Sensitivity Assessment

1. Direct sensitivities to changes in temperature and precipitation

- Temperature
    - Means and extremes
        - Observed mean weekly stream temperatures ranged from 5.6 to 22.0˚C at 29 sites in the Sierra Nevada, ranging from 500 – 3250 m elevation (Null et al. 2012). Observed maximum weekly stream temperatures were recorded between Julian weeks 27-36 (Null et al. 2012).
    - System's sensitivity, composition and response to temperature
        - Stream temperatures are strongly correlated with climate (see: Morrill et al. 2005). Relationship between air and stream temperature is not linear, particularly as stream temperature exceeds 20˚C, when evaporative cooling slows heating (Null et al. 2012).
        - Stream temperatures directly influence the biological, physical, and chemical properties of lotic ecosystems, including metabolic rates and life histories, dissolved oxygen levels, nutrient cycling, productivity, and rates of chemical reactions (see: Vannote and Sweeney 1980, Poole and Berman 2001). Stream warming may alter stream habitat conditions, reduce community biodiversity, change the distribution and abundance of organisms, drive local extinctions, and ease the introduction of invasive species (Null et al. 2012). Warm stream temperatures inhibit distribution and survival of coldwater species (see: Moyle et al. 2002).
- Precipitation
    - Means and extremes
        - Mean precipitation at watershed outlets of 15 (5-7 Strahler stream order) streams in the Sierra Nevada ranged between 560 - 1,675 mm/yr (Null et al. 2012). Precipitation averages 1,080 mm/yr for the Sierra Nevada region.
    - System's sensitivity, composition and response to precipitation.
        - The frequency, abundance and nature of precipitation events impact water temperature (Null et al. 2012), level, and velocity (Meyers et al. 2010). Flow changes may result in altered channel topography and substrate (Yarnell et al. 2010), ephemeral streams, and altered dynamics of salmon redd scour and dewatering (Meyers et al. 2010).

2. Sensitivity of component species

- Dominant species
    - Coldwater assemblages: Most native fish species requiring cold water (<22˚C) were rated highly or critically vulnerable to climate change (Moyle et al. 2012). However, uncertainty remains regarding temperature thresholds for coldwater guild species, and thresholds are variable by life stage, previous acclimation,

  - duration of thermal maxima and minima, food abundance, competition, predation, body size and condition (see: McCullough 1999).
  - All native anadromous fish were rated highly or critically vulnerable to climate change (Moyle et al. 2012). All California salmonid populations are being adversely impacted by the shrinking availability of coldwater habitats (Katz et al. 2012). Because they are at the southern boundary of their range, small thermal increases in summer water temperatures can result in suboptimal and lethal conditions with consequent reductions in distribution and abundance of California's endemic salmon, trout and steelhead (Katz et al. 2012).
- Ecosystem engineers
- Keystone species
  - The maximum thermal tolerance for Chinook salmon (*O. tshawytscha*) and steelhead trout is reported as 24˚C (see: Eaton and Scheller 1996), although both can tolerate warmer temperatures for shorter periods (see: Myrick and Cech 2001). Water temperatures above 20˚C can have adverse spawning and rearing effects in Chinook salmon (Yates et al. 2008). The egg and alevin life stages require lower than 24˚C temperatures for optimal growth and survival.

3. Sensitivity to changes in disturbance regimes

- Wildfire
- Disease
  - Stream warming projected to magnify the distribution and virulence of disease organisms and parasites, increasing the impact on native salmonids (Rahel et al. 2008).
- Flooding
- Insects
- Wind
- Drought
- Other

4. Sensitivity to other types of climate and climate-driven changes

- Altered hydrology
  - Predicted quick pulses of higher winter rainfall in contrast to slower snowmelt will change how sediments are sorted and deposited, resulting in more homogenous channel substrates; channel bars may become more steeply sloped, creating less habitat availability and less overall biodiversity (Yarnell et al. 2010).
  - Reduced streamflow may shift some streams into intermittent flow (Perry et al. 2012), which could affect coldwater species (including amphibians and macro-invertebrates) (Null et al. 2012; see: Blaustein et al. 2010).
  - Increased terrestrial inputs to Sierran lakes, precipitated by increased frequency of rain events, may result in reduced primary production, increased periods of

    hypoxia and anoxia, and shift toward net heterotrophy during ice-free season (Coats 2010; see: Sadro and Melack 2012).

- Altered fire regimes
- Evapotranspiration and soil moisture
- Extreme precipitation and temperature
- Water temperature
    - In their model, Null et al. (2012) found that average annual stream temperatures warmed approximately 1.6˚C for each 2˚C rise in average annual air temperature. The greatest rise in stream temperatures in response to air temperatures was projected at mid elevation (1,500 – 2,500 m), where climate warming shifted precipitation from snowmelt to rainfall. The largest thermal change occurred during spring in the models, when stream warming could exceed 5˚C for each 2˚C rise in air temperature (Null et al. 2012). Stream temperatures are affected by riparian vegetation species, height, density and location, as well as stream orientation (see: LeBlanc and Brown 2000) and topographic shading (Null et al. 2012). Above 2,750 m elevation, shading may be negligible due to short growing season and poor soils (Null et al. 2012).
    - Stream temperatures directly influence the biological, physical, and chemical properties of lotic ecosystems, including metabolic rates and life histories, dissolved oxygen levels, nutrient cycling, productivity, and rates of chemical reactions (see: Vannote and Sweeney 1980, Poole and Berman 2001). Predicted reduction in magnitude of snowmelt rate is forecast to cause longer, warmer low-flow seasons, with shorter duration of cold water in the system (Yarnell et al. 2010).
    - Stream warming may alter stream habitat conditions, reduce community biodiversity, change the distribution and abundance of organisms, drive local extinctions, and ease the introduction of invasive species (Null et al. 2012). Warm stream temperatures inhibit distribution and survival of coldwater species (see: Moyle et al. 2002), including abundance of aquatic insects (Perry et al. 2012) and amphibian species that breed in vernal pools and intermittent headwater streams (see: Blausten et al. 2010). Modeling results indicate that habitat for coldwater species declined with climate warming (Null et al. 2012).
    - In lakes, increased temperature decreases the solubility of gases, and processes such as denitrification and nitrogen fixation are accelerated. Such changes will lead to water quality problems in Lake Tahoe and other lakes (Coats 2010).
- Storm frequency and intensity
- Other

5. Sensitivity to impacts of other non-climate related threats

- Residential and commercial development
- Agriculture and aquaculture
- Energy production and mining
- Transportation and service corridors

- Biological resource use
- Altered interspecific interactions
    - Stocking. Above 2,000 m rivers on the western slope of the Sierra Nevada were mostly fishless prior to stocking with native rainbow trout (*Onchorhynchus mykiss*) and golden trout (O*. mykiss aguabonita*), as well as non-native brown trout (*Salmo truta*) and brook trout *(Salvelinus fontinalis*) (Null et al. 2012).
- Human intrusions and disturbance
- Natural system modification
    - Water regulation.
        - Dams. After construction of large dams, salmon runs, once among the most productive on the pacific coast, have largely been extirpated from Sierra Nevada rivers (see: Yoshiyama et al. 1998).
        - Channel alteration.
- Invasive and other problem species
    - Freshwater fish species native to California tend to be more affected by climate change than alien fish species (Moyle et al. 2012). Longer warm, low-flow seasons may expand abundance of nonnative fauna (Yarnell et al. 2010).
- Pollution and poisons
- Geological events

6. Other Sensitivities

- Management

Adaptive Capacity

1. Extent and Characteristics

- Geographic extent in California
    - 39 m – 4,418 m elevation (Null et al. 2012).

2. Landscape Permeability

- Barriers to dispersal or fragmentation
    - Reduced streamflow may shift some streams into intermittent flow (Perry et al. 2012). Increasing temperatures may result in a thermal block for coldwater species migration, such as Chinook salmon (Null et al. 2012).
    - Dams. Dams operating without consideration of thermal management, and without adequate passage to coldwater habitat impact coldwater fish populations (Null et al. 2012).

3. System Diversity

- Diversity of component species
    - The southernmost steelhead (*O. mykiss*) populations are characterized by a relatively high genetic diversity compared to populations further north (see:

McCusker et al. 2000). It is likely that southern salmonid gene pools reflect a history of resilience as well as adaptations to watersheds characterized by aridity and extreme seasonal variation (see: Nielsen et al. 1999).

Exposure

Aquatic species in California are likely to be impacted by changes associated with climate change, including changes in water temperature, quality, and the frequency, intensity and timing of stream flow (Coats 2010, Null 2010, Yarnell 2010, Kiernan and Moyle 2012).

Although climate change scenarios project little change to the total annual precipitation in the Sierra Nevada mountains, both model projections and empirical data indicate trends of advancing timing of precipitation events, an increase in the ratio of rain to snow, and increased inter-annual variability (Coats 2010, Kiernan and Moyle 2012). Models predict a decrease in magnitude of initial spring snowmelt, along with reduction in rate of snowmelt. Because reduction in magnitude negates the reduction in snowmelt rate, longer warm, low-flow seasons are expected, with shorter duration of cold water within the system (Yarnell et al. 2010).

During summer and fall, rising water temperatures are exacerbated by lower base flows resulting from reduced snowpack (see: Stewart et al. 2004, Hamlet et al. 2005, Stewart et al. 2005). Snowpack losses are expected to increase significantly at lower elevations, with elevations below 3000 m in the Sierra Nevada suffering reductions of as much as 80% (see: Hayhoe et al. 2004). Consequently, in the long run, 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 (see: Mote et al. 2005) (Katz et al. 2012). Scenarios modeling increased atmospheric temperatures at 2°C, 4°C and 6°C run by Null et al. (2010) forecast that, 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. Modeling results suggest the American and Mokelumne Rivers are most vulnerable to all three metrics run by Null et al. (2010), and the Kern River is the most resilient, in part due to the high elevations of the watershed. Flow reductions in the northern Sierra Nevada will likely stress traditional water uses for irrigation and urban water storage, as well as aquatic and riparian ecosystems. (Null 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). The abiotic impacts will be more complex in California’s Mediterranean-montane basins, where the predicted quick pulses of higher winter rainfall in contrast to slower snowmelt will change how sediments are sorted and deposited. Channel substrates will become more homogenous; channel bars may be more steeply sloped, creating less habitat availability (Yarnell et al. 2010). A flashy spring hydrograph may lead to a system dominated by two flow stages (i.e., flood and low-flow), rather than multiple stages, resulting in a stream with greater habitat homogeneity and less overall biodiversity (Yarnell et al. 2010).

No native freshwater fishes in California are likely to benefit from climate related changes (Moyle et al. 2012). As stream flows become more variable, and water temperature and quality changes, fish extinction rates are likely to increase (Moyle et al. 2011). All native anadromous fishes in California were rated highly or critically vulnerable to climate change (Moyle et al. 2012). Fishes in the families *Cyprinodontidae*, *Embiotocidae*, *Osmeridae*, *Petromyzontidae*, *Salmonidae*, for example, were almost all rated highly or critically vulnerable. However, that the family with the most species, *Cyprinidae*, had 18 species scoring in the categories indicating least vulnerability to climate change (Moyle et al. 2012). In addition, warmer streamwater and intermittent flows may reduce abundance of some aquatic insects, which as adults are important riparian prey (Perry et al. 2012)

Lakes as large as Lake Tahoe have experienced warming over the last century (Coats 2010). If rain events increase in frequency, as many climate change models predict, increased terrestrial inputs to Sierran lakes may result in more frequent periods of reduced primary production, increased periods of hypoxia and anoxia, and an ecosystem shift toward net heterotrophy during the ice-free season (Sadro and Melack 2012, Coats 2010). With increasing temperature, the solubility of gases decreases and processes such as denitrification and nitrogen fixation are accelerated. Such changes will lead to many water quality problems in lakes such as Lake Tahoe (Coats 2010).

Where mountain ranges provide ‘islands’ of habitat and species cannot easily migrate to higher latitude reaches, climate warming is likely to reduce total habitat for coldwater species such as salmonids (Null et al. 2012) Consequently, an elevational shift in the distribution of cold- and warm-water fish species will occur as cold-water species are limited to higher elevations (Yarnell et al. 2010). Amphibians that breed in ephemeral and often isolated bodies of water (e.g., vernal pools and intermittent headwater streams) are especially vulnerable to changes in temperature and precipitation (Blaustein et al. 2010).

Downstream species are also threatened by climate related changes. As the conditions in the San Francisco Estuary-Watershed diverge from those to which native species are adapted, increasing risk of native species extinction and emergence of nonnatives as dominant components are expected (Cloern et al. 2011).

Freshwater fish species native to California tend to be more affected by climate change than alien fish species (Moyle et al. 2012). Longer warm, low-flow seasons may expand the abundance of nonnative fauna (Yarnell et al. 2010).

Cold water fish assemblages

Scenarios run by Moyle et al. (2012) found that most native species requiring cold water (<22°C) were highly or critically vulnerable to climate change (Moyle et al. 2012). Warming may cause thermal refuges to disappear from streams in many areas, leaving coldwater fishes no place to escape unfavorable conditions (Moyle et al. 2011). On the South Fork American River in the Sierra Nevada, model results of projected air temperature increases of 2°C, 4°C and 6°C reduced available coldwater habitat (with stress threshold 21°C) by 57%, 91% and 99.3%, respectively (Null et al. 2012).

All California salmonid populations are being adversely impacted by the shrinking availability of coldwater habitats. Because they are at the southern edge of their range, small thermal increases in summer water temperatures can result in suboptimal and lethal conditions with consequent reductions in distribution and abundance. It is possible that a majority of California's endemic salmon, trout and steelhead could become extinct within the next 50 to 100 years, particularly pink salmon (*Onchorhynchus gorbuscha*) and chum salmon (*Oncorhynchus. keta*) (Katz et al. 2012).

Exposures of Chinook salmon (*Oncorhynchus. tshawytscha*) to water temperatures above 20°C can result in adverse effects during spawning and rearing (Yates et al. 2008). Increased water temperatures in the Sacramento Valley could jeopardize Chinook (*O. tshawytscha*), particularly in drought years. Temperatures exceeding 24°C are expected slightly earlier in the spring, and to last later into August and September, when peak numbers of fall-run Chinook, the most abundant run in California, historically immigrated into freshwater streams (Yates et al. 2008). Yates et al. (2008) predict the percentage of years in which temperatures at stream outlets will exceed 24°C (for at least 1 week) is likely to increase with climate change. If air temperatures rise by 6°C, most Sierra Nevada rivers are expected to exceed 24°C at watershed outlets for several weeks each year, with the Feather River a notable exception (Null et al. 2012). Yates et al. (2008) suggest that cold pool reservoirs, such as Shasta, may offset the impacts of 2°C warming throughout the 21st century, but maintenance of a cold pool with warming of 4°C could be challenging.

According to the model run by Jager el at. (1999), a shift to earlier high streamflows had a strong positive effect on brown trout (*Salmo trutta*) abundance in the Sierra Nevada. This shift increased redd scouring for winter spawning brown trout, but construction of redds during lower fall flows mitigated dewatering and compensated for scouring. Under a scenario of 2°C increase in average annual temperature, brown trout populations increased in upstream reach and decreased in the downstream reaches of the Sierra Nevada (Jager et al. 1999). In spite of an increased incidence of summer starvation of brown trout in the upstream reach (with elevated temperature of 2°C), growth and fecundity of the survivors was enhanced.

For spring-spawning rainbow trout (*O. mykiss*), on the other hand, the Jager et al. (1999) model predicted that a shift to earlier high streamflows would lead to reduced redd scouring, but increased dewatering events as spring flow was reduced (Jager et al. 1999). Rainbow trout increase in upstream reaches under the 2°C increase is attributed to better growth conditions and therefore, lower predation mortality. Increased temperatures during incubation of rainbow trout caused them to spawn earlier (Jager et al. 1999).

In the Jager et al. (1999) model, temperature in the Tule River had significant effects on the timing of spawning and incubation. For brown trout, spawning was delayed by several weeks, but eggs and alevins developed faster and fry emerged earlier. For rainbow trout, spawning was earlier, particularly in warmer downstream reaches (Jager et al. 1999). However, in these simulations, the effects of streamflow and temperature were not additive, as shown by the tremendous increase in rainbow trout abundance in upstream reach when both temperature and flow (higher winter flows during rain-on-snow events) effects were simulated (Jager et al. 1999).

The southernmost steelhead (*O. mykiss*) populations are characterized by a relatively high genetic diversity compared to populations further north (see: McCusker et al. 2000). It is likely that southern salmonid gene pools reflect a history of resilience as well as adaptations to watersheds characterized by aridity and extreme seasonal variation (see: Nielsen et al. 1999). Extinction of these highly endangered southern populations will likely result in loss of traits adapted to the very environmental characteristics that embody predicted climatic changes to watersheds further north (Katz et al 2012).

Bull trout (*Salvelinus confluentus*) in North America have an optimal temperature range lower than other salmonids, and are threatened by climate change directly through thermally stressful temperatures and indirectly by increased competitive ability of other trout species (Rahel et al. 2008). Under 2°C and 4°C warming scenarios run by Meyers et al. (2010) a shift to increased winter floods predicted a likely long-term decline in the number of brook trout (*Salvelinus fontinalis*) and increase in number of rainbow trout (*O. mykiss*) in Sagehen Creek. In the Sagehen Creek scenarios, brook trout were less able to recover between winter flood events, which were expected to increase both in intensity, and to increase in frequency five-fold under moderate 2°C warming (Meyers et al. 2010). While it is unlikely that temperatures will exceed the functional range of rainbow trout (25°C) in Sagehen Creek, maximum temperatures already surpass functional maximum temperatures (19°C) of brown trout (Meyers et al 2010).

Other factors contributing to the projected survival of brook trout (*S. fontinalis*) and rainbow trout (*O. mykiss*) in Sagehen Creek include the impacts of climate change on various aspects of habitat quality, such as water temperature, nutrient availability, stream morphology (i.e., the availability of pools and riffles), and riparian cover. The effects on stream temperature of a 2°C or 4°C increase climate temperature will be temporally and spatially variable—depending on coldwater inputs, summer low flows, and vegetative cover—but they would not be greater than the increase in air temperature (Meyers et al. 2010).

Downstream species, such as the delta smelt (*Hypomesus transpacificus*), may also be particularly vulnerable to temperature changes. Rising temperatures are likely to reduce spawning season, or eliminate spawning entirely (Hanak and Lund 2011).

Disease

Stream warming will magnify the distribution and virulence of disease organisms and parasites (see: Marcogliese 2001) that are temperature dependent, increasing the impact on native salmonids (Rahel et al. 2008).

Little Kern golden trout

No information found

Warm water fish assemblages

No information found

Mountain yellow-legged frog

No information found

Sierra Nevada yellow-legged frog

No information found

Primary Sources

Cloern, J. E., Knowles, N., Brown, L. R., Cayan, D., Dettinger, M. D., Morgan, T. L., ... & Jssby, A. D. (2011). Projected evolution of California's San Francisco Bay-Delta-River system in a century of climate change. PlosOne, 6 (9), 1-13.

Coats, R. (2010). Climate change in the Tahoe basin: regional trends, impacts and drivers. Climatic Change, 201, 435-466.

Hanak, E. & Lund, J. R. (2011). Adapting California's water management to climate change. Climatic Change, 1-28. DOI 10.1007/s10584-011-0241-3

Jager, H. I., van Winkle, W., & Holcomb, B. D. (1999). Would hydrologic climate changes in Sierra Nevada streams influence trout persistence? Transactions of the American Fisheries Society, 128, 222-240.

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

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

Meyers, E. M., Dobrowski, B., Tague, C. L. (2010). Climate Change Impacts on Flood Frequency, Intensity, and Timing May Affect Trout Species in Sagehen Creek, California. Transactions of the American Fisheries Society, 139 (6), 1657-1664.

Moyle, P. B., Katz, J. V. E., & Quinones, R. M. (2011). Rapid decline of California's native inland fishes: A status assessment. Biological Conservation, 144, 2414-2423.

Moyle, P. B., Kiernan, J. D., Crain, P. K. & Quicones, R. M. (2012). Projected effects of future climates on freshwater fishes of California. California Energy Commission. Publication number: CEC-500-2012-028.

Moyle, P. B., Kiernan, J. D., Crain, P. K. & Quicones, R. M. (2012). Projected effects of future climates on freshwater fishes of California. California Energy Commission. Publication number: CEC-500-2012-028.

Null, S. E., Viers, J. H., Deas, M. L., Tanaka, S. K. & Mount, J. F. (2012). Stream temperature sensitivity to climate warming in California's Sierra Nevada: impacts to coldwater habitat. Climatic Change, DOI 10.1007/s10584-012-0459-8

Perry, L. G., Anderson, D. C., Reynolds, L. V., Nelson, S. M., & Shafroth, P. B. (2012). Vulnerability of riparian ecosystems to elevated CO_2 and climate change in arid and semiarid western North America. Global Change Biology, 18, 821 - 842.

Rahel F.J., Bierwagen B., Taniguchi, Y. (2008). Managing Aquatic Species of Conservation Concern in the Face of Climate Change and Invasive Species. Conservation Biology, 22(3), 551-561.

Yarnell, S. M., Viers, J. H. & Mount, J. F. (2010). Ecology and management of the spring snowmelt recession. BioScience, 60(2), 114 – 127.

Yates, D., Galbraith, H., Purkey, D., Huber-Lee, A., Sieber, J., West, J., Herrod-Julius, S., &Joyce,

B. (2008). Climate warming, water storage, and Chinook salmon in California's Sacramento Valley. Climatic Change, 91, 335-350.

Secondary sources

Blaustein, AR, Walls, BA, Bancroft BA, Lawler et al. (2010). Direct and indirect effects of climate change on amphibian populations. Diversity 2010 2(2), 281-313.

Hamlet AF, Mote PW, Clark MP, Lettenmaier DP (2005) Effects of temperature and precipitation variability on snowpack trends in the western United States. Journal of Climate 18:4545–4561

Hayhoe K, Cayan D, Field CB, Frumhoff PC, Maurer EP, Miller NL, Moser SC, Schneider SH, Cahill KN, Cleland EE, Dale L, Drapek R, Hanemann M, Kalkstein LS, Lenihan J, Lunch CK, Neilson RP, Sheridan SC, Verville JH (2004) Emissions pathways, climate change, and impacts on California. Proceeding of the National Academy of Sciences 101:12422–12427

LeBlanc RT, Brown RD (2000) The use of riparian vegetation in stream-temperature modification. Water and Environment Journal 14(4):297–303

Marcogliese, D. J. 2001. Implications of climate change for parasitism of animals in the aquatic environment. Canadian Journal of Zoology 79:1331–1352.

McCullough DA (1999) A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon. Prepared for the U.S. EPA 910-R-99-010.

McCusker MR, Parkinson E, Taylor EB (2000) Mitochondrial DNA variation in rainbow trout (Oncorhynchus mykiss) across its native range: testing biogeographical hypotheses and their relevance to conservation. Molecular Ecology 9:2089–2108

Morrill JC, Bales RC, Conklin MH (2005). Estimating stream temperature from air temperature: implications for future water quality. Journal of Environmental Engineering-ASCE 131(1):139–146.

Mote PW, Hamlet AF, Clark MP, Lettenmaier DP (2005) Declining mountain snowpack in western North America. Bulletin of American Meteorological Society 86:39–49

Moyle PB, Van Dyck PC, Tomelleri J (2002) Inland fishes of California. University of California Press, Berkeley

Myrick, C.A., J.J. Cech, Jr. 2001. Temperature effects on Chinook salmon and steelhead: a review focusing on California’s Central Valley populations. Bay-Delta Modeling Forum Technical Publication 01–1. Available online at: http://www.cwemf.org/Pubs/TempReview.pdf.

Nielsen EE, Hansen MM, Loeschcke V (1999) Genetic variation in time and space: microsatellite analysis of extinct and extant populations of Atlantic salmon. Evolution 53:261–268

Poole GC, Berman CH (2001) An ecological perspective on in-stream temperature: natural heat dynamics and mechanisms of human-caused thermal degradation. Environmental Management 27(6):797–802. doi:10.1007/s002670010188

Sadro S, and Melack JM (2012) The effect of an extreme rain event on the biogeochemistry and ecosystem metabolism of an oligotrophic high elevation lake. Arctic, Antarctic and Alpine Research. 44(2). 222-231

Stewart IT, Cayan DR, Dettinger MD (2004) Changes in snowmelt runoff timing in Western North America under a 'business as usual' climate change scenario. Climate Change 62:217–232

Stewart IT, Cayan DR, Dettinger MD (2005) Changes toward earlier streamflow timing across Western North America. Journal of Climate 18:1136–1155

Vannote RL, Sweeney BW (1980) Geographic analysis of thermal equilibria: a conceptual model for evaluating the effect of natural and modified thermal regimes on aquatic insect communities. Am Nat 115(5):667–695

Yoshiyama RM, Fisher FW, Moyle PB (1998) Historical abundance and decline of chinook salmon in the Central Valley Region of California. North American Journal Fish Management 18:487–521.