Sierra Nevada Ecosystem Vulnerability Assessment Briefing: Aquatic

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 aquatic systems is likely moderate, due to its high sensitivity to climate and non-climate stressors, and moderate-high adaptive capacity[1].

Aquatic systems are sensitive to climate-driven changes such as:

- altered precipitation (e.g. volume and timing),
- altered snowmelt (e.g. volume and timing),
- increased temperature,
- altered flow, and
- altered fire regimes.

The aquatic system is sensitive to climate and climate-driven changes that influence stream hydrology, and water temperature and quality, including precipitation type, timing and volume, air temperature, and wildfire regimes. Changes in precipitation timing and volume can result in sediment redistribution and channel homogenization, as well as periods of low and zero flow. Low flows combined with rising air temperatures are expected to lead to warming water temperatures, potentially reducing biodiversity.

Aquatic systems systems are also sensitive to several non-climate stressors including:

- fish stocking,
- water diversions and hydropower production,
- residential and commercial development,
- agricultural practices, and
- timber harvest and grazing.

[1] Based on responses for Sensitivity and Adaptive Capacity sections only; no responses recorded for Exposure.

These non-climate factors can fragment and degrade aquatic habitat, and exacerbate climate-driven changes. Water diversions and dams can block fish migratory pathways, exacerbating the habitat fragmentation anticipated with increasingly warm and low flow stream reaches. Timber harvest facilitates erosion, and an increasing frequency of severe precipitation events may compound this contribution of terrestrial inputs to aquatic systems. The adaptive capacity of aquatic systems is strongly limited by the geographic isolation of bodies of water.

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Sensitivity & Exposure

Sensitivity to climate and climate-driven changes

The aquatic system is sensitive to a broad spectrum of climate and climate-driven changes, including increased temperature, changes in hydrology (e.g. precipitation volume and timing, snowmelt volume and timing, runoff and flows), and altered wildfire regimes. 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). In addition, warming temperatures influence the partitioning of precipitation between rain, snow, runoff and infiltration, and these changes in the nature, frequency, and abundance of precipitation also impact water temperature (Null et al. 2012). Stream warming directly influences oxygen levels and nutrient cycling (Poole and Berman 2001), and may alter habitat conditions, reducing overall biodiversity, and facilitating introduction of invasive species in aquatic systems (Eaton and Scheller 1996, Rahel and Olden 2008 cited in Null et al. 2012). Riparian vegetation density, height, location and species composition are important factors in buffering stream temperature (LeBlanc and Brown 2000). However, riparian shading may be negligible in watersheds above 2,750 m elevation (Null et al. 2012) where solar radiation is buffered instead by topographic shading.

Changes in precipitation also impact water level and velocity (Meyers et al. 2010), shifting some streams into intermittent flow (Perry et al. 2012), altering channel topography and substrate (Yarnell et al. 2010), as well as habitat quality (Meyers et al. 2010). Reduced summer flows and increased water temperatures may reduce the suitability of stream reaches for temperature-sensitive aquatic species (Myrick and Cech 2004). For instance, fish extinction rates are likely to increase (Moyle et al. 2011). Most native species requiring cold water (<22°C) and all native anadromous fishes in California are rated highly or critically vulnerable to climate change (Moyle et al. 2012). California salmonid populations are at the southern boundary of their range, and small thermal increases in summer temperatures can result in suboptimal or lethal conditions (Katz et al. 2012).

In Sierran lakes, extreme rain events may increase terrestrial inputs, resulting in more frequent periods of reduced primary production, and increased periods of hypoxia and anoxia (Coats 2010; Sadro and Melack 2012). Changes in wildfire regimes may also impact temperature, sediment load and pH of aquatic systems. Wildfires alter riparian vegetation and stream shade (Dwire and Kauffman 2003, Pettit and Naiman 2007 cited in Isaak et al. 2010), and combined with altered forest and riparian communities, may change inputs of sediment and large woody debris (Miller et al. 2003, Barnett et al. 2008 cited in Rieman and Isaak 2010).

Future climate exposure

Important climate and climate-driven factors to consider for aquatic systems include changes that impact system hydrology, including precipitation volume and timing, snowpack volume and timing, groundwater recharge, runoff and flows, as well as air temperature, wildfire, and shifts in vegetation.

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 2-6°C was modeled to reduce coldwater habitat (with stress threshold 21°C) on the South Fork American River in the Sierra Nevada by between 57-99.3% (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). 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: A shift from snowfall to rainfall will also change distribution and deposition of aquatic sediments, homogenizing substrate and reducing habitat availability in California's basins (Yarnell et al. 2010). A reduction in the magnitude of flow at the start of spring snowmelt also implies lower redistribution of sediment, creating large abiotic changes in stream systems (Yarnell 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.

Wildfire: 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

Aquatic systems are also sensitive to a number of non-climate stressors that may compound climate-driven changes. Non-climate stressors include fish stocking (Null et al. 2012); water diversion and hydropower production (Yoshiyama et al. 1998; Null et al. 2012); residential and commercial development (Null et al. 2012); and logging, grazing, and agricultural practices. The western slope of the Sierra Nevada above about 2000 m (6562 ft) was mostly fishless prior to stocking, although rivers are now managed to sustain native rainbow trout (*Onchorynchus mykiss*) and golden trout (*O. mykiss aguabonita*), as well as non-native brown (*Salmo trutta*) and brook trout (*Salvelinus fontinalis*) (Viers and Rheinheimer 2011). Water regulation and land use changes have altered the thermal regime of Sierra Nevada rivers, degrading habitat and creating a dispersal barrier to cold water assemblages (Null et al. 2012; Perry et al. 2012). Today, blockage of migratory pathways by large dams has resulted in the extirpation of most runs of Chinook salmon (*Oncorhynchus tshawytscha*) from Sierra Nevada streams (Yoshiyama et al. 1998, Moyle 2002 cited in Viers and Rheinheimer 2011). Warming stream temperatures and increased frequency and duration of low flow and zero flow periods may further compound fragmentation of cold-water fish habitat. Grazing and timber harvest intensifies mercury contamination moving from mining areas into rivers and streams in northern Sierra Nevada catchments (Alpers et al. 2005 cited by Viers and Rheinheimer 2011). Timber harvest and grazing also results in erosion, which degrades or eliminates fish spawning habitat (Moyle 2002 cited in Viers and Rheinheimer 2011). Erosion and sediment influxes may be exacerbated by increases in frequency of high severity precipitation events.

Adaptive Capacity

The adaptive capacity of aquatic systems is largely limited by the system's dependence on high elevation inputs of cold water, and by the geographic isolation of the bodies of water, an impediment to species redistribution in the steeply dissected Sierra Nevada. However, recent evidence suggests that aquatic species and communities may have the capacity to rapidly adapt to changing conditions. Evidence exists that fishes can adapt relatively quickly to changing conditions through behavioral or phenotypic plasticity and rapid evolution (Crozier et al. 2008 cited in Rieman and Isaak 2010). Many salmonids can exploit new habitats almost as they become available (Isaak and Thurow 2006, Isaak et al. 2007, Milner 1987, Milner et al. 2000, 2008 cited in Rieman and Isaak 2010). This may be due in part to a diversity of life histories. Multiple life histories within a population or closely allied populations of sockeye salmon (*Oncorhynchus nerka*), for example, may stabilize overall numbers, as certain life histories are better suited to emerging conditions (Hillborn et al. 2003 cited in Rieman and Isaak 2010).

Changes in thermal conditions may also lead to local adaptations in thermal tolerances. For example, fall Chinook salmon in the Snake River appear to be evolving novel rearing and migration timing in response to changes in flow and temperature caused by water development over the last 40 years (Williams et al. 2008 cited in Rieman and Isaak 2010). The capacity for rapid evolution in thermal tolerance, however, is unclear and may be more limited than with others (McCullough et al. 2009). Thermal refugia may exist where topographic shading reduces solar radiation.

Moreover, the effects of human development have largely eroded the mechanisms that support adaptive capacity in aquatic populations (i.e. connectivity among habitats and populations, local adaptations, and genetic and phenotypic diversity) (Rieman and Dunham 2000, McClure et al. 2008, Bisson et al. 2009 cited in Rieman and Isaak 2010). Reducing the impacts of these non-climate stressors may increase the adaptive capacity of the aquatic system. Habitat connectivity may be improved by managing road corridors, and sensitive watersheds may be supported through management of grazing and timber extraction.

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P.O. Box 11195
Bainbridge Island, WA 98110

EcoAdapt.org
+1 (206) 201 3834