Central Valley Landscape Conservation Project

Climate Change Vulnerability Assessment (January 2017 version)

Salmonids

Vulnerability Assessment Summary

Overall Vulnerability Score and Components:

Vulnerability Component	Score
Sensitivity	High
Exposure	High
Adaptive Capacity	Moderate-high
Vulnerability	**High**

Overall vulnerability of salmonids was scored as high. The score is the result of high sensitivity, high future exposure, and moderate-high adaptive capacity scores.

Key climate factors for salmonids include altered streamflow, water temperature, snowpack amount, timing of snowmelt and runoff, storms, drought, and dissolved oxygen. These factors impact stream hydrology, including flow and water quality, affecting the salmon migration, egg survival in redds, and survival of juveniles and adults.

Key non-climate factors for salmonids include urban/suburban development, land use change, agricultural and rangeland practices, impervious surfaces, roads, highways, and trails, pollutions and poisons, nutrient loading, dams, levees, and other water diversions, groundwater overdraft, invasive and problematic species, hatcheries, and increasing human populations. These factors contribute to direct mortality (e.g. predation by invasive fish, pesticide exposure) and destroy, fragment, and degrade habitat, affecting salmonid recruitment, distribution, and dispersal opportunities.

Key disturbance mechanisms for salmonids include wildfire, flooding, and disease. Intense wildfire may degrade habitat, removing streamside vegetation that stabilizes banks and provides shelter and shade opportunities for juveniles. Flooding can increase fine sedimentation as well as streambed and bank scour, degrading potential spawning habitat and destroy existing redds. Finally, salmonids may be more susceptible to pathogens and disease in warmer water.

Salmonid populations in the Central Valley and surrounding foothills are declining, and stream-spawning habitat is patchily distributed and often difficult (or impossible) to access.

Urban/suburban development, energy practices and mining, agricultural and ranching practices, land use change, and dams all act as landscape barriers, preventing movement and/or increasing mortality during dispersal. Although genetic diversity has declined due to hatcheries and dams, salmonids exhibit high life history diversity across genera and species, as well as within species and populations. Some flexibility in life history strategies may increase the resilience of this species group in the face of climate change, particularly if gene flow can be improved.

Management potential for salmonids was scored as moderate and likely includes increasing water use efficiency and decreasing toxic contaminant runoff from urban and agricultural areas. Additionally, the release of water to create floodplains may increase stream connectivity, and increasing stream heterogeneity will likely improve salmon survival and fitness.

Table of Contents

Introduction

Description of Priority Natural Resource

Salmonids (*Oncorhynchus* spp.) in the Central Valley, including steelhead (*O. mykiss*), Chinook salmon (*O. tshawytscha*), and coho salmon (*O. kisutch*), depend on stream channels for spawning and nursery habitat, as well as freshwater and marine environments utilized by anadromous adults.

As part of the Central Valley Landscape Conservation Project, workshop participants identified salmonids as a Priority Natural Resource for the Central Valley Landscape Conservation Project in a process that involved two steps: 1) gathering information about the species group's management importance as indicated by its priority in existing conservation plans and lists and, 2) a workshop with stakeholders to identify the final list of Priority Natural Resources, which includes habitats, species groups, and species.

The rationale for choosing the salmonids as a Priority Natural Resource included the following: the species group has high management importance, and the species group's conservation needs are not entirely represented within a single priority habitat. Please see Appendix A: "Priority Natural Resource Selection Methodology" for more information.

Vulnerability Assessment Methodology

During a two-day workshop in October of 2015, 30 experts representing 16 Central Valley resource management organizations assessed the vulnerability of priority natural resources to changes in climate and non-climate factors, and identified the likely resulting pressures, stresses, and benefits (see Appendix B: "Glossary" for terms used in this report). The expert opinions provided by these participants are referenced throughout this document with an endnote indicating its source[1]. To the extent possible, scientific literature was sought out to support expert opinion garnered at the workshop. Literature searches were conducted for factors and resulting pressures that were rated as high or moderate-high, and all pressures, stresses, and benefits identified in the workshop are included in this report. For more information about the vulnerability assessment methodology, please see Appendix C: "Vulnerability Assessment Methods and Application." Projections of climate and non-climate change for the region were researched and are summarized in Appendix D: "Overview of Projected Future Changes in the California Central Valley".

Vulnerability Assessment Details

Climate Factors

Workshop participants scored the resource's sensitivity to climate factors and this score was used to calculate overall sensitivity. Future exposure to climate factors was scored and the overall exposure score used to calculate climate change vulnerability.

Climate Factor	Sensitivity	Future Exposure
Air temperature	-	High
Altered stream flow	High	High
Extreme events: drought	High	High
Extreme events: more heat waves	-	High
Extreme events: storms	High	-
Increased flooding	-	High
Increased wildfire	-	High
Other factors	High	-
Precipitation (amount)	-	High
Precipitation (timing)	-	High
Snowpack amount	High	High
Timing of snowmelt/runoff	High	High
Water temperature	High	High
Overall Scores	**High**	**High**

Streamflow

Sensitivity: *High (high confidence)*
Future exposure: *High (High confidence)*

Salmonids rely on stream channels that are highly sensitive to changes in hydrology, caused in part by changes in precipitation that affect water level and velocity (Meyers et al. 2010), as well as channel topography and substrate (Yarnell et al. 2010). Severely dry years and prolonged drought conditions lead to very low stream flows; the San Joaquin Valley is more likely than other regions to experience extremely dry years (Null et al. 2013). Under these conditions, some streams may transition from perennial to intermittent or even to ephemeral flows (Myrick & Cech 2004), limiting the area and heterogeneity of salmon habitat. Low stream flows can also delay upstream migration of anadromous salmon returning to their spawning grounds (Shapovalov & Taft 1954; Groot & Margolis 1991; Moyle 2002; Lestelle 2007) and reduce rearing areas for juvenile salmon (Cedarholm & Scarlett 1982). Sufficient water velocity through redds is critical for proper oxygenation of eggs, and stream flow is highly correlated with egg survival as well as size upon hatching (Silver et al. 1963; Groot & Margolis 1991).

Water temperature

Sensitivity: *High (high confidence)*
Future exposure: *High (High confidence)*

Stream temperatures are also expected to increase by an average of 1.6°C for each 2°C rise in air temperature on the western slopes of the Sierra Nevada, with most warming occurring during the spring months (Null et al. 2013).

Warming air temperatures and low stream flows contribute to increased water temperatures (Yarnell et al. 2010), which have a direct influence on dissolved oxygen levels, nutrient cycling, and productivity, as well as the metabolic rates and life histories of aquatic organisms (Vannote & Sweeney 1980; Poole & Berman 2001). Cold-water species, such as salmonids, have limited thermal tolerance (Eaton & Scheller 1996; Myrick & Cech 2004) and warming water temperatures may affect salmonid fitness and survival (McCullough 1999; Myrick & Cech 2004), potentially leading to local extinctions (Eaton & Scheller 1996; Hari et al. 2006). Streams that are on the west slopes of the Sierra Nevada and/or are at middle elevations may be the most sensitive to warming temperatures (Null et al. 2013).

Snowpack amount

Sensitivity: *High (high confidence)*
Future exposure: *High (High confidence)*

Snowpack is projected to decline by 65% by the end of the century, leading to earlier and swifter annual snowmelt recessions (Yarnell et al. 2010; Pierce & Cayan 2012; Null et al. 2013), which will likely result in higher winter and spring flood risks.

Reduced snowpack may lead to earlier and more rapid snowmelt (Yarnell et al. 2010; Pierce & Cayan 2012; Null et al. 2013) and reduced annual and spring peak flows, particularly in the summer months (Knowles & Cayan 2002; Miller et al. 2003; Medellín-Azuara et al. 2007; Vicuna et al. 2008). Shorter periods of peak flow and longer durations of low flow can delay upstream salmonid migrations (Shapovalov & Taft 1954; Groot & Margolis 1991; Moyle 2002; Lestelle 2007), and contribute to warmer water temperatures (Null et al. 2013) that reduce salmonid fitness and survival (McCullough 1999; Myrick & Cech 2004).

Timing of snowmelt & runoff

> ***Sensitivity:*** *High (high confidence)*
> ***Future exposure:*** *High (High confidence)*

Total annual water year runoff has increased for the Sacramento River basins and decreased for the San Joaquin River basins, but both areas experienced decreases in spring runoff (April-July), which declined by 9% for the Sacramento River basins and declined by 7% for the San Joaquin River basins these trends may continue through 2050 (Hunsaker et al. 2014).

The timing of peak runoff has advanced by one month since the first half of the 20th century (Stewart 2009), due in part to reduced snowpack (Pierce & Cayan 2012). Earlier snowmelt may lead to a longer duration of warm, low-flow conditions and a shorter period when there is cold water within the system (Yarnell et al. 2010). An earlier and shorter period of snowmelt is likely to limit the extent of suitable habitat and recruitment success for woody riparian plant species (Rood et al. 2005; Stella et al. 2006) which, compounded by an increase in sustained low flows, may diminish arthropod and macroinvertebrate diversity and homogenize stream structure (Yarnell et al. 2010). This loss of heterogeneity could have cascading impacts throughout stream and riparian ecosystems (Nakano et al. 1999), greatly affecting salmonids (Groot & Margolis 1991; Beakes et al. 2014). Changes could lead to the loss of redd habitat, as well as the variety of habitat conditions (e.g., stream depth, velocity, substrate, and bank cover) that young anadromous salmonids require on their migration to marine environments (Groot & Margolis 1991; Lestelle 2007).

Storms

> ***Sensitivity:*** *High (high confidence)*

Increased intensity and frequency of winter rainfall under changing climate conditions (Cannon & DeGraff 2009) could threaten salmonids due to increased flooding (Vivoni et al. 2009), sediment movement (Jensen et al. 2009; Wildhaber et al. 2014), and reduced stream channel stability (Perry et al. 2012). Flooding from winter storms, especially those that coincide with earlier peak flows, may result in stream bank scouring, disturbing salmon embryos (Montgomery et al. 1996; Schuett-Hames & Adams 2003) and decreasing salmon abundance over time (Moscrip & Montgomery 1997).

Drought

> ***Sensitivity:*** *High (high confidence)*
> ***Future exposure:*** *High (High confidence)*

Over the coming century, the frequency and severity of drought is expected to increase due to climate change (Hayhoe et al. 2004; Cook et al. 2015; Diffenbaugh et al. 2015; Williams et al. 2015), as warming temperatures exacerbate dry conditions in years with low precipitation, causing more severe droughts than have previously been observed (Cook et al. 2015; Diffenbaugh et al. 2015). Regardless of changes in precipitation, warmer temperatures are expected to increase evapotranspiration and cause drier conditions (Cook et al. 2015). Recent studies have found that anthropogenic warming has substantially increased the overall likelihood of extreme California droughts, including decadal and multi-decadal events (Cook et al. 2015; Diffenbaugh et al. 2015; Williams et al. 2015).

More frequent, longer, and/or more severe droughts in the context of climate change (Hayhoe et al. 2004; Cook et al. 2015; Diffenbaugh et al. 2015; Williams et al. 2015) will likely reduce both availability and quality of salmonid habitat. Drought heavily impacts streamflow, leading to more frequent and/or longer periods of low- or no-flow conditions in stream reaches (Gasith & Resh 1999), and even occasional dewatering of salmon redds has large negative impacts on egg survival (Groot & Margolis 1991). Multi-year droughts may cause longer-term changes to stream channels, primarily due to the absence of occasional flooding and scouring events (Gasith & Resh 1999). Drought may also impact riparian vegetation, reducing the stream inputs of organic matter that support benthic invertebrates, a primary food source for salmonids (Griggs 2009).

Precipitation (amount)

Future exposure: *High (high confidence)*

Precipitation (timing)

Future exposure: *High (high confidence)*

Although precipitation models for California are highly uncertain, some projections suggest that annual precipitation in the Sacramento and San Joaquin River Basins will remain quite variable over the next century, increasing slightly by 0.6% in the Sacramento River Basin and decreasing by 4.2-5.3% in the San Joaquin River Basin by 2050 (Bureau of Reclamation 2015).

Heat waves

Future exposure: *High (high confidence)*

Statewide, heat wave season may last 22 days longer in the mid-21st century compared to the late 20th century; Sacramento may experience 39 more heat wave days per year (Hayhoe et al. 2004).

Workshop participants did not further discuss the following factors beyond assigning scores.

Dissolved oxygen

Sensitivity: *High (high confidence)*

Air temperature

Future exposure: *High (high confidence)*

Climatic changes that may benefit the species group:

- Storm events, higher precipitation amounts, and increased snowpack could lead to higher flows and cooler temps

- Higher flows could inundate floodplains, which would support the production of anadromous species

Non-Climate Factors

Workshop participants scored the resource's sensitivity and current exposure to non-climate factors, and these scores were then used to assess their impact on climate change sensitivity.

Non-Climate Factor	Sensitivity	Current Exposure
Agriculture & rangeland practices	High	High
Dams, levees, & water diversions	High	High
Groundwater overdraft	High	High
Impervious surfaces	High	High
Invasive & other problematic species	High	High
Land use change	High	High
Nutrient loading	High	High
Other factors	High	High
Pollution & poisons	High	High
Roads, highways, & trails	High	High
Urban/suburban development	High	High
Overall Scores	**High**	**High**

Urban/suburban development

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Widespread across the landscape.*

Urban/suburban development impacts streams through direct modification of stream channels and streambanks, as well as indirectly through increases in runoff, pollution, invasive species, recreational use, and other pressures (Nelson et al. 2009). Urban streams may also have less large woody debris (due to both flooding and direct removal), reducing habitat heterogeneity and the number and volume of stream pools (Fausch & Northcote 1992; Moscrip & Montgomery 1997; Finkenbine et al. 2000). Finally, runoff from urban areas and roads often contains pesticides and contaminants that can cause premature death in spawning adult salmonids (Feist et al. 2011) and reduce survival of smolts (King et al. 2014). In some cases, increased flooding and runoff may remove fine sediments and help to maintain gravel substrates appropriate for salmon redds (Finkenbine et al. 2000).

Impervious surfaces

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Widespread across the landscape.*

Impervious surfaces are abundant in urban and suburban areas, and increase runoff and flooding frequency or intensity in nearby streams, with impacts to salmonids that depend on local conditions (Moscrip & Montgomery 1997; Finkenbine et al. 2000).

Dams, levees, & water diversions

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Widespread across the landscape.*

Dams, levees, and water diversions limit salmonids access to upstream waters, preventing migration and dramatically impacting Pacific salmon by limiting genetic diversity and adaptability (McClure et al. 2008; Braun et al. 2016). Additionally, water infrastructure directly impacts streamflow, altering flooding regimes, sediment transport processes, and channel structure; under these conditions, stream biodiversity is often impacted negatively (Moyle & Mount 2007; Wohl et al. 2015). Dams and levees typically trap upstream sediment supply in regulated rivers, creating sediment deficits downstream (Yarnell et al. 2015). Water releases that do not contain enough sediment may cause extreme stream scour and bed degradation during downstream flooding (Grams et al. 2007), potentially disturbing salmon redds (Montgomery et al. 1996). By contrast, some regulated rivers may have large sediment inputs from unregulated tributaries, or may lack the capacity to transport capacity because of flow diversions (Yarnell et al. 2015); under these conditions, too much sediment may limit oxygen supply to salmon redds and reduce egg-to-fry survival (Jensen et al. 2009; Wildhaber et al. 2014).

Groundwater overdraft

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Widespread across the landscape.*

Large-scale groundwater extraction may cause adverse environmental impacts on stream systems because of the close linkages between groundwater and biogeochemical cycles and ecological processes (Loáiciga 2002, 2003). For instance, groundwater overdraft can lead to declines in surface-water levels, decreased recharge of aquifers, declines in streamflow, and changes in riparian vegetation (Zektser et al. 2004). Where shade-producing vegetation is reduced or eliminated, subsequent increases in water temperature may affect fitness and/or survival for some salmonids (McCullough 1999; Myrick & Cech 2004).

Invasive & other problematic species

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Widespread across the landscape.*

Shifts in water temperature and streamflow may favor invasive fish such as largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and green sunfish (*Lepomis cyanellus*; Rahel et al. 2008; Rahel & Olden 2008), compete with and prey upon native juvenile salmonids (CA NRA 2010). Invasions of aquatic invertebrates such as the zebra mussel (*Dreissena* spp.) may also have unforeseen effects on salmonid habitat quality (Bisson et al. 2009).

Prolonged warming temperatures and a longer dry season may shift dominant vegetation in riparian areas toward invasive plant species, affecting associated assemblages of insects, fish, and wildlife (Heckman 1999; Boersma et al. 2006; Bartolome et al. 2014).

Agricultural & rangeland practices

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Widespread across the landscape.*

The Central Valley is dominated by agricultural development, which has been possible due to a massive water distribution system that transfers water from the north to arid central and southern parts of the state (Duffy & Kahara 2011). Nearly 93% of all water used in the region is for agricultural production, and changes in water management to maintain reservoir storage and delivery of water supplies will likely impact stream flow, particularly by decreasing streamflow (Perry et al. 2012). Earlier and/or larger irrigation water withdrawals could substantially reduce late spring and summer flows (Eheart & Tornil 1999), compounding climate-projected reductions in streamflow and further stressing to plants and animals (Perry et al. 2012).

Grazing by domestic animals has direct and indirect effects on stream ecosystems (Ohmart 1996). Riparian areas surround stream channels and are therefore favored grazing locations by livestock because they have relatively high productivity of herbaceous species and have available water and shade (Kauffman & Krueger 1984). Heavy grazing in riparian areas can lead to soil compaction, destabilization of channel banks, and increased sediment concentrations (Lusby et al. 1971; Kauffman & Krueger 1984; Ohmart 1996; Scott et al. 2003), further homogenizing stream morphology and limiting oxygen supply to salmon redds (Jensen et al. 2009; Wildhaber et al. 2014). Grazing can also reduce streamside vegetation, which can contribute to warmer water temperatures (McCullough 1999; Myrick & Cech 2004), and water contamination can occur from livestock feces and urine (Craun et al. 2005). Eutrophication in rivers and streams resulting from agricultural and grazing practices may have additional impacts on water quality (e.g., reducing dissolved oxygen) and may lead to the loss of species diversity and shifts in community composition (Poff 2002; Ficke et al. 2007).

Roads, highways, & trails

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Widespread across the landscape.*

Roads, highways, and trails reduce stream connectivity, as culverts associated with stream crossings often impede flow, sediment transport, and the movement of wildlife (Trombulak & Frissell 2000). Runoff from roads may also contain contaminants that can reduce survival of spawning adults and smolts (Feist et al. 2011; King et al. 2014).

Land use change

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Widespread across the landscape.*

Land use change impacts salmonids indirectly through crop conversion, which increases the runoff of nutrients and pesticides, water diversions for irrigation, and the introduction of alien species (Duffy & Kahara 2011).

Pollution & poisons

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Widespread across the landscape.*

Contaminant runoff from urban areas, highways, and agriculture may negatively impact water quality in salmon streams (e.g., Ryan et al. 2013). For salmonids, toxic contaminants can cause premature death in spawning adults (Feist et al. 2011) and reduce survival of smolts (King et al. 2014).

Nutrient loading

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Widespread across the landscape.*

Excess nutrients, including nitrogen (N) and phosphorus (P), reach riparian areas and streams via runoff from both agricultural and urban activities (Carpenter et al. 1998). While agriculture is the primary source for nutrient loading in the Central Valley, wastewater treatment plants and industrial sites can also contribute nutrients to urban runoff (Carpenter et al. 2007; Klose et al. 2012). Because nutrients (especially nitrogen) are limiting factors for many plant species, increased nutrient availability can increase production of algae, decrease dissolved oxygen, and alter the species composition of plant, invertebrate, and aquatic vertebrate communities (Carpenter et al. 1998; Klose et al. 2012).

Hatcheries

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*

Pattern of exposure: *Widespread across the landscape.*

Although hatcheries attempt to supplement declining wild salmonid populations, recent research has suggested that this effort is not always successful (Naish et al. 2007). The introduction of hatchery fish may have exceeded stream and oceanic carrying capacity (Beamish et al. 1997; Levin et al. 2001) and reduced wild salmonid genetic diversity (Waples 1991; Utter & Epifanio 2002; Pearse et al. 2010; Braun et al. 2016). For example, Levin et al. (2001) demonstrate that survival of wild chinook decreased as hatchery production increased over 25 years.

Increasing human populations

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Widespread across the landscape.*

The population of California is expected to increase by 19–30% by the year 2025 (Public Policy Institute of California 2006), which is likely to lead to a substantial increase in the demand for water (Duffy & Kahara 2011), limiting streamflow for salmon.

Disturbance Regimes

Workshop participants scored the resource's sensitivity to disturbance regimes, and these scores were used to calculate climate change sensitivity.

Overall sensitivity to disturbance regimes: *High (high confidence)*

Flooding

Future exposure: *High (high confidence)*

Increases in heavy winter rainfall could translate to more extreme hydrographs and more flooding, which can result in stream bank scouring and the removal of riparian vegetation, which affects stream temperature, sediment loads, and the abundance of large woody debris (Naiman et al. 1993; Stromberg et al. 1993). Stream scouring can disturb salmon redds and cause egg loss (Montgomery et al. 1996; Schuett-Hames & Adams 2003), and increased deposition of fine sediments can limit oxygenation (Jensen et al. 2009; Wildhaber et al. 2014) and cause changes to the streambed substrate that reduce habitat suitability for salmonids (Groot & Margolis 1991). High flows are also associated with channel widening and/or deepening and with increased turbidity[1]. If flow is high enough to overflow stream banks, however, new floodplains can provide extensive habitat opportunities, particularly for juvenile salmonids, and increase connectivity between existing streams (Henning et al. 2006).

Decreased flooding eliminates natural scouring processes, contributing to sediment buildup and reduced hydrologic connectivity between the channel and floodplain (Poff et al. 1997). The loss of natural flooding regimes also impacts riparian vegetation recruitment and habitat extent, which contributes to changes in riparian arthropod and aquatic macroinvertebrate communities (Yarnell et al. 2010).

Wildfire

Future exposure: *High (high confidence)*

Large fire occurrence and total area burned in California are projected to increase over the next century, with a possible 74% increase in total area burned by 2085 (Westerling et al. 2011).

Although low- to moderate-severity fires may help stabilize streamside vegetation by stimulating root growth (Dwire & Kauffman 2003), fires that occur during extreme weather conditions (e.g., hot, dry wind storms) can be particularly severe (Van de Water & North 2011), and these can remove vegetation altogether, potentially impacting ecosystem function (Segura & Snook 1992; Skinner & Chang 1996; Camp et al. 1997). The removal of streamside vegetation may cause increases in water temperature (Beakes et al. 2014), which can affect salmonids fitness and survival (McCullough 1999; Myrick & Cech 2004) due to their limited thermal tolerance, even leading to local extinctions (Eaton & Scheller 1996; Hari et al. 2006). Habitat suitability can also be reduced for juvenile salmonids, which require shaded areas in woody debris or tree roots alongside banks (Mundie 1969; Lister & Genoe 1970; Fausch et al. 2001; Lestelle et al. 2006). Additionally, severe flooding is common after wildfires, and these can wash large amounts of sediment, debris, and contaminants into streams, sometimes wiping out local fish populations(Cooper et al. 2014; Morrison & Kolden 2015).

Fires and post-fire impacts to streams may reduce prey availability for salmonids (Beakes et al. 2014) and change inputs of sediment and large woody debris into streams (Miller et al. 2003; Barnett et al. 2008). Changes in the stream channel can lead to wider, shallower, and more homogeneous streams lacking the pools important for salmonid redds and juvenile habitat (Vronskiy 1972; Groot & Margolis 1991; Fausch & Northcote 1992; Moyle 2002), but processes of erosion and sedimentation can also increase habitat heterogeneity (Yarnell et al. 2015).

Disease

Overall, climate-induced thermal stress can lower salmonid resistance to pathogens and disease and increase the virulence of disease outbreaks (McCullough 1999; Marcogliese 2001). A combination of warm temperatures, low stream flow, and disease could lead to higher salmonid mortality; this combination occurred in the Klamath River during 2002, causing a substantial die off of approximately 35,000 salmon (Fedor 2003). Warmer waters may also enable the spread of pathogens beyond populations that have been historically exposed to those that have little resistance (Crozier et al. 2008).

Dependency on habitat and/or other species

Workshop participants scored the resource's dependency on habitat and/or other species, and these scores were used calculate climate change sensitivity.

***Overall degree of specialization**: High (high confidence)*
***Dependency on one or more sensitive habitat types:** High (high confidence)*
***Description of habitat:** Spawning habitats, floodplains, rearing habitat in the Delta, coldwater streams.*
Dependency on specific prey or forage species:
***Juveniles:** Moderate (high confidence)*
***Adults:** High (high confidence)*
***Dependency on other critical factors that influence sensitivity:** High (high confidence)*
***Description of other dependencies:** Dissolved oxygen, hatchery production*

Salmonids depend on stream spawning habitat with particular characteristics (e.g., cold temperatures and gravel substrates), and these habitat are sensitive to many potential impacts of climate change, which include warmer water temperatures (Yarnell et al. 2010; Null et al. 2013), reduced insect prey availability (Nakano et al. 1999; Beakes et al. 2014), and decreased salmonid spawning habitat availability (Fausch & Northcote 1992; Jager et al. 1999; Beakes et al. 2014). Adults are additionally dependent on ocean conditions to provide anchovy and smelt prey[1].

Adaptive Capacity

Workshop participants scored the resource's adaptive capacity and the overall score was used to calculate climate change vulnerability.

Adaptive Capacity Component	Score
Extent, Status, and Dispersal Ability	Moderate
Landscape Permeability	Low-moderate
Intraspecific Species Group Diversity	High
Resistance & Recovery	High
Other Adaptive Capacity Factors	High
Overall Score	**Moderate-high**

Extent, status, and dispersal ability

***Overall degree extent, integrity, connectivity, and dispersal ability:** Moderate (high confidence)*
***Geographic extent:** Transcontinental (high confidence)*
***Health and functional integrity:** Degraded (high confidence)*
***Population connectivity:** Patchy with some connectivity (high confidence)*
***Dispersal ability:** High (high confidence)*

Salmonids occur across a broad geographical area and a wide variety of habitats. Salmon species found in central California, including chinook and coho, are also across the northern Pacific Rim, including Japan, Alaska, and down the Pacific coast of North America (Groot & Margolis 1991).

Landscape permeability

Overall landscape permeability: *Low-moderate (high confidence)*
Impact of various factors on landscape permeability:
- ***Urban/suburban development:*** *High (high confidence)*
- ***Agricultural & rangeland practices:*** *High (high confidence)*
- ***Dams, levees, & water diversions:*** *High (high confidence)*
- ***Land use change (floodplains):*** *High (high confidence)*
- ***Energy production & mining:*** *Moderate-high (high confidence)*
- ***Roads, highways, & trails:*** *Moderate (high confidence)*
- ***Invasive & other problematic species:*** *Moderate (high confidence)*
- ***Geologic features:*** *Moderate (high confidence)*
- ***Riprap:*** *Low (high confidence)*

Dams, levees, and water diversions create direct barriers to salmonid dispersal, limiting salmonid access to important upstream spawning habitat (National Marine Fisheries Service 1996). Other human land-use practices associated with development, agriculture, and energy production, as well as the impacts of those practices (e.g., increased invasive species) may degrade water quality and habitat structure (Moscrip & Montgomery 1997; McClure et al. 2008; Pearse et al. 2010), effectively fragmenting habitat by limiting the connectivity between patches of suitable habitat. Salmonid populations that are unable to move through the stream network to access refuges may go extinct (Eaton & Scheller 1996; Hari et al. 2006).

Resistance and recovery

Overall ability to resist and recover from stresses: *High (high confidence)*
Resistance to stresses/maladaptive human responses: *High (high confidence)*
Ability to recover from stresses/maladaptive human response impacts: *High (high confidence)*

The ability of salmonids to recover from and adapt to current and impending stresses is heavily influenced by salmonids' ability to access suitable cold-water habitat (McCullough 1999), and salmonid populations that are unable to access thermal refugia may go extinct (Eaton & Scheller 1996; Hari et al. 2006). A myriad of factors contribute to warming water temperatures (e.g. decreased snowpack and earlier snowmelt), limiting coldwater streams to higher elevations and higher latitudes (Jager et al. 1999; Hari et al. 2006).

Species group diversity

Overall species group diversity: *High (high confidence)*
Diversity of life history strategies: *High (high confidence)*

Genetic diversity: *Moderate-high (high confidence)*
Behavioral plasticity: *High (high confidence)*
Phenotypic plasticity: *High (high confidence)*

In general, salmonids as a group are highly variable in their life history strategies, even within genera, species, and populations (Groot & Margolis 1991). *Onchorhynchus* species are all anadromous and semelparous but vary in their time to maturity, their spawning strategies (timing and habitat), and relative time spent in freshwater versus marine environments (Groot & Margolis 1991). For example, chinook may spend 3 or 4 years in the ocean before reaching maturity while coho generally return to their natal streams after about 16 months (Sandercock 1991; Lestelle 2007). Within central California chinook, there are three separate spawning runs (spring, fall, and winter); spring-run chinook spend a relatively long period in freshwater before they spawn in stream headwaters in the late summer while fall-run chinook have a shorter upriver migration and spawn almost immediately (Groot & Margolis 1991). There is also some individual variation that likely helps to maintain genetic diversity within populations (Lestelle 2007). For example, in relatively productive years or in locations of generally high quality habitat, some male coho salmon mature quickly and spend only a few months in the ocean; when they return to spawn, they provide the sole means of gene flow between coho brood years (Young 1999). However, barriers to movement (e.g., dams) and hatcheries have dramatically impacted the population and genetic diversity of Pacific salmon (McClure et al. 2008; Pearse et al. 2010; Braun et al. 2016).

Other Factors

Overall degree to which other factors affect habitat adaptive capacity: *High (high confidence)*

Ocean/bay conditions

Ocean/bay conditions

Although most salmonid management focuses on the recovery of freshwater spawning habitat, anadromous salmonids spend the majority of their adult life in marine environments. Truly effective management for salmonid recovery will require a holistic approach that considers the entire life cycle, including the role of ocean conditions on salmon survival and population regulation (Bisbal & McConnaha 1998).

Management potential

Workshop participants scored the resource's management potential.

Management Potential Component	Score
Species value	High
Societal support	Moderate-high
Agriculture & rangeland practices	High
Extreme events	Low
Converting retired land	Low-moderate
Managing climate change impacts	Low-moderate
Overall Score	**Moderate**

Value to people

Value to people: *High (high confidence)*
Description of value: *Commercial/recreational fishing.*

Support for conservation

Degree of societal support for management and conservation: *Moderate-high (high confidence)*
Description of support: *Some regulation and legislative action has been taken, and the number of statutes indicates some value, but little financial support exists. Societal support in California is low and possibly dropping.*

Degree to which agriculture and/or rangelands can benefit/support/increase resilience: *High (high confidence)*
Description of support: *They can modify operations (water/pesticides/etc.), and provide water quality benefits, flow, floodplain productivity and access.*

Degree to which extreme events (e.g., flooding, drought) influence societal support for taking action: *Low (high confidence)*
Description of events: *No event is significant enough for a high score (except perhaps a major fish die-off).*

Likelihood of converting land to support species group

Likelihood of (or support for) converting retired agriculture land to maintain or enhance species group: *Low-moderate (high confidence)*
Description of events: *It depends on where the land is – land is only significant if it frees up water for river/ecological quality.*

Likelihood of managing or alleviating climate change impacts: *Moderate (moderate confidence)*
Description of likelihood: *Passage over rim dams/barriers could be highly adaptive, but likelihood is low due to perceived impacts to water supplies.*

Although substantial portions of both the Sacramento and San Joaquin Rivers are degraded, there is significant potential and societal support for conserving salmonid habitat and restoring wild salmonid populations. Ideally, physical habitat restoration, sediment transport, and flow regimes should be considered together in order to achieve greater stream heterogeneity and stream health (Yarnell et al. 2015). Adjustments to agricultural practices, such as increasing water efficiency and reducing pesticide use, could increase water quality and maintain higher flows. Additionally, levee breaching could enhance floodplain connectivity (Florsheim & Mount 2002). Finally, efforts to de-armor bends and reconnect abandoned channels isolated by land conversion could increase opportunities for rivers to meander (Perry et al. 2012), creating heterogeneous habitat with the pools, varied flow, and woody debris required by salmonids (Groot & Margolis 1991). Although habitat restoration is unlikely to fully mitigate the negative effects of climate change on salmonids, restoration efforts may support fish populations, especially those that focus on increasing juvenile rearing capacity and improving low-elevation reaches (Battin et al. 2007).

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