SACRAMENTO RIVER WINTER-RUN CHINOOK SALMON
Oncorhynchus Tshawytscha

Critical Concern. Status Score = 1.3 out of 5.0. Sacramento River winter-run Chinook salmon (winter-run) face immediate risk of extinction. The ESU is extirpated from its native spawning range and has been reduced to a single small spawning population, which is wholly dependent on artificially-created spawning habitat and cold water releases from Shasta Dam.

Description: There are few obvious morphological differences separating the four runs of Central Valley Chinook salmon, though winter-run tend to be smaller than fall Chinook. For a full description of Chinook salmon, see the North Central Coast Chinook salmon account.

Taxonomic Relationships: While Sacramento River winter-run Chinook salmon are genetically distinct from other Central Valley runs, the four runs of Central Valley Chinook salmon are more closely related to each other than they are to fish from outside the Central Valley. Historically, there were four separate populations of winter-run Chinook that spawned in headwater reaches of the upper Sacramento, McCloud, and Pit rivers and Battle Creek (Tehama Co.). For a more complete discussion of taxonomic relationships among Central Valley Chinook salmon, see the Central Valley spring Chinook salmon account.

A major problem, however, has been identification of members of each run when they are juveniles, especially when mixed in downstream reaches. The standard method for separating runs has been a simple length-at-date measurement, based on the assumption that fish hatching at different times would retain the difference in size as they grew larger and moved downstream. Harvey et al. (2014) found that, in fact, many genetically identified fall, late-fall, and spring-run were being identified as winter-run because they were bigger than expected under length-at-date criteria. Part of the reason for these inaccuracies is likely due to the fact the growth rates differ according to the habitats in which juveniles rear. However, the growth rates, which underlie the length-at-date criterion, were based on solely on models for in-channel rearing, therefore when individuals gain access to more productive off-channel or floodplain habitats growth rates can be accelerated leading to possible misidentification. "The two central assumptions of the length-at-date approach (i.e. segregated [length] ranges and a constant shared growth rate among races) were not supported by the [length] data for genetically identified juveniles (Harvey et al. 2014, p. 1182)." Merz et al. (2014), found that using morphometric measurements decreased the rate at which genetically identified fall-run and late-fall-run Chinook juveniles were counted as winter-run or spring-run.

Life History: For the basic life history of Chinook salmon, see the North Central Coast Chinook account. Winter-run Chinook, which are known only from the Sacramento Valley, have a life history strategy that differs from all other Chinook salmon. Winter-run life histories were shaped in response to access to year-round, spring-fed, cold-water stream reaches, a rare hydrologic feature among salmon bearing streams, of the headwaters of the Sacramento River watershed. Eventually, breeding in isolation from other runs led to the evolution of distinctive strategies affecting all winter-run life stages including adult migration timing, spawn timing, egg incubation duration and juvenile outmigration.

Winter-run enter fresh water as sexually immature adults in January through May with runs peaking in mid-March. Prior to dam construction, winter-run migrated to the headwaters of the Sacramento River Watershed, where they exploited spring-fed stream reaches in the basalt and porous lava region of the northeastern part of the state. They would hold in these perennial, cold water reaches for several months until spawning in April through early August (Williams 2006).

The spring through mid-summer spawn and egg incubation period (the most temperature-sensitive of Chinook salmon life stages) typically occurs during the hottest part of the year when water temperatures in many California rivers exceed the lethal range for Chinook embryos. The consistently cold temperatures of winter-run streams presumably lengthened incubation duration of winter-run eggs relative to eggs of other runs incubating in warmer water reaches.

In the post-dam era in the reach below Keswick Dam, fry emerge from the gravel in July through mid-October (Yoshiyama et al. 1998, Williams 2006) and juveniles rear for approximately 5-10 months before moving downstream (Yoshiyama et al. 1998). Thus, spawning in summer gives winter-run an advantage over the spring- and late-fall runs by providing longer rearing times in the stream, without juveniles having to over-summer in the following year (Stillwater 2006).

Peak movement for juveniles of all runs of Chinook salmon in the Central Valley tends to be at night, thus reducing predation risk. Juvenile entry into the Sacramento-San Joaquin Delta occurs from January to April (Stillwater 2006). According to Williams (2006), most fry migrate past Red Bluff diversion dam in summer or early fall, but many apparently rear in the river below Red Bluff for several months before moving to the Delta in early winter.

Habitat Requirements: For general Chinook salmon habitat requirements, see the North Coast Chinook salmon account.

Adult migration and holding. Winter-run historically migrated high into the spring-fed reaches of the McCloud, Pit, and Sacramento rivers and Battle Ck to spawn, which required migration during winter-run and early spring when flows were high enough enabling passage. Once they reached their spawning grounds, they held for several months in deep pools with good cover until they were ready to spawn. Today, winter-run Chinook still attempt to migrate to the highest upstream spawning habitats available to them but are stopped by Keswick Dam (Stillwater 2006). Optimal temperatures for holding range from 10-16°C (see thermal tolerance table in North Coast Chinook account); optimal holding velocities range from 0.47 to 1.25 m/s, significantly higher than selected by the other runs (Table 1, USFWS 2003).

Spawning and egg incubation. Winter-run Chinook require water temperatures that must be cold enough during summer to enable successful embryo incubation, but warm enough in winter-run to support juvenile rearing (Stillwater 2006). Little is known of winter-run spawning habitats prior to dam construction. From observations below Keswick Dam, they appear to spawn in deeper water than the other runs of Central Valley Chinook, generally from 1-5 m (USFWS 2003), but have been observed spawning in water as deep as 7 m (Moyle 2002). Stream temperatures that exceed the 13.3°C (56°F) daily average temperature limit winter-run egg survival (NMFS 2016a):

Juvenile rearing and outmigration. Winter-run juveniles appear to occupy fresh water nearly all year round. In 1898 Rutter (1903) observed extensive numbers of juvenile salmon of multiple size classes over-summering in pools of the upper Sacramento River near Simms. That same year in Battle Creek Rutter captured hundreds of small salmon (between 35-50 mm) in October and November suggesting a midsummer emergence from the gravel that would match up with the winter-run life history strategy. Today winter-run run are first detected in July close to their natal grounds in the Sacramento River near Red Bluff, and smolts are last detected at Chipps Island leaving the Delta as late as May (del Rosario et al. 2013). In a seine survey in July 1898, Rutter found no salmon juveniles rearing in the river downstream of the mouth of Battle Creek (Rutter 1902). In the reaches below Keswick Dam, juveniles emerge from the gravel in mid-summer and are restricted to reaches that maintain cool summer temperatures (generally upstream of the mouth of Deer Creek at Rkm 354) between July and September for rearing (Stillwater 2006). Once water temperature cools in the downstream reaches in the early fall, the rapidly growing parr use more of the river for rearing.

Because of their distinctive emergence time, winter-run Chinook fry generally have little competition from other juvenile salmonids during the first few months of life, although the extent to which juveniles of other runs held over the summer in the McCloud River and other historical habitats is unclear. As winter-run Chinook move downstream, they share rearing habitat with spring-run Chinook juveniles entering the Sacramento River from the Mill, Deer, and Butte Creek drainages, which may be as much as a year old and are thus considerably larger than winter-run Chinook juveniles (Williams 2006, Stillwater 2006). While this may result in a competitive advantage for spring-run, there is some indication that the two runs use habitat differently based on their sizes and thus do not directly compete (Stillwater 2006). They also mix with juveniles from other runs during their outmigration, making identification difficult (Merz et al. 2014); thus any general description of the migratory behavior of juvenile winter-run Chinook, such as the one that follows, should be viewed with caution.

Outmigration appears to be tightly correlated with the first high flows of the migration season. Winter-run tend to migrate past Knights Landing on the Sacramento River (Rkm 144) *en masse* shortly after flows reach a threshold of 400 cubic meters per second measured at the Wilkins Slough gage (del Rosario et al. 2013). These "first flush" events may occur anytime between October and April, depending on the water year. However, in most years outmigration is concentrated in November and December with the majority of the population passing Knights Landing by early January (del Rosario et al. 2013).

Residence times in the lower river and estuary (between Knights Landing and Chipps Island) average about 3 months (ranging from 41 to 117 days) with juveniles that arrive earlier in the migration season apparently residing for longer periods in the lower river and Delta. Winter-run-sized fish have been detected at Chipps Island as early as December and as late as May, with peak outmigration from the Delta in mid-March (del Rosario et al. 2013).

Winter-run juveniles would have historically benefitted from the typical winter-run flooding which would have made hundreds of thousands of acres of floodplain and off-channel habits available for rearing in the Sacramento River basin. Inundation of floodplains increases residence times, allowing water to warm compared to the relatively cool river channel; increases in residence time and water temperature facilitate greater decomposition of terrestrial vegetation and increase primary production in the form of algal phytoplankton (Ahearn et al. 2006, Grosholz and Gallo 2006). Detrital decomposition and algal primary production are the primary sources of carbon that fuels aquatic food webs and supports zooplankton and other invertebrate populations, which are the primary source of food for juvenile fish. Fish food densities are typically far greater on the floodplain than in the river (Conrad et al. 2016, Katz et al. *in press*). In addition, juvenile salmonids may use less energy to maintain themselves on floodplains than they would in the mainstem Sacramento River, further increasing growth rates. For these reasons, growth rates for juvenile Chinook rearing in floodplain habitats tend to far exceed those rearing in riverine habitats (Sommer et al 2001, Jeffres et al. 2008, Katz et al. *in press*). Rapid growth results in larger out-migrants and higher survival rates in the ocean (Unwin 1997, McCormick et al. 1998, Hayes et al. 2008, Williams et al. 2016). However, there are very few floodplains now available to salmonid juveniles in the Sacramento River Watershed, which may have a profound negative impact on winter-run survival and recruitment, in addition to the loss of spawning habitat upstream of Shasta Dam.

Distribution: All four winter-run Chinook populations have been extirpated from their historical spawning areas in the Upper Sacramento, Pit, and McCloud Rivers and Battle Creek (Lindley et al. 2007). The closing of Shasta Dam in 1945 halted migration into the Upper Sacramento, Pit and McCloud River drainages. The Battle Creek population was extirpated by hydropower dam operations. Additionally, the weir at Coleman National Fish hatchery was a barrier to upstream migration until recently (NMFS 1997, Lindley et al. 2007). Battle Creek remains unsuitable for holding and spawning due to high summer water temperatures, particularly during dry years (Lindley et al. 2007, NMFS 2016a).

Currently, there is only a single winter-run Chinook population, which spawns in the Sacramento River below Keswick Dam near Redding (NMFS 1997). This population holds and spawns at the base of Keswick Dam, where cold-water releases from Shasta Reservoir, combined with artificial gravel additions, have created headwater-type habitat on the valley floor (NMFS 2016a).

Trends in Abundance: Historical abundance of winter-run Chinook is thought to have been approximately 200,000 spawners per year (NOAA 2005). Winter-run have been in decline for the last decade with the 2011 escapement of 827 spawners being the lowest run since the construction of the LSNFH conservation hatchery in 1997 (NMFS 2016b, Figure 1). In 2015, an estimated 3,500 winter-run Chinook salmon returned to the Sacramento River to spawn (NMFS 2016b, Figure 2). Drought conditions and warm water releases from Shasta Reservoir contributed to extremely low fry-to-egg survival in the 2014 and 2015 brood years. Low returns are expected from these brood years, with the additional concern that the proportion of hatchery spawners will also likely increase. Recent abnormally warm conditions in the ocean may also negatively impact winter-run returns for the next 2 to 3 years (NMFS 2016a, Williams et al. 2016).

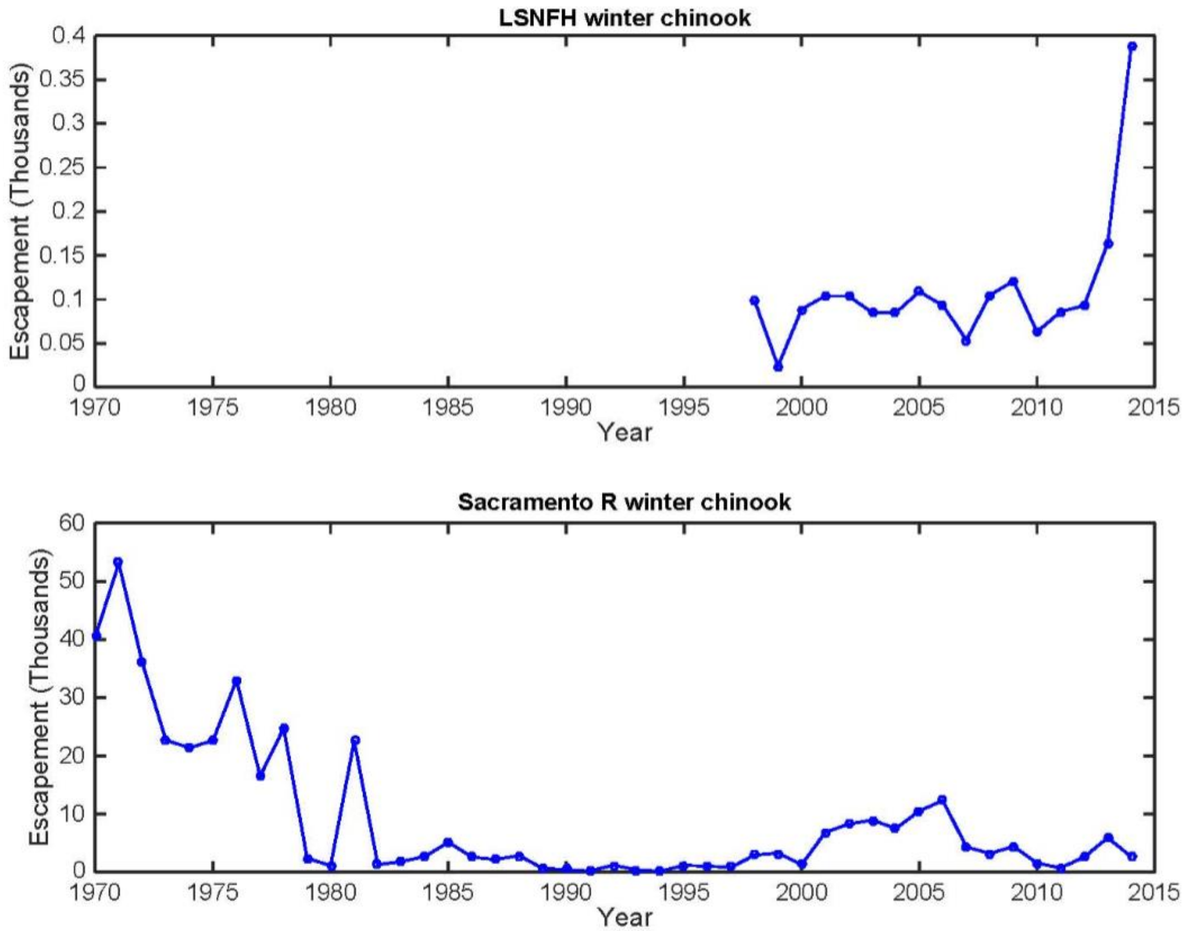

Figure 1. Time series of escapement for SR winter-run Chinook salmon populations (a) used as broodstock at LSNFH and (b) spawning in-river. Estimates for in-river spawners is the average number of adults counted at Red Bluff Diversion Dam and the carcass survey mark-recapture estimates (when available). Note: only mark-recapture estimates used beginning in 2009; From NMFS 2016b, based on Azat 2014.

Accurate abundance data has been difficult to collect, and there have been numerous instances (e.g. Williams et al. 2006) in which putative winter-run were discovered to be either spring or late fall-run fish. Livingston Stone Hatchery produces approximately 200,000 winter-run smolts per year that are marked and tagged before release (Williams 2006), and percentage of hatchery fish spawning below Keswick Dam in recent years has increased to an overall trend

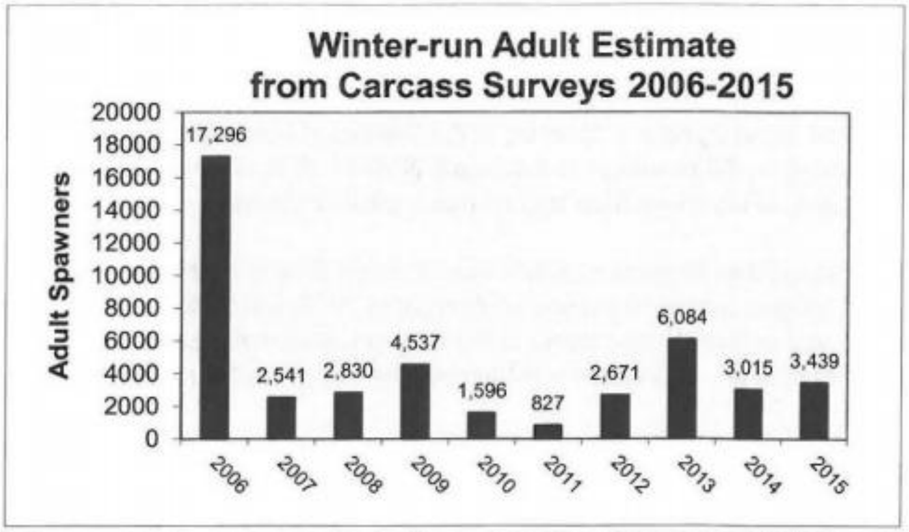

Figure 2. Winter-run Chinook salmon spawner escapement in the Sacramento River, 2006-2015. Data from CDFW GrandTab, 2015. From NMFS 2016b, Fig. 1. pg. 2.

Factors Affecting Status: Major factors affecting or potentially affecting the status of Sacramento winter-run Chinook salmon in the Central Valley are discussed below.

The biggest single cause of decline of winter-run Chinook salmon was the construction of Shasta and Keswick Dams in the 1940s, which blocked access to historical spawning habitat. The subsequent steep decline of winter-run abundance in the late 1980s-early 1990s was precipitated by a combination of 1) excessively warm water released from Shasta Dam, 2) barriers to passage of both juveniles and adults, 3) entrainment in diversions, 4) possibly heavy metal contamination and acid mine drainage from Iron Mountain Mine (NMFS 1997), 5) loss of floodplain rearing habitat, and 6) commercial and recreational fisheries, which do not discriminate between hatchery fall-run Chinook and wild fish of any run (NMFS 2016a). NMFS (1997) has also expressed concern over climatic factors further affecting habitat-based issues, primarily through extended droughts, low flows, and higher temperatures. The effects of poor conditions for growth and survival in fresh water are also exacerbated when poor conditions naturally occur in salt water (Satherthwaite et al. 2014). Unfavorable ocean conditions from periodic El Nino events in the Pacific Ocean can reduce salmon survival by altering upwelling and decreasing productivity, thus reducing food availability (NMFS 1997).

Dams. Shasta and Keswick Dams effectively prevented all upstream spawning migration for winter-run Chinook, denying access to all historical spawning and most rearing areas (NMFS 1997, Williams 2006). Ironically, the cold water releases from the dam also kept the run from going extinct. It was not expected that winter-run would survive after Shasta Dam was built (Moffet 1949), but the cold water releases allowed spawning to occur in a previously unsuitable river reach directly below Keswick Dam (NMFS 1997). Keswick Dam, located 14 km below Shasta Dam, regulates the releases from Shasta Reservoir, as well as flows diverted from the Trinity River. Initially, water temperatures were cold enough below Keswick Dam for annual spawning of winter-run Chinook. However, drought years and high levels of water removal rendered water temperatures below Keswick Dam unsuitable (up to 27°C) with enough frequency that the population all but disappeared in the late 1980s and early 1990s (NMFS 1997, NOAA 2005). The high temperature water released from Shasta Dam was credited by NMFS as one of the main factors that led to their listing as endangered under the federal Endangered Species Act (NMFS 1997). A temperature control device (TCD) was installed on Shasta Dam in 1997 to provide a continuous supply of cold water, as well as to improve dissolved oxygen and turbidity levels. The TCD was built for winter-run Chinook in particular, but has also benefited other runs.

During the recent drought, management of the cold water releases from Shasta Dam was among the most controversial of all water issues in the state. Flows released early in the season (May-June), encouraged adults to spawn over a wide area below the dam. However, flows then abruptly decreased in July and August because of the depleted cold-water pool in the reservoir, resulting in extremely high mortality rates of developing embryos, presumably from a combination of warmer temperatures and reduced hyporheic flow, reducing oxygen delivery to embryos (Martin et al. 2017).

An additional impact of Shasta and Keswick Dams has been coarsening of the substrate in spawning areas from large releases from the dam. Such releases move spawning gravel downstream, while preventing new gravel inputs from upstream (Stillwater 2006). This has led to a decrease in available spawning habitat over time and requires continuous gravel augmentation in the reaches below the dams to provide spawning habitat.

Red Bluff Diversion Dam (RBDD) is widely credited with causing 30 years of significant passage impairment to both upstream migrating adults and out-migrating juveniles due to inadequate fish passage (i.e., poorly designed fish ladders). In addition, predatory fish gathered at the base of the dam and historically devoured many out-migrating juveniles with the assistance of the RBDD’s lighting system, which made the juveniles visible at night. This has since been changed. Initially a NMFS Biological Opinion required that the dam gates be raised for six to nine months of the year; since 2012, the gates at RBDD have been open year-round to allow unimpeded upstream and downstream fish passage and minimize the impacts of predation at the dam.

Agriculture. Agricultural diversions along the Sacramento River presumably have some impact on out-migrating juvenile winter-run salmon (Moyle and Israel 2006). There has been a concerted effort at improving diversions through screening and most large diversions, such as the Anderson-Cottonwood Irrigation District, Glenn Colusa Irrigation District, Reclamation District 108, and Reclamation District 1004 are now screened (CDFG 2004).

A more important driver of both direct and indirect mortality are the Central Valley Project and State Water Project pumps in the southern Delta. Kimmerer (2008) estimated that the loss rate as the result of project pumps was “on the order of 10% or less” (p. 24), a rate which varies according to numbers of fish entrained as well as pre- and post-entrainment mortality (which are poorly understood). The tendency to increase pumping in the winter-run in order to reduce pumping at other times of year (for protection of Delta smelt and other species) may further increase entrainment mortality rates for winter-run Chinook salmon (Kimmerer 2008).

NMFS partners with the U.S. Fish & Wildlife Service, California Department of Fish & Wildlife, the State Water Resources Control Board the Department of Water Resources, and others to ensure that water operations do not put the continued existence of winter-run Chinook in jeopardy. They do so through extensive monitoring near the massive Delta pumps, and rely on coded-wire tags and genetic samples from winter-run Chinook daily salvage and loss counts. The baseline for these assessments is an estimate of survival to the Delta, which was estimated at 42% for 2012-2015 (NMFS 2016a). Since the 2009 Biological Opinion on the operation of the pumping stations in the Delta was released, NMFS authorizes incidental ‘take,’ as defined in the

Endangered Species Act, of up to 1% of the total juvenile production estimate (JPE) for winter-run Chinook salmon per water year before adjustments to the State Water Project and Central Valley Project operations must be made (NMFS 2016a). For water year 2015, these mortality allowances were about 1,000 wild and 1,500 hatchery fish (NMFS 2016a). There is some flexibility, as water operations managers can choose another operational trigger if 2.5 winter-run juveniles become entrained per thousand acre-foot of water released in the Delta (NMFS 2016a). How well these measures protect winter-run Chinook salmon population is not known.

Urbanization. Current winter-run spawning and holding habitat is proximate to heavily developed urban areas near the city of Redding. Streams in urban settings often face elevated risk of pollution from surface runoff, sewage discharges and storm drains, which can degrade water quality during vulnerable life history stages such as adult holding and egg incubation. The effects of the City of Redding on winter-run Chinook salmon are largely unknown.

Mining. Iron Mountain Mine is a superfund site which drains highly contaminated heavy metal contaminate effluent into Keswick Reservoir and has severely impacted water quality in the Sacramento River in the past by discharging toxic metals and acid mine drainage. It is an EPA Superfund Site and millions of dollars have been spent on remediation and clean up. A dam on Slickrock Creek has reduced 95% of the release of toxic metals, resulting in low levels of dissolved heavy metals in Sacramento River water. Despite ongoing funding, the mitigation solutions must be regarded as temporary, given the potential for dam failure and other factors causing massive pollution of the river. A particularly severe problem would be failure of the dirt dam holding back toxic waste from Iron Mountain Mine, which could wipe out fish and aquatic life in an extended reach of river below Keswick Reservoir (NMFS 2016a).

Transportation. The Sacramento River flows through urban Redding. Through this stretch, the river is crossed by numerous auto and train bridges, which also increase the possibility of toxic spills into the river. A disaster similar to the 1991 spill of pesticides at the Cantara Loop Bridge on the upper Sacramento River could impact an entire year class of winter-run Chinook and other aquatic life.

Estuarine alteration. There is growing appreciation of the importance of "biocomplexity" for the persistence of salmon in a variable environment (Hilborn et al. 2003, Carlson and Satterthwaite 2011). Biocomplexity (AKA the Portfolio Effect) is defined as multiple variations in life history that improve the ability of populations to persist in changing environmental conditions. Historically, juvenile fall-run Chinook salmon probably entered the estuary in different months and spent varying amounts of time there. Loss of habitat diversity in the San Francisco Estuary has limited life history diversity and the best strategy for juvenile salmon today seems to be to move through the estuary as quickly as possible. Large pumping stations in the south Delta divert approximately 40% of historical Delta flows, resulting in substantial modifications in flow direction (Nichols et al. 1986). This pumping also increases likelihood of out-migrating smolts entering the interior Delta where longer routes, impaired water quality, higher predation and entrainment lead to higher mortality rates (Perry et al. 2010).

Despite long-term monitoring, causes of apparent high mortality rates as fish pass through the estuary are poorly understood. General observations suggest that rearing conditions in the estuary are often poor; highest survival occurs during wet years, when passage through the estuary is likely most rapid (Brandes and McLain 2001, Baker and Morhardt 2001). Flooding in wet years also increases rearing habitat in the Delta and Yolo Bypass, which may also have a positive effect on growth and survival. To improve survival, most hatchery juveniles are transported and released downstream of the Delta in San Pablo and Grizzly bays (CDFW 2014).

Transporting smolts improves survival, but it also increases rates of straying upon return as adults. High straying rates contribute to homogenization of population structure and reductions in fitness by facilitating gene flow between populations in different streams, thus reducing biocomplexity within the CV Chinook salmon complex.

Recreation. The upper Sacramento River through the city of Redding supports substantial angling pressure for rainbow trout. Angler pressure tends to be greatest in locations and at times where winter-run Chinook are actively spawning and therefore more susceptible to impacts. Some are inadvertently hooked in this section of river must be released without being removed from the water, however, the process of hook-and-release likely still negatively impacts adults. An additional concern is that wading anglers could inadvertently trample redds while pursuing rainbow trout. To reduce these impacts, the Sacramento River from Keswick Dam downstream to the Highway 44 Bridge in Redding was closed by emergency regulations adopted by the California Fish and Game Commission in 2016 (CDFW 2016).

Harvest. Myers et al. (1998) examined harvest impacts and found that freshwater harvest was negligible, but that ocean harvest had considerable impacts on winter-run Chinook, because fishermen cannot distinguish between hatchery fall-run Chinook and endangered winter-run- and spring-run Chinook, and taking only a small number of fish from such a small population can have a large impact. Winter-run Chinook salmon are primarily impacted by fisheries south of Point Arena, California, due to their more southerly distribution in the ocean compared to other CV salmon stocks (NMFS 2016a). For the years 2000-2013, omitting 2008-2010 when the fishery was closed, approximately 19% of the age-3 winter-run were taken annually by the ocean fishery (PFMC 2015). The recreational fishery south of Point Arena has been closed since the early 2000s in February and March to protect winter-run Chinook, which are known to congregate in that area at that time of year (NMFS 2016a). The entire ocean fishery was halted in 2008-2010 because of the rapid decline of the fall Chinook population. Fall-run Chinook numbers have since increased sufficiently to reopen the fishery, but the winter-run Chinook population has not rebounded, indicating that even present incidental harvest rates may be excessive, when combined with other mortality factors (Kimmerer 2008).

Hatcheries. The long-term negative impacts of hatcheries on wild salmon populations are discussed in the Central Valley fall Chinook account. Two major concerns are (1) the effects of hatchery rearing of winter-run Chinook salmon on their behavior and genetics, because hatchery fish are increasingly contributing to the in-river spawning population (Williams 2006), and (2) the effects of competition from large numbers of hatchery fall-run Chinook when ocean productivity is low (Levin et al. 2001). The concerns boil down to the likelihood of hatcheries accelerating the decline of naturally-spawning Chinook of all runs. Hatchery proportion of LSNFH-origin spawners in the river has been steadily on the rise, increasing from an already alarmingly high of ~20% in 2005 to greater than 30% in 2012. NMFS places the population at a moderate risk of extinction from what they term "excessive hatchery influence" (NMFS 2016a).

In 2015, in response to extreme drought conditions the USFWS, NMFS, and CDFW collectively decided to re-initiate a captive broodstock program using juvenile hatchery fish from the LSNFH Conservation Hatchery Program. Program fish which will only be reared to maturity at the LSNFH and not released. This is a last resort safety measure with the stated goals, listed in order of priority, to provide: 1) a genetic reserve of winter-run Chinook salmon in a safe and secure environment to be available for use as hatchery broodstock in the event of a catastrophic decline; 2) a future source of winter-run Chinook salmon to contribute to multi-agency efforts to reintroduce them upstream of Shasta Dam and into restored habitats of Battle Creek; and 3) a future source to fulfill the needs of research projects (NMFS 2016a).

Alien species. Predation on juvenile salmon by non-native predators such as striped bass (*Morone saxatilis*), smallmouth bass (*Micropterus dolomieu*) and largemouth bass (*Micropterus salmoides*) and native species such as Sacramento pikeminnow (*Ptychocheilus grandis*) may be a major source of mortality of out-migrating juveniles. This is true especially in areas where structures concentrate large predators, such as Clifton Court Forebay at the South Delta pumps near Tracy (San Joaquin County). Preliminary results of 2013-2015 studies, which used hatchery winter-run smolts implanted with acoustic tags, showed survival rates to the ocean that varied from 5-12% (A. Ammann, NMFS, pers. comm. 2015). The highest mortality rates were observed in the middle reaches of Sacramento River, presumably due to predation (NMFS 2016a).

Factor	Rating	Explanation
Major dams	Critical	Dams have blocked access to entire native spawning range, and reduced ESU to a single population below Keswick Dam that is dependent on coldwater releases from Shasta Reservoir.
Agriculture	High	Competition for limited cold water during drought is a major stressor. Levees protect and drain farmland but have reduced floodplain habitats by 95%. Diversions and drains may cause juvenile and adult mortality. Most locations have been screened, but south Delta water diversion and pumping remains one of the most pressing factors contributing to extinction risk.
Grazing	Low	Impacts likely small.
Rural /residential development	Low	Generally minimal impact on large river systems (e.g., Sacramento), but increasingly connected to urbanized areas.
Urbanization	Low	Water diversion and groundwater pumping can negatively impact cold water flows.
Instream mining	Low	Some legacy impacts from gravel mining.
Mining	Medium	Could be rated as "High" if Iron Mountain Mine contamination remains a major threat to all fish in the Sacramento River.
Transportation	Medium	Toxic spills from roads or the railway, while unlikely, represent a clear threat to the single population holding and spawning in an urban area bisected by multiple bridges.
Logging	Low	Potential impacts of logging could increase if winter-run are reintroduced into the upper portions of their historical watersheds.
Fire	Low	Little threat of fire on Sacramento River.
Estuary alteration	Medium	The San Francisco Estuary is heavily altered, to the detriment of all native species of fish migrating through it.
Recreation	Low	Redds can be disturbed by wading anglers. Boating, swimming, and fishing may impact holding and spawning behavior of winter-run but magnitude of impacts is unknown.
Harvest	Medium	The ocean fishery may harvest winter-run at unsustainable rates.
Hatcheries	High	NMFS places the population at a moderate risk of extinction from what they term "excessive hatchery influence."
Alien species	Medium	Predation from diverse predators is a source of juvenile mortality.

Table 1. Major anthropogenic factors limiting, or potentially limiting, viability of the Sacramento River winter-run Chinook population. Factors were rated on a five-level ordinal scale where a factor rated “critical” could push a species to extinction in 3 generations or 10 years; a factor rated “high” could push the species to extinction in 10 generations or 50 years; a factor rated “medium” is unlikely to drive a species to extinction by itself but contributes to increased extinction risk; a factor rated “low” may reduce populations but extinction unlikely as a result; and a factor rated “no” has no known negative impact. Certainty of these judgments is high based on peer reviewed and gray literature, direct observation, expert judgment, and anecdotal information. See methods for explanation.

Effects of Climate Change: A recent NMFS summary of climate change impacts found that freshwater and marine productivity and survival tend to be lower in warmer years for most west coast salmon and steelhead populations (Williams et al. 2016). Winter-run are likely among the most ‘at risk’ salmonids because of their unique life history in which spawning and incubation takes place at the most thermally challenging time of the year. This makes them especially vulnerable to climate change and drought. Reduced availability of cold water leads to increased water temperature conditions degrading adult holding, spawning, and rearing conditions, but egg development is most acutely impacted. Climate change is likely to make maintaining cold water conditions on which the only naturally spawning population depends increasingly difficult. California’s recent, historic drought (2012-2016) reduced the cold water pool in Shasta reservoir. Stream temperatures that exceed the 13.3°C (56°F) daily average temperature limit winter-run egg survival (NMFS 2016a): warm water during the periods of egg incubation and fry emergence were particularly severe during in 2014 and 2015 below Keswick Dam when the egg-to-fry survival was estimated to be 5.6% and 4.2%, respectively (NMFS 2016a), dramatically lower than the average of 26.4% for brood years 2002-2012 (Poytress et al. 2014).

Lindley et al. (2007) provide thermal suitability maps based on several warming scenarios that show that without passage around dams to cooler headwater areas, impacts to winter-run (and all other runs of Central Valley Chinook) may be severe. The hatcheries, too, are not immune from increases in drought frequency and severity associated with a warming climate, where low flows and high temperatures will likely increase the threat of disease (NMFS 2016a). Continued monitoring is critical, as well as developing adaptive management strategies should warming in their current habitat approach or exceed winter-run Chinook thermal tolerances.

Status Score = 1.3 out of 5.0. Critical Concern. Sacramento River winter-run Chinook salmon have a high likelihood of extinction, as reflected in their listing as an endangered species by both state and federal governments. Abundance has declined from having perhaps 200,000 fish divided among four populations, to having a few thousand (once a few hundred) in just one population. Lindley et al. (2007) indicate that catastrophic events in the region such as prolonged drought, catastrophic forest fire, or volcanic activity, could have extremely detrimental impacts on the population, particularly because there is now only a single population with no geographic redundancy. The proportion of hatchery-produced fish spawning in the wild is also on the rise. Winter-run salmon’s continued persistence shows their remarkable resiliency, but they remain extremely vulnerable to loss or alteration of artificially maintained habitats, especially with respect to a warming climate that will make maintaining cold water conditions on which they depend increasingly difficult. Multiple critically dry years in a row or an extension of the most recent severe drought could potentially devastate the population.

In 1985, the California-Nevada Chapter of the American Fisheries Society (AFS) petitioned the National Marine Fisheries Service (NMFS) to list Sacramento River winter-run salmon as a threatened species under the Endangered Species Act (ESA) (NMFS 1997). In 1987, NMFS concluded that, while the decline was alarming, the conservation efforts that had already been implemented, in addition to those planned for the future, should enable recovery of the species without formal listing. This elicited a lawsuit by the Sierra Club Legal Defense Fund on behalf of AFS and eventually winter-run were listed as threatened in 1990. They were subsequently reclassified as endangered in 1994 (NMFS 1997) a status that was reconfirmed in 2005, 2011 and 2016. The State of California listed winter-run Chinook as endangered in 1989.

Metric	Score	Justification
Area occupied	1	A single population in a reach below dams; extirpated from their historical range.
Estimated adult abundance	2	The recent (2007-16) assessments indicate an average of < 3,000 returning spawners, therefore an effective population size of 600. In some years, the number of adults is below 1,000.
Intervention dependence	1	A captive broodstock program has been initiated to augment the conservation hatchery program at Livingston Stone Fish Hatchery. The naturally spawning population depends entirely on cold water releases from Shasta Dam.
Tolerance	1	Winter-run Chinook spawn in the most thermally challenging times of the year and are particularly at risk to high temperatures and low dissolved oxygen levels.
Genetic risk	2	Considerable genetic drift resulting from consolidation of winter-run populations into a single population is likely exacerbated by the large influence of hatchery broodstock.
Climate change	1	Extremely vulnerable because of reliance on cold water habitat and releases from Shasta Reservoir.
Anthropogenic threats	1	1 Critical, 2 High, 5 Medium threats.
Average	1.3	9/7.
Certainty	4	Well-studied population.

Table 2. Metrics to determine the status of Sacramento River winter-run Chinook, where 1 is poor value and 5 is excellent and 2-4 are intermediate values. Certainty of these judgments is high. See methods for explanation.

Management Recommendations: Since the ESA listing in 1990, there have been a great number of conservation measures instituted to help support populations of winter-run Chinook salmon, including:

- Opening the gates year-round at Red Bluff Diversion Dam to allow passage of adults and juveniles and minimize predation.
- Installation of a temperature control device on Shasta Dam in 1997 to provide a continuous supply of cold water and improve dissolved oxygen and turbidity levels.
- Construction and operation of the Livingston Stone Conservation hatchery.
- Screening almost all large water diversions on the Sacramento River.
- Construction of barriers at the Knights Landing Outfall gates (2015) and Wallace Weir

(2016) to block adults from straying into the Colusa Basin Drain.

- Attempts to stabilize mainstem flows so as to not dry out winter-run redds.
- Ocean harvest restrictions.
- Attempts to reduce entrainment and increase survival for entrained individuals at the south Delta export pumps.
- Dumping of large quantities of gravel below Keswick Dam to improve spawning habitat.

Improving habitats for spawning and rearing of Chinook salmon in the Central Valley remains an ongoing process. Two major initiatives will help with the recovery of winter-run: 1) reintroduction to Battle Creek and 2) reconnection of off-channel/floodplain rearing habitats.

Battle Creek. In 1999, Pacific Gas and Electric Company (PG&E), National Marine Fisheries Service, U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, and California Department of Fish and Wildlife reached an agreement to restore salmon and steelhead in Battle Creek, one of the original four watersheds of winter-run Chinook. Restoration and re-colonization of Battle Creek could provide 67 km (42 mi) of additional spawning habitat for all five of the anadromous salmonid runs as well as higher instream flows and cooler temperatures. The project will remove five dams, install fish screens and ladders on three dams, and end the diversion of water from the North Fork to the South Fork specifically to benefit listed salmon runs (NMFS 2016a), with full implementation expected by 2020. Restoration of floodplains in lower Battle Creek will offer critical support to establishing and sustaining a winter-run population should they be reintroduced to the watershed. Reconnecting the floodplains of Rancho Brisgau, once known as Bloody Island, located at the confluence of Battle Creek and the Sacramento River, would benefit all runs of Chinook from both streams.

When cold-water habitat is restored, Battle Creek will represent the only location, other than the mainstem Sacramento River where a winter-run population can swim through their entire life cycle. Such is not the case for proposed reintroduction to the McCloud River, which will involve relocation of adults over Shasta Dam (likely in so a so-called “trap and haul” program) and capture of juveniles in the McCloud River or Shasta Reservoir for trucking and relocation back to Sacramento River below Keswick Dam. NMFS has proposed that winter-run Chinook should be re-introduced to the McCloud River using two-way trap and haul (TH2), in which adults are transported around dams to spawn and juveniles are then captured as they migrate downstream and released in the Sacramento River below Shasta Dam (NMFS 2016a). Lusardi and Moyle (*in press*) indicate that any such trap and haul program should proceed with extreme caution. They view such aggressively interventionist efforts not as restoration efforts but as extinction prevention efforts and as such they should only be implemented after all other restoration measures have failed. If a reintroduction above Shasta were to be carried out it move forward under an experimental framework to designed to resolve potential uncertainties in adaptive fashion. Analysis of existing TH2 programs in the Pacific Northwest suggests they rarely, if ever, work for effectively increasing salmon abundance. Typically the greatest difficulties involve capturing out-migrating juveniles, which is likely to prove particularly challenging in the McCloud arm of Shasta Reservoir where surface water elevation can fluctuate dramatically.

Other concerns of a winter-run Chinook trap and haul program include its high cost and need for perpetual funding, making the species particularly vulnerable to future economic trends. Another danger is moving precious few adults above the dam creates a “population sink,” whereby above dam populations that cannot sustain themselves actually drag down the below dam populations as well, and the major changes to the McCloud River since winter-run were extirpated from it including diversion of over 75% of its summer base flow into the Pit River as part of PG&E's Pit-McCloud hydropower project (DFW 2004).

Floodplain reconnection. Del Rosario (2013) has shown that winter-run spend about three months on average rearing in the lower river, estuary, and Delta. This is a considerably more time than other runs, which makes sense when you consider that the majority of winter-run juveniles have entered the Delta before most fall run hatch from gravel. The extended rearing in the food-rich, off-channel habitats of the lower Valley was likely one of the drivers of evolution of the unique winter-run life history. Since European settlement, over 95% of floodplain and tidal marsh habitats have been drained, which drastically diminishes the benefits to fish rearing in the lower system. Accordingly, restoration of floodplains and tidal marshes is viewed as a critical recovery action for the species. To mitigate for the ecological impacts of water development, the legally binding Biological Opinion for the operation of the State and Central Valley Water projects calls for restoring 17,000 to 20,000 acres of floodplain and tidal marsh habitat for juvenile salmon rearing in the Lower Sacramento River and Delta. These actions are primarily aimed at increasing the frequency with which the Yolo Bypass floods and thus gives access to and provides habitat for rearing juvenile salmonids. This process began in 2007 and restoration actions are scheduled to be completed by 2023.

Off-channel and floodplain restoration actions are needed not just in the Delta and lower river but throughout the system. In the upper and mid reaches of the Sacramento River a thorough assessment of all potential floodplain reconnection opportunities within the federal levee system needs to be carried out. There is no one perfect project type, but instead a portfolio of projects, which hydrologically reconnect side channels, oxbow lakes, and varied small floodplains (such as the Willow Bend floodplain restoration north of Colusa) must be aggressively pursued along the entire length of CV river systems. In the lower River and Delta this approach is being used to implement a suite of projects to address the aquatic, sub-tidal, tidal, riparian, floodplain, and upland ecosystem needs are being pursued by a multitude of entities and funding sources including the state and federal public water agencies required to mitigate the ecological impacts of the CVP and SWP, the Central Valley Project Improvement Act, Propositions 1 and 1E, the AB 32 Greenhouse Gas Reduction Fund, and local, federal, and private investment. Yet there remains no central venue to bring the many players together to guide planning, set specific regionally explicit salmon habitat targets, and implement priority projects. The launch of the Central Valley Salmon Habitat Project in spring 2017 is envisioned to fill this critical gap.

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