Chinook Salmon (Oncorhynchus tshawytscha)

Sacramento River winter-run Chinook

Overall vulnerability—Very high (100% Very high)
Biological sensitivity—Very high (100% Very high)
Climate exposure—High (86% High, 14% Very high)
Adaptive capacity—Low (1.4)
Data quality—79% of scores ≥ 2

Life History Synopsis

Sacramento River winter-run Chinook adults leave the ocean in from December through April, before fully mature and predominantly as age-3 fish (O’Farrell et al. 2012, Satterthwaite et al. 2017). Adults hold in fresh water until spawning, from late-April through September, with peak spawning in July (Fisher et al. 2014, Killam et al. 2016). Fry emerge from July to mid-October, and recent evidence from otolith reconstructions suggests they rear in diverse tributary habitats along the Sacramento and lower Sacramento River and in freshwater reaches of the delta for several months prior to seaward migration (Phillis et al. 2018a). Summertime spawning of this DPS is unique among Chinook salmon, and is presumably an adaptation to
hydrologic and thermal conditions in the spring-fed headwaters of the Sacramento River, which have been inaccessible for the past 8 decades due to construction of impassable dams.

Migrating smolts from this DPS experience higher survival during years with greater freshwater flows and ensuing favorable water quality conditions (Perry et al. 2016). In wetter years, a significant proportion of juveniles can also gain access to productive floodplain habitats, where growth rates are very high (Sommer et al. 2001).

Juveniles leave San Francisco Bay between January and April and enter the Gulf of the Farallones (Pyper et al. 2013). For the Central Valley fall-run Chinook DPS, growth in the first ocean year is negatively related to sea surface temperature, curl, and scalar winds and positively related to summer upwelling (Wells et al. 2012). Faster freshwater growth rates have been shown to influence early marine survival when ocean conditions are poor (Woodson et al. 2013). Sacramento River winter-run Chinook has a more southerly ocean distribution than Central Valley fall-run Chinook salmon and is concentrated off the California central coast (Satterthwaite et al. 2015, Johnson et al. 2016). Whether these ocean distributions occur upon entry as juveniles or later during the marine stage is unclear. Sacramento River winter-run Chinook individuals are smaller at a given age than Chinook from other Central Valley DPSs (Satterthwaite et al. 2012).

**Climate Effects on Abundance and Distribution**

Several factors contribute to ranking of very high vulnerability for Sacramento River winter-run Chinook persisting in the face of climate change. The greatest risk to this DPS is its sensitivity to population viability, which was ranked very high, driven primarily by its structure as a single population spawning outside of its historical range. The DPS is not thriving under present climate conditions, which are likely to worsen.

As exemplified by the series of drought conditions and extreme warm ocean temperatures during 2012-2016, this DPS is highly vulnerable to cumulative life-cycle impacts over multiple life stages, as well as in consecutive cohorts (Johnson et al. 2016). Sensitivity to cumulative life-cycle effects ranked very high. During the 2012-2016 drought, the limited amount of cold water resulted in eggs being exposed to lethal temperatures during summer and early fall (Johnson et al. 2017, Martin et al. 2017), leading to near extirpation of the wild year classes. Exposure to hydrologic regime shift, stream temperature, and summer water deficit were ranked on the cusp between moderate and high. These exposures are expected to worsen under future warming/drier climate scenarios. Adults (their gametes), eggs, and early juvenile life stages all rely on the availability of cold water in Shasta Reservoir for survival during summer. The amount of cold water available to achieve tolerable, let alone optimal, temperatures for these life stages is insufficient in some years and varies as a function of cumulative snowfall, rainfall, reservoir stratification, and previous water deliveries (NMFS 2009).

The extent to which Sacramento River winter-run Chinook experience reduced frequency of wetter year conditions will likely influence recovery opportunities. While flooding may pose
Higher flood flows are thought to provide beneficial conditions for juvenile salmon rearing and migration, with increased turbidity and cooler temperatures reducing predation risk (reviewed in Perry et al. 2016). Large floodplain habitats such as the Sutter and Yolo Bypasses are only fully inundated and available to juvenile salmon during flood conditions. Access to productive, shallow-water rearing habitats confers significant growth and likely survival benefits (Sommer et al. 2001, Woodson et al. 2013). Thus, to the extent that climate change reduces the frequency and duration of floodplain inundation, Sacramento River winter-run Chinook could be negatively impacted. This was reflected in a high exposure rank for flooding, a moderate exposure rank for hydrologic regime shift, and moderate to high sensitivity rank for the juvenile freshwater stage.

Sea-level rise is thought to be more pronounced in the southern estuaries along the West Coast (Limburg et al. 2016). Recent projections for California estuaries suggest potential sea-level rise exceeding 10 feet by the end of the century if there is rapid loss of the Antarctic ice sheet (Griggs et al. 2017). Salmon transiting the San Francisco Bay estuary are thought to have higher mortality rates associated with tidal flows in the delta and estuary relative to unidirectional riverine flows (Perry et al. 2016). The extent to which sea-level rise reduces the quantity of habitat that experiences unidirectional flow may influence juvenile salmon survival in the migration corridor. There is large uncertainty on how sea-level rise will influence the tidal prism and the suitability of habitats currently used by Sacramento River winter-run Chinook. Sea level rise is also expected to reduce the availability of tidal marsh habitats used by juveniles because most estuarine shorelines are or will be armored, which will prevent migration to marshes of higher elevations (Stralberg et al. 2011). Overall, rankings were high for exposure to sea level rise and sensitivity in the estuary stage.

Sacramento River winter-run Chinook were ranked moderate for sensitivity in the marine stage, and high for exposure to upwelling. This DPS exhibits a relatively unique ocean migratory behavior and possibly contracted distribution in the marine environment. Genetic and coded-wire-tag analysis indicate that these fish have a more southerly and nearshore marine distribution compared to other Chinook salmon ESUs and can be found schooling together (Satterthwaite et al. 2015, Johnson et al. 2016). They also enter the ocean somewhat earlier and at a larger size than Central Valley fall-run/late fall-run Chinook. To the extent that changes in climate conditions vary with latitude, this DPS may respond asynchronously and may be more or less vulnerable than other Chinook salmon ESUs to changes in ocean conditions.

**Extrinsic Factors**

Sacramento River winter-run Chinook is listed as endangered under the U.S. and California Endangered Species Acts. This DPS is found near the southern edge of the Chinook
salmon species range. These fish are blocked from historical spawning habitats, and spawning is now restricted to a single reach (50 km) on the mainstem Sacramento River downstream of Keswick Dam. This constricted spawning distribution makes them particularly vulnerable to extinction (Lindley et al. 2007). Life-cycle modeling evaluations identify Sacramento River winter-run Chinook as highly vulnerable to extinction due to the frequency of drought conditions in its constrained spatial range (Lindley et al. 2007, Hendrix 2008). Multiple life stages are blocked from cooler and ecologically distinct headwaters due to Keswick and Shasta Dams. Therefore, efforts to reintroduce these fish to historical habitats in Battle Creek and the McCloud River above Shasta Dam are a high priority for recovery (NMFS 2009). Comparisons of summer temperatures on the McCloud River in 2014 versus the lethal temperatures in the mainstem Sacramento River highlight the loss of cooler summer temperatures in historical habitats currently unavailable to this DPS. Sensitivity to population viability and other stressors (including habitat loss) ranked very high.

Livingston Stone National Fish Hatchery is a conservation hatchery that plays an increasingly important role in reducing extinction risk when natural returns of Sacramento River winter-run Chinook are low. Thus, sensitivity to hatchery influence ranked very high. During the 2012-2016 drought, egg-to-fry survival in the Sacramento River was exceptionally low for this DPS (<5% in 2014 and 2015: Johnson et al. 2017). A threefold increase in the production and release of hatchery juveniles will likely play an important role in preventing cohort failure of adult returns in 2017 and beyond. However, there is an important tradeoff in response of the conservation hatchery to potential climate impacts: to ensure adequate adult abundance while balancing potential impacts on long-term genetic integrity of this DPS from an increasing proportion of hatchery fish (Johnson et al. 2016).

Adaptive Capacity

Sacramento River winter-run Chinook is sensitive to elevated temperatures under present climate conditions at multiple life stages. This DPS is likely at its physiological limit for adaptive capacity. At the southern-most range of the species, the California Central Valley offers the least adaptive capacity among all Chinook salmon recovery domains. Thus, overall adaptive capacity ranked low for this DPS.

Sacramento River winter-run Chinook lacks within-DPS genetic diversity relative to other Chinook salmon DPSs due to historical population bottlenecks (Banks et al. 2000, Lindley et al. 2007). This lack of genetic diversity may ultimately compromise its adaptive capability to respond to future climate change.

Efforts to reintroduce Sacramento River winter-run Chinook to its historical habitats may reduce extinction risk by providing spatial diversity and reducing reliance on inconsistent cold-water reserves in Shasta Reservoir. Such reintroductions will provide the DPS with the habitat and water quality templates upon which they evolved. By reinstating access to some of the habitats and conditions that sustained these fish during severe climate events historically (e.g,
locally adapted populations may emerge that are capable of coping with future hydrologic regimes.

Age diversity in Sacramento River winter-run Chinook adults and juveniles is low relative to that in other Chinook salmon DPSs (Satterthwaite et al. 2017). The vast majority (85-100%) of adults leave the ocean and return to spawn at age-3, suggesting very little carryover to older ages (O’Farrell et al. 2012). All juveniles migrate as age-0; however, they leave natal spawning reaches over a protracted season (Poytress et al. 2014). These juveniles rear in a diversity of habitats as a function of hydrologic conditions prior to entering the ocean over a narrower window of time (Pyper et al. 2013, Phillis et al. 2018b). Reconstructions of adult otoliths indicate that juveniles rearing in the delta and in tributaries to the mainstem Sacramento River (Deer and Mill Creeks; American River) contribute significantly to adult returns (Phillis et al. 2018b). This work also revealed that juveniles exhibit greater diversity in size, timing, and habitat-use than previously thought (Johnson et al. 2017). This phenotypic diversity and migration phenology may become increasingly important in ensuring some component of the DPS experiences favorable riverine, estuarine, and ocean conditions (Satterthwaite et al. 2014, Sturrock et al. 2015). Highlighting this remnant phenotypic diversity is not intended to understate the loss of significant juvenile rearing opportunities in headwater and intermittent streams, floodplains, and freshwater marshes. Such opportunities likely played a significant role in supporting a thriving Sacramento River winter-run Chinook DPS that adapted to past climate extremes.

**Literature Cited**


Hendrix, N. 2008. A statistical model of Central Valley Chinook incorporating uncertainty. Description of *Oncorhynchus* Bayesian Analysis (OBAN) for winter run Chinook. R2 Resource Consultants, Inc, Redmond, WA.


