain yellow-legged frogs are sensitive to a number of non-climatic stressors, including high-elevation non-native fish stocking (Bradford 1989; Knapp and Matthews 2000; Null et al. 2012), agrochemical contamination (Davidson et al. 2002, Davidson and Knapp 2007), and fungal infections (Fellers et al. 2001; Wake and Vredenburg 2008), which may compound species sensitivity to climate-driven changes. Rivers on the western slope of the Sierra Nevada above about 2000 m (6562 ft) were mostly fishless prior to stocking, although they are now managed to sustain several native and non-native trout (Viers and Rheinheimer 2011). Studies have found that stocked non-native trout have contributed to the decline of mountain yellow-legged frogs (Bradford 1989; Bradford et al. 1994; Knapp and Matthews 2000) and may severely limit breeding habitat to smaller ponds prone to desiccation (Lacan et al. 2008), compounding possible mortality from desiccation and other climate-driven changes. In addition, it has been suggested that airborne pesticides have contributed to the decline of mountain yellow-legged frog populations (Davidson et al. 2002; Fellers et al. 2004). The long metamorphosis of tadpoles in the Sierra Nevada populations and the fact that adults spend nearly all their time in the water make them especially susceptible to pesticide poisoning (Fellers et al. 2004). Declines of mountain yellow-legged frog were found concentrated in lower elevation sites in California, and were associated with the amount of upwind agricultural land use, suggesting that mountain yellow-legged frogs may be particularly sensitive to agrochemicals (Davidson et al. 2002). Analysis of tissue from other Sierra Nevada frogs indicates that high-elevation frogs accumulate pesticides, and that tissue concentrations can be better indicators of exposure than water and soil concentrations (Smalling et al. 2013). Sub-lethal impacts resulting from pesticides, including reduced resistance to disease, are also likely (Sparling 1994 cited in Fellers et al. 2004; Smalling et al. 2013). In contrast, other studies suggest that pesticides may not contribute to the decline of mountain yellow-legged frogs in the alpine regions of the southern Sierra Nevada, but rather that declines are consistent with a pattern of spread of chytridiomycosis (Bradford et al. 2011). Chytridiomycosis, an emerging infectious disease caused by a fungal pathogen, *Batrachochytrium dendrobatidis*, is having a devastating impact on native frogs of the Sierra Nevada, already weakened by the effects of pollution and introduced predators (Fellers et al. 2001; Wake and Vredenburb 2008; Bradford et al. 2011).

Adaptive Capacity

Reliance upon high-elevation (i.e. 1370 m to 3660 m) (4495 ft to 12008 ft) lakes, seeps and springs, and slow-moving streams (Lacan et al. 2008), as well as strong sensitivity to non-climate stressors likely limit the adaptive capacity of mountain yellow-legged frogs. The Sierra Nevada yellow-legged frog is endemic to the Sierra Nevada and has experienced population losses estimated between 69-93% for Sierra Nevada yellow-legged frog, and 86-92% for the northern distinct population segment of mountain yellow-legged frog (USFWS 2013). Early and Sax (2011) suggest that an amphibian's ability to shift its range in response to drying may be determined as much by the ability of a species to persist during short periods of unfavorable climate, as their ability to disperse (Early and Sax 2011). Mountain yellow-legged frogs can disperse over land, potentially supporting their capacity to track climate-driven shifts in range. However, leading causes of mountain yellow-legged frog decline include non-climate stressors, which are not likely ameliorated by dispersal capacity. Reducing the impacts of non-climate stressors on aquatic habitats may increase the adaptive capacity mountain yellow-legged frogs.

Literature Cited

Blaustein, A. R., S. C. Walls, B. A. Bancroft, J. J. Lawler, C. L. Searle and S. S. Gervasi (2010). "Direct and Indirect Effects of Climate Change on Amphibian Populations." Diversity **2**(2): 281-313.

Bradford, D. F. (1989). "Allotopic Distribution of Native Frogs and Introduced Fishes in High Sierra Nevada Lakes of California: Implication of the Negative Effect of Fish Introductions." Copeia **1989**(3): 775-778.

Bradford, D. F., S. D. Cooper, A. D. Brown and G. Mahood (1994). Distribution of aquatic animals relative to naturally acidic waters in the Sierra Nevada. Final Report. Los Angeles, CA, California University, Office of Environmental Science and Engineering. **No. PB-94-161528/XAB**.

Bradford, D. F., R. A. Knapp, D. W. Sparling, M. S. Nash, K. A. Stanley, N. G. Tallent-Halsell, L. L. McConnell and S. M. Simonich (2011). "Pesticide distributions and population declines of California, USA, alpine frogs, Rana muscosa and Rana sierrae." Environ Toxicol Chem **30**(3): 682-691.

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.

Coats, R. (2010). "Climate change in the Tahoe basin: regional trends, impacts and drivers." Climatic Change **102**(3-4): 435-466.

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.

Davidson, C. and R. A. Knapp (2007). "Multiple stressors and amphibian declines: dual impacts of pesticides and fish on yellow-legged frogs." Ecological Applications **17**(2): 587-597.

Davidson, C., H. B. Shaffer and M. R. Jennings (2002). "Spatial Tests of the Pesticide Drift, Habitat Destruction, UV-B, and Climate-Change Hypotheses for California Amphibian Declines." Conservation Biology **16**(6): 1588-1601.

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.

Early, R. and D. F. Sax (2011). "Analysis of climate paths reveals potential limitations on species range shifts." Ecology Letters **14**(11): 1125-1133.

Fellers, G. M., E. D. Green and J. E. Longcore (2001). "Oral Chytridiomycosis in the Mountain Yellow-Legged Frog (Rana muscosa)." Copeia **2001**(4): 945-953.

Fellers, G. M., L. L. Mcconnell, D. Pratt and S. Datta (2004). "Pesticides in mountain yellow-legged frogs (Rana muscosa) from the Sierra Nevada mountains of California, USA." Environ Toxicol Chem **23**(9): 2170-2177.

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.

Hamlet, A. F., P. W. Mote, M. P. Clark and D. P. Lettermaier (2005). "Effects of Temperature and Precipitation Variability on Snowpack Trends in the Western United States." Journal of Climate **18**: 4545-4561.

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.

Katz, J., P. B. Moyle, R. M. Quiñones, J. Israel and S. Purdy (2012). "Impending extinction of salmon, steelhead, and trout (Salmonidae) in California." Environmental Biology of Fishes.

Kiernan, J. D. and P. B. Moyle (2012). "Flows, droughts, and aliens: factors affecting the fish in a Sierra Nevada, California, stream." Ecological Applications **22**(4): 1146-1161.

Kiernan, J. D., P. B. Moyle and P. K. Crain (2012). "Restoring native fish assemblages to a regulated California stream using the natural flow regime concept." Ecological Applications **22**(5): 1472-1482.

Knapp, R. A. and K. Matthews (2000). "Non-Native Fish Introductions and the Decline of the Mountain Yellow-Legged Frog from within Protected Areas." Conservation Biology **14**(2): 428-438.

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

Kupferberg, S. J., A. Catenazzi, K. Lunde, A. J. Lind and W. J. Palen (2009). "Parasitic Copepod (Lernaea cyprinacea) Outbreaks in Foothill Yellow-legged Frogs (Rana boylii) Linked to Unusually Warm Summers and Amphibian Malformations in Northern California." Copeia **2009**(3): 529-537.

Lacan, I., K. Matthews and K. Feldman (2008). "Interaction of an introduced predator with future effects of climate change in the recruitment dynamics of the imperiled Sierra Nevada yellow-legged frog (Rana sierrae)." Herpetological Conservation and Biology **3**(2): 211-223.

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, 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.

Mote, P. W., A. F. Hamlet, M. P. Clark and D. P. Lettenmaier (2005). "Declining Mountain Snowpack in Western North America*." Bulletin of the American Meteorological Society **86**(1): 39-49.

Null, S. E., J. H. Viers, M. L. Deas, S. K. Tanaka and J. F. Mount (2012). "Stream temperature sensitivity to climate warming in California’s Sierra Nevada: impacts to coldwater habitat." Climatic Change **116**(1): 149-170.

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).

Paull, S. H., B. E. LaFonte and P. T. J. Johnson (2012). "Temperature-driven shifts in a host-parasite interaction drive nonlinear changes in disease risk." Global Change Biology **18**(12): 3558-3567.

Poole, G. C. and C. H. Berman (2001). "An Ecological Perspective on In-Stream Temperature: Natural Heat Dynamics and Mechanisms of Human-CausedThermal Degradation." Environmental Management **27**(6): 787-802.

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**.

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)**.

Smalling, K. L., G. M. Fellers, P. M. Kleeman and K. M. Kuivila (2013). "Accumulation of pesticides in Pacific chorus frogs (Pseudacris regilla) from California's Sierra Nevada Mountains, USA." Environ Toxicol Chem **32**(9): 2026-2034.

Stewart, I., D. Cayan and M. D. Dettinger (2004). "Changes In Snowmelt Runoff Timing in Western North America under a ‘Business as Usual’ Climate Change Scenario." Climatic Change **62**: 217-232.

Stewart, I., D. Cayan and M. D. Dettinger (2005). "Changes toward Earlier Streamflow Timing across Western North America." Journal of Climate **18**: 1136-1155.

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**.

USFWS (2013). Proposed Rule: Endangered and Threatened Wildlife and Plants; Endangered Status for the Sierra Nevada Yellow-Legged Frog and the Northern Distinct Population Segment of the Mountain Yellow-Legged Frog, and Threatened Status for the Yosemite Toad. U. S. F. a. W. Service. **Federal Register Vol. 78**.

Vannote, R. L. and B. W. Sweeney (1980). "Geographic analysis of thermal equilibria: a conceptual model for evaluating the effect of natural and modified thermal regimes on aquatic insect communities." American naturalist: 667-695.

Viers, J. H. and D. E. Rheinheimer (2011). "Freshwater conservation options for a changing climate in California’s Sierra Nevada." Marine and Freshwater Research **62**: 266-278.

Wake, D. B. and V. T. Vredenburg (2008). "Colloquium paper: are we in the midst of the sixth mass extinction? A view from the world of amphibians." Proceedings of the National Academy of Sciences USA **105 Suppl 1**: 11466-11473.

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.

Yarnell, S. M., J. H. Viers and J. F. Mount (2010). "Ecology and Management of the Spring Snowmelt Recession." BioScience **60**(2): 114-127.

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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