CENTRAL VALLEY FALL-RUN CHINOOK SALMON
Oncorhynchus tshawytscha ESU

Status: High Concern. The abundance of Central Valley (CV) fall-run Chinook salmon has varied significantly in recent years, but the run is widespread and the number of spawners typically exceeds 100,000 fish. The run continues to be of concern because it is supported, to a large extent, by hatchery production which has ecological and genetic impacts on the sustainability of the run. Reliance upon hatchery stocks to augment low numbers of natural spawning (wild) CV fall-run Chinook is unlikely to be sustainable and likely will lead to, if not already, a largely homogenized population with reduced life history variability. Central Valley fall-run Chinook salmon are also one of the main populations contributing to California and Oregon ocean and inland fisheries. It is unknown what impacts the fisheries may be having on the wild stocks in the run.

Description: Members of the CV fall-run Chinook salmon Evolutionary Significant Unit (ESU), like other Chinook salmon, have numerous small black spots on the back, dorsal fin, and both lobes of the tail in both sexes. This spotting on the caudal fin and the black coloration of their lower jaw make them distinguishable from other sympatric salmonid species. They have 10-14 major dorsal fin rays, 14-19 anal fin rays, 14-19 pectoral fins rays, and 10-11 pelvic fin rays. There are 130-165 scales along the lateral line. Branchiostegal rays number 13-19. They possess more than 100 pyloric caeca and have rough and widely spaced gill rakers, 6-10 on the lower half of the first gill arch.

Spawning adults are the largest Pacific salmonid, often 75-80 cm SL, but lengths may exceed 140 cm. California Chinook are usually smaller, typically 45-60 cm SL. The average weight is 9-10 kilograms, although the largest Chinook salmon taken in California was 38.6 kg. Spawning adults are olive brown to dark maroon without streaking or blotches on the side. Males are often darker than females and develop a hooked jaw and slightly humped back during spawning. Juveniles have 6-12 parr marks, which often extend below the lateral line, and the marks are typically equal to or wider than the spaces between them. Parr can also be distinguished from other salmon species by the adipose fin, which is pigmented on the upper edge, but clear at the base and center. Some parr begin to show spots on the dorsal fin, but most fins are clear. There are no morphological features to separate this ESU from other Chinook salmon ESUs, so separation is based on genetic data and life history characteristics.

Taxonomic Relationships: Central Valley fall-run Chinook salmon are part of the CV Chinook complex consisting of four life-strategy runs differentiated by genetic and life history characteristics, including time of spawning migrations, maturity of fish entering fresh water, spawning location, incubation times, and out-migration timing of juveniles (Moyle 2002). The seasonal runs of CV Chinook salmon (winter, spring, fall and late fall) are more closely related to each other than they are to populations outside the CV (Williams 2006). Winter- and spring-runs are recognized as distinct ESUs, while the National Marine Fisheries Service groups the fall-run and late fall-run in a single ESU. This report differs from that taxonomy in that we regard the late-fall run to be a distinct life-history strategy, with specific management concerns. CDFW continues to work with NMFS in its scientific evaluation of the genetic relationship of late-fall-run (see Williams 2006).

Life History: Chinook salmon life history strategies are differentiated by the timing of immigration, a fact implicit in the naming of the different "runs" according to the season of their spawning migration. However, movement between habitat types, synchronized to specific life stages, defines the entire life history of salmon. Adult spawning migration timing is only one differentiating characteristic of the multiple life history attributes of CV Chinook salmon (Table 1). This account focuses on life history and migratory characteristics specific to the CV fall-run which have classic "ocean type" life history that minimizes time spent in fresh water. Because both fry and smolts out-migrate in spring before water temperatures become too warm in summer, the fall-run can exploit the extensive lower elevation reaches of Central Valley rivers and streams, where temperatures exceed thermal tolerances during summer and early fall. In contrast, spring and winter-run Chinook salmon exhibit a stronger "stream-type" life history, which is dependent upon year-round cool freshwater habitat; as such, spawning locations for these runs are restricted to higher elevation stream reaches where year-round cool water is found.

Adult CV fall-run Chinook salmon enter rivers as mature individuals and move relatively quickly to spawning grounds. Spawning usually occurs within several weeks to two months of freshwater entry. Peak spawning time is typically in October-November, but can continue through December and into January. Juveniles typically emerge from the gravel in December through March and rear in fresh water for 1-7 months, usually moving downstream into large rivers within a few weeks. Salmon smolts initiate migration during storm events and flow is positively correlated with migration rate (McCormick et al. 1998, Michel et al. 2013). In the clear upper reaches of the Sacramento River, out-migrating smolts employ a nocturnal migration strategy, a behavior likely influenced by predation. Turbidity also has a strong positive relationship with increased survival during out-migration, likely by decreasing predation efficiency. However, this relationship is also influenced by the strong positive association between turbidity and large flow events (Michel et al. 2013). The slowest movement rates were observed in the estuary, with intermediate rates observed in the lower Sacramento River (Michel et al. 2013).

In the past, before entering the San Francisco Estuary, CV fall-run juveniles likely foraged extensively on floodplains. Today, less than 10% of historical CV wetland habitats remain accessible to CV salmon (Frayer et al. 1989). Juvenile fish foraging in these highly productive habitats grow much more quickly than those in major river channels (Sommer et al. 2001, Jeffres et al. 2008). Historically, this rapid growth before ocean entry was likely very important to the survival of fall-run juveniles, which enter the ocean at relatively small size and young age compared to other CV runs.

From the estuary, juvenile salmon move through the Golden Gate into the Gulf of the Farallons, which is typically an extremely food-rich region because of wind-driven upwelling associated with the California Current. Immature fish spend 2-5 years at sea, where they feed on fish and shrimp before returning as adults. Most of the fish remain off the California coast between Point Sur and Point Arena during this period, but many move into the coastal waters of Oregon as well. Their movements in the ocean during the rearing period are poorly understood but inshore, offshore and along-shore movements are likely in response to changing temperatures and upwelling strength.

There are many exceptions to this general life cycle, including juveniles that spend as long as one year in freshwater. However, the general attributes of fall-run Chinook salmon that have made them so well adapted to low-elevation regulated rivers have also made them the preferred run for use in hatcheries; they can be spawned as they arrive and juveniles can be reared for a short time before being released.

	Migration period	*Peak migration*	*Spawning period*	*Peak spawning*	*Juvenile emergence period*	*Juvenile stream residency*
Sacramento River basin						
Late fall run	October–April	December	Early January–April	February–March	April–June	7–13 months
Winter run	December–July	March	Late April–early August	May–June	July–October	5–10 months
Spring run	March–September	May–June	Late August–October	Mid-September	November–March	3–15 months
Fall run	June–December	September–October	Late September–December	October–November	December–March	1–7 months

Table 1. Generalized life history timing of Central Valley Chinook salmon complex. Source data from Yoshiyama et al. 1998.

Habitat Requirements: The general habitat requirements of CV fall-run are similar to those of other "ocean type" Chinook salmon that minimize their time in fresh water (Healey 1991, Moyle 2002).

Chinook salmon use the largest substrate of any California salmonid for spawning, a mixture of large gravel and small cobble. Such coarse material allows sufficient water flow through the substrate to provide oxygen for developing embryos, while simultaneously removing their metabolic waste. As a result, the selection of redd sites is often a function of gravel permeability and subsurface water flow. Typically, redds are observed at depths from a few centimeters to several meters and at water velocities of 15-190 cm/sec. Preferred spawning habitat seems to be at depths of 30-100 cm and at water velocities of 40-60 cm/sec. Because females dig the redds, redd size is a function of female size as well as the degree of substrate mobility. Redds are typically over 2-15 m^2 in size, where the loosened gravels permit steady interstitial flow of well oxygenated water (Healey 1991). For maximum embryo survival, water temperatures must be between 5º and 13º C and oxygen levels close to saturation. With optimal conditions, embryos hatch after 40-60 days and remain in the gravel as alevins for another 4-6 weeks, usually until the yolk sac is fully absorbed.

Once alevins emerge and become fry, they tend to aggregate along stream edges, seeking cover in vegetation, swirling water, and dark backgrounds. As they grow larger and become increasingly vulnerable to avian predators, especially herons and kingfishers, they move into deeper (>50 cm) water. Larger juveniles may utilize the tails of pools or other moderately fast-flowing habitats, where food is abundant and some protection from predators is afforded. As juveniles move downstream, they use more open waters at night while seeking protected pools during the day. Pools that are cooler than the main river, from upwelling or tributary inflow, may be preferred by migrating juveniles as daytime refuges.

Juveniles use off-channel habitats, including floodplains, for rearing where they grow faster because of warmer temperatures and abundant food (Sommer et al. 2001, Limm and Marchetti 2006, Jeffres et al. 2008). Historically, these habitat types were widespread along the valley reaches of rivers and likely contributed to the large numbers of salmon produced in the past.

Off-channel habitat was also important in the San Francisco Estuary (e.g., tidal marshes), but these habitats are now largely unavailable, cut off from main river channels behind levees.

The route by which Sacramento River smolts pass through the Delta has a significant effect on survival. Those that migrate through the interior Delta have higher mortality rates than fish remaining in the mainstem Sacramento River (Perry et al. 2010).

Ocean habitats used for the first few months are poorly documented, but it is assumed that fish stay in coastal waters where the cold California Current creates rich food supplies, especially small shrimp, by upwelling. During the day, juveniles and subadults avoid surface waters. Sub-adult Chinook salmon consume anchovies, herring, and other small fishes, typically at depths of 20-40 m and move offshore into deeper waters in response to temperature, food availability and avoidance of predators.

Distribution: Central Valley fall-run Chinook salmon historically spawned in all major rivers of the CV, migrating as far as the Kings River to the south and the Upper Sacramento, McCloud, and Pit rivers to the north. Today, in the Sacramento and San Joaquin River watersheds, they spawn upstream as far as the first impassible dams. Passage into the mainstem San Joaquin River, above the confluence with the Merced River, is intentionally blocked at the CDFW-operated weir at Hills Ferry. Overall, it is estimated that over 70% of spawning habitat has been blocked by dams (Yoshiyama et al. 2001), although coldwater releases from dams now allow spawning where it did not formerly exist (Yoshiyama et al. 1998). Habitat for fall-run Chinook salmon spawning has been impacted less by dam construction than spawning habitat for winter and spring-run Chinook salmon, because the fall-run historically spawned only in low elevation reaches, up to 500 – 1,000 feet above sea level (Yoshiyama et al. 2001). Levees also block access for juveniles to the historic floodplain and tidal marsh rearing habitats.

	Sub-Optimal	Optimal	Sub-Optimal	Lethal	Notes
Adult Migration	<10ºC	10-20°C	20-21°C	>21-24°C	Migration usually stops when temperature climbs above 21ºC, with partial mortality occurring at 22-24ºC. Lethal temperature under most conditions is 24ºC. Fish observed moving at high temperatures are probably moving between cooler refuges.
Adult Holding	<10ºC	10-16°C	16-21°C	>21-24°C	Adults can experience heavy mortality above 21ºC under crowded conditions but will survive temperatures up to 24ºC for short periods of time. In some holding areas, maximum temperatures exceed 20ºC for over 50 days in summer.
Adult Spawning	<13ºC	13-16°C	16-19°C	>19°C	Egg viability is reduced with exposure to higher temperatures.
Embryo Incubation	<9°C	9-13°C	13-17°C	>17°C	This is the most temperature sensitive phase of life cycle. American River salmon have 100% mortality >16.7°C; Sac. River salmon mortality exceeded 82% > 13.9°C.
Juvenile Rearing	<13°C	13-20°C	20-24°C	>24°C	Past exposure (acclimation temperatures) has a large effect on thermal tolerance. Fish with high acclimation temperatures may survive 28-29ºC for short periods of time. Optimal conditions occur under fluctuating temperatures, with cooler temperatures at night. When food is abundant, juveniles that live under conditions that fluctuate between 16 and 24ºC may grow very rapidly.
Smoltif-ication	<10ºC	10-19°C	19-24°C	>24°C	Smolts may survive and grow at suboptimal temperatures but have a harder time avoiding predators; measured optimal temperatures are 13-17ºC (Marine and Cech 2004) but observations in the wild indicate a greater range.

Table 2. Chinook salmon thermal tolerances in fresh water. All lethal temperature data are presented as incipient upper lethal temperatures (IULT), which is a better indicator of natural conditions because experimental designs use a slower rate of change (ca. 1°C/day). Information largely from McCullough (1999).

Trends in Abundance: The historic abundance of fall-run Chinook salmon is difficult to estimate, because populations declined before extensive monitoring occurred and good records were kept. Hydraulic mining operations during the Gold Rush Era buried spawning and rearing areas under mining debris before the first estimates of salmon numbers were made. Likewise, Chinook salmon were extensively harvested in-river during the 19^{th} century and accurate, detailed records of run and river source were not documented. The best estimates of historic numbers suggest that fall-run Chinook salmon were one of the largest runs in the CV, with about a million spawners returning per year (Yoshiyama et al. 1998).

Yoshiyama et al. (1998) reported that exploitation by fisheries and alteration of California rivers during the Gold Rush had already reduced fall-run Chinook salmon abundance to about 10% of historical numbers by the 1940s. Construction of large dams throughout the CV in the 1940s-60s further reduced wild Chinook numbers. However, the extent of these impacts on CV Chinook populations is uncertain because artificial propagation began in this era and no effort was made to differentiate wild Chinook from those produced in hatcheries. Until recent years, escapement estimates for CV fall-run salmon included both hatchery and natural-origin fish with the relative proportions unknown. .

From 1967 to 1991, an average of 250,000 adult fish returned to spawn with an additional 375,000 harvested each year in the commercial and sport fisheries (USFWS 2011). From 1992 to 2006, average escapement was nearly 400,000 with an annual average of 484,000 harvested in the fisheries. In 2007, escapement plummeted to fewer than 100,000 fish with about 121,000 harvested in fisheries, prompting the first-ever closure of the California ocean salmon fishery. Returns dropped to 71,000 in 2008 and, in 2009, escapement reached a record low of 53,000 spawners, even though the ocean fisheries remained closed (CDFW GrandTab 2011). Escapement in 2010 increased to 163,000 with a limited ocean fishing season, harvesting 20,400 fish. Central Valley escapement continued to rebound to approximately 228,000 fish in 2011 and 342,000 fish in 2012.

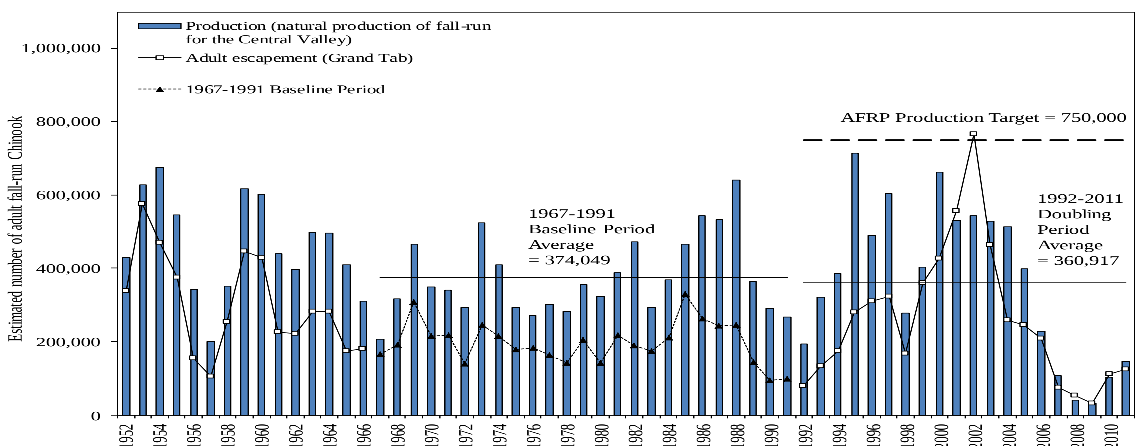

Figure 2. Estimated yearly natural production and in-river escapement of adult fall-run Chinook salmon in the Central Valley rivers and streams. 1952 - 1966 and 1992 - 2011 numbers are from CDFG Grand Tab (Apr 24, 2012). 1967-1991 Baseline Period numbers are from Mills and Fisher (CDFG, 1994).

Figure 1. Estimated natural production and in-river escapement of adult fall-run Chinook salmon in Central Valley rivers and streams. 1952-1966 and 1992-2011 data are from CDFW GrandTab (updated April 24, 2012). 1967-1991 Baseline Period data are from Mills and Fisher (CDFG 1994).

The effects of hatchery production on abundance and population dynamics of CV fall-run Chinook has been poorly documented, but recent studies are allowing a better analysis of stock composition in the CV. Data from the CV Constant Fractional Marking Program indicates that a high proportion of fall-run Chinook salmon spawning in-river are of hatchery origin, particularly in streams with large hatchery facilities. Recent studies of otolith michrochemistry suggest the same (Barnett-Johnson et al. 2007, Johnson et al. 2012, Kormos et al. 2012). In addition, stray rates between river basins are variable and in some cases relatively high (Kormos et al. 2010). Genetic evidence suggests that CV fall-run Chinook populations are now genetically homogenous (Williamson and May 2003, Lindley et al. 2009).

Nature and Degree of Threats: Widespread and intensive development of the CV over the last 150 years has simplified river, floodplain, and estuarine habitats, altered ecological processes (i.e., hydrology, sediment transport, nutrient cycling) and fundamentally altered the CV Chinook salmon complex, from a diverse collection of numerous wild populations employing diverse life histories to one dominated by fall-run Chinook salmon produced in four large hatcheries (Lindley et al. 2009). Important factors continuing to limit population viability of CV fall-run Chinook salmon include: water management, habitat loss and alteration, climate change, and hatchery practices.

Dams. Large dams on the Sacramento River and its tributaries have blocked fall-run Chinook salmon access to historic spawning grounds. Habitat downstream of the dams has been altered; some changes have negatively impacted remaining spawning and rearing habitats. Regulated flows and resulting water temperatures are sometimes unsuitable for salmon spawning and rearing. Spawning gravel can be limited by lack of recruitment from upstream areas and deposition of fine sediments. Most large dams now have flow requirements for salmon spawning, rearing, egg incubation and juvenile emigration, but flows may not provide optimum habitat or water conditions. Large quantities of gravel are now trucked to spawning areas below dams to improve spawning habitat; however, effectiveness of these restoration actions at the population level is not well documented and require regular, human intervention (Mesick 2001, Wheaton et al. 2004).

Agriculture. There are large numbers of agricultural diversions along the Sacramento and San Joaquin rivers and their tributaries, as well as in the Sacramento-San Joaquin Rivers Delta (Delta), which entrain juvenile salmon. Although some large diversions are screened to prevent entrainment, some large and a considerable number of small to medium diversions remain unscreened. Moyle and Israel (2005) noted that fish screens on rivers are subject to failure and may create holding areas for salmon predators (e.g., catfishes, striped bass). They also acknowledged that, despite their numbers, small diversions, even cumulatively, probably do not kill many salmon, unless they are on small tributaries. In general, the higher the proportion of flow taken by a diversion, the more likely the diversion is to have a negative impact on local salmon populations through entrainment.

The largest diversions in the Central Valley are those of the State Water Project (SWP) and the federal Central Valley Project (CVP) in the south Delta, which export water for both agricultural and urban use. They entrain large numbers of fall-run Chinook salmon (as well as salmon of other runs), especially from San Joaquin River tributaries (Kimmerer 2008). These diversions have louver screens that divert salmon to be salvaged from the projects by capture, trucking, and then release downstream in the Delta. However, both direct and indirect mortality associated with these operations is likely high (Kimmerer 2008). Direct mortality is also caused by high predation rates in Clifton Court Forebay, from which the SWP pumps water prior to running it through the salvage facility.

	Rating	Explanation
Major dams	Medium	Dams prohibit access to large geographic areas that supported historic spawning, alter flows, and simplify stream geomorphology; however, flow releases generally provide adequate water quality and temperatures below major dams; lack of gravel recruitment below dams necessitates augmentation in many lower river reaches
Agriculture	Medium	Diverted water reduces stream flow and entrains juvenile salmon; levees protecting agricultural lands limit salmon access to floodplains, tidal marshes, and other important habitats
Grazing	Low	Relatively little grazing takes place on the CV valley floor
Rural residential	Low	Generally minimal impact on large river systems (e.g., Sacramento), but increasingly connected to urbanized areas
Urbanization	Medium	Urban areas widespread and growing in many portions of historic range; urban landscapes generally simplify habitats, impair aquatic ecosystem function and pollute streams
Instream mining	Medium	Gravel pits in rivers are problematic in some locations, particularly in the San Joaquin River basin
Mining	Low	Legacy effects of hydraulic and hard rock gold mining remain; impacts may still be severe at a localized scale
Transportation	Low	Most Chinook streams have roads and railroads along them, often leading to habitat simplification
Logging	Low	Little logging in the CV although logging may affect upper portions of CV watersheds
Fire	Low	Little threat of fire in the CV although fire may affect upper portions of CV watersheds and effects can be propagated downstream
Estuary alteration	High	San Francisco Estuary is a highly altered system; fall-run Chinook salmon, however, have short residence periods in the estuary; the Sacramento-San Joaquin Rivers delta is greatly altered and current physical and water habitat conditions impact effective migration of adults and juveniles in both river basins
Recreation	Low	Recreation can disturb redds and spawners
Harvest	Medium	Ocean and inland fisheries may harvest natural-origin (wild spawned) fish at unsustainable rates
Hatcheries	Medium	A large proportion of fall-run Chinook are produced in hatcheries
Alien species	Low	Introduced species may increase predation, competition, or decrease food supply

Table 3. Major anthropogenic factors limiting, or potentially limiting, viability of populations of Central Valley fall-run Chinook salmon. 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, whichever is less; a factor rated “high” could push the species to extinction in 10 generations or 50 years whichever is less; 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 is unlikely as a result. A factor rated "n/a" has no known negative impact. Certainty of these judgments is high. See methods section for descriptions of the factors and explanation of the rating protocol.

Indirect mortality resulting from changes in Delta hydrology due to project operations is likely considerably higher than direct mortality. Salmon are often diverted into unfavorable parts of the Delta where habitat conditions are poor and predation is high. In general, when flows are higher and diversion rates are lower, survival of outmigrants tends to be higher, although there is no simple relationship between diversion rates and salmon survival (Brandes and McLain 2001). San Joaquin fall-run Chinook salmon are affected to a greater extent by Delta pumping, because juveniles emigrate in the vicinity of the export facilities and are, therefore, vulnerable to entrainment.

Agriculture in the CV also contributes to loss of juvenile habitat by limiting access, via an extensive network of flood protection levees, to the shallow riverine habitats needed for feeding and protection from predators during migration, management of floodplain for agriculture and not fish habitat, and limiting expansion of native riparian habitat. Construction of levees to channelize rivers has had multiple effects, including simplifying bank structure through use of rip-rap and removal of trees, reduction in shade, and reduced access to floodplains. Bank hardening has been enhanced by the reduction of peak flows. Reduction of floodplain habitat has likely contributed to population declines of CV fall-run Chinook salmon. Recent studies have demonstrated the importance of floodplains for increased juvenile salmon growth and survival (Sommer et al. 2001, Jeffres et al. 2008).

Agricultural development can also degrade water quality conditions for Chinook salmon rearing in CV streams and the Delta. A new threat is the use of pyrethroid pesticides, which are particularly toxic to fish. Although mortality events are periodically recorded, the interacting effects of multiple pollutants on juvenile salmon survival are largely unknown. Even if pollutants are sublethal in concentration, they can stress both adult and juvenile fish, making them more vulnerable to disease, predation and other stressors.

Urbanization. Urbanization can simplify habitats and degrade water quality conditions for Chinook salmon. Water diversions, levees (and their intensive maintenance) and channel straightening all contribute to habitat simplification. Juvenile salmon are exposed to toxic materials discharged into rivers from urban and agricultural sources. Of particular concern is the poor water quality observed seasonally in the Stockton Deepwater Ship Channel. The channel serves as an area of concentration of pollutants from agricultural wastewater, discharges from the City of Stockton's sewage treatment facilities, storm drains, and other sources. Low dissolved oxygen levels in the fall have been shown to delay adult fall-run immigration into the San Joaquin basin.

Mining. Historic (and, to a lesser degree, ongoing) gold and gravel mining have dramatically altered many CV streams. Hydraulic and dredge mining in the 19th and early 20th centuries caused major morphological and hydrological changes in many rivers, degrading salmon spawning and rearing habitats. Many of these waterways are still recovering. Deep gravel pits in a number of CV rivers (e.g. Tuolumne, Merced, San Joaquin) reduce water velocities and allow for the aggregation of predatory fishes, potentially increasing mortality of juvenile salmon moving downstream. In the past, Iron Mountain Mine, northwest of Redding, drained highly acidic water laden with heavy metals into the Sacramento River, resulting in acute mortality to Chinook salmon. Although discharge is now highly controlled, failure of the Spring Creek retention reservoir could result in impacts to aquatic life.

Estuary alteration. There is growing appreciation of the importance of "biocomplexity" for the persistence of salmon in a variable environment (Hilborn et al. 2003). Biocomplexity 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 the historic Delta flows, resulting in substantial modifications in flow direction (Nichols et al. 1986). This pumping also increases the 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. To improve survival, most hatchery juveniles are transported and released downstream of the Delta. 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.

The Delta ecosystem is as, if not more, altered than the estuary. Land and water management practices have altered the delta's landscape and ecological processes such that fall-run Chinook salmon and other native fishes encounter poor to extremely poor habitat conditions when migrating through the Delta's waters.

Harvest. In most years, salmon populations support major sport and commercial fisheries along the California and Oregon coasts and major inland sport fisheries in freshwater. Hatchery fish can sustain higher harvest rates than wild fish, but the two cannot be discriminated within the fishery. It is, therefore, possible that existing recreational fisheries, in spite of being highly regulated and managed, may harvest natural-origin fish at unsustainable rates (Williams 2006). Wild-spawned fish, while a fraction of the overall fall-run, may be of particular importance in maintaining genetic attributes that increase life history diversity and adaptability to localized selection processes, particularly in the face of changing environmental conditions, such as those predicted under climate change models (e.g., Hayhoe et al. 2004, Mote et al. 2005).

Fisheries also affect Chinook salmon populations through continual removal of larger and older individuals. This selection results in spawning runs made up primarily of two and three-year-old fish, which are smaller and, therefore, produce fewer eggs per female. The removal of older fish also removes much of the buffering that salmon populations have against natural disasters, such as severe drought, that may eliminate an entire cohort. Under natural conditions, the four- and five-year-old fish still in the ocean help to buffer against population declines due to short-term environmental changes. In order to protect the low stock of Sacramento River fall-run Chinook salmon, ocean salmon fisheries were greatly restricted in 2006-2010 by the National Marine Fisheries Service and the Pacific Fisheries Management Council (Congressional Record, 50 CFR Part 660). The Chinook salmon sport fishery in the Sacramento River system was also severely restricted in 2008 and 2009. Since that time, ocean and inland fisheries have not been limited by low abundance of CV fall-run Chinook.

Hatcheries. Returns of CV fall-run Chinook were very low in 2007 and 2008. The proximate cause of the poor returns is thought to have been poor ocean conditions that resulted in low juvenile survival when outmigrating smolts first entered the Gulf of the Farallones (Lindley et al. 2009). However, the homogenizing influence of hatcheries on population diversity has made the fall-run more susceptible to adverse conditions, such as drought and corresponding low flows in freshwater habitats, or periods of reduced upwelling in coastal waters (Moyle et al. 2008, Carlson et al. 2011). The negative effects of hatchery production on wild stocks can be divided into ecological and genetic impacts, although the two interact considerably.

Ecological effects include competition, predation, and disease transfer from hatchery stocks to wild populations (Allendorf and Ryman 1987). Competition between hatchery and naturally-produced Chinook can reduce abundance (Pearsons and Temple 2010), growth rate (Williams 2006) and survival of wild juveniles in river, estuarine and marine habitats (Nickelson et al. 1986, Levin et al. 2001, Levin and Williams 2002, Nickelson 2003). Hatchery releases can even exceed the carrying capacity of ocean habitats, particularly in times of low ocean productivity (Beamish et al. 1997, Levin et al. 2001), resulting in high ocean mortality (Beamish et al. 1997, Heard 1998, Kaeriyama 2004). Historically, a high degree of genetic variation and the availability of complex and diverse habitats resulted in diverse salmon behavior and many distinct life history strategies which ensured persistence in California's extremely variable climate. Hatchery propagation has not only narrowed this behavioral variation in hatchery stocks (most fish are released over a short time period), leaving them vulnerable to climatic anomalies (ocean conditions, drought, etc.) and management decisions (water releases, storage), but it has also resulted in domestication of the stock, favoring a salmon genome that is well adapted to comparatively stable hatchery conditions but may be unfit under variable natural conditions.

Alien species. For the past 150 years, numerous species have been introduced to the Central Valley. Probably most significant are predatory fishes, including striped bass, largemouth bass, smallmouth bass, and spotted bass. Striped bass are known to prey on large numbers of juvenile salmon at diversion structures such as Red Bluff Diversion Dam, or where hatcheries release large numbers of juvenile fish. The three bass species can also be important predators, particularly when they inhabit in-channel gravel pits or other obstacles to juvenile salmon migration.

Effects of Climate Change: Climate change may be one of the biggest threats to the persistence of CV salmon (Williams 2006, Katz et al. 2012). At the southern edge of the Chinook salmon range along the Pacific Coast, the CV fall-run, at times, already experiences environmental conditions near the limit of its tolerance (Moyle et al. 2008). For instance, summer temperatures in some streams already exceed 22°C (California Data Exchange Center 2009). Thus, small thermal increases in summer water temperatures could result in suboptimal or lethal conditions and consequent reductions in distribution and abundance (Ebersole et al. 2001, Roessig et al. 2004). Changes in precipitation patterns in California may also significantly alter CV fall-run habitats. Climate change models predict that a larger proportion of annual precipitation will fall as rain, rather than snow, running off quickly and earlier in the season. With less water stored in snowpack, reservoirs will potentially have less water available for fishery releases, particularly during summer and fall months. The available water is also likely to be warmer. During summer and fall, high water temperatures will be exacerbated due to the lower base flows resulting from reduced snowpack (Hamlet et al. 2005, Stewart et al. 2005).

For fall-run Chinook salmon, adults may have to ascend streams later in the season and juveniles may leave earlier, narrowing the window of time for successful spawning and rearing. Snowpack losses are expected to be increasingly significant at lower elevations, with elevations below 3,000 m suffering reductions of as much as 80% (Hayhoe et al. 2004). Consequently, in the long-term, changes in stream flow and temperature are expected to be much greater in the Sacramento River and its tributaries, which are fed by the relatively lower Cascades and northern Sierra Nevada, than are changes in rivers to the south, which are fed by snowpack that is expected to remain more consistent in the higher elevations of the southern Sierra Nevada (Mote et al. 2005).

One of the least understood effects of climate change is the impact on ocean conditions. However, the implications of predicted rises in sea level and temperature, along with changes in wind patterns, ocean currents, and upwelling, all suggest major impacts to CV salmon populations while in the ocean environment. Ocean survival rates in California salmon have been closely linked to several cyclical patterns of regional sea surface temperature, such as the Pacific Decadal Oscillation, El Niño Southern Oscillation (Beamish 1993, Hare and Francis 1995, Mantua et al. 1997, Mueter et al. 2002), and the North Pacific Gyre Oscillation (Di Lorenzo et al. 2008). With increasing temperatures, concentrations of zooplankton, the primary food source for juvenile salmonids entering the ocean, may decrease, resulting in lower salmon survival (McGowan et al. 1998, Hays et al. 2005). Smolt-to-adult survival is also strongly correlated with upwelling in the Gulf of the Farallones, driven by strong winds during the spring and fall (Scheuerell and Williams 2005). In recent years (2005-2008), short-term anomalies in ocean conditions, resulting in decreased upwelling during critical times of year, were the likely proximate cause of low ocean survival for CV Chinook salmon (Barth et al. 2007, Lindley et al. 2009). Thus, as climate change results in more variable upwelling conditions, salmon populations may fluctuate more widely.

Status Determination Score = 2.7 – High Concern (see Methods section Table 2). The Central Valley fall-run Chinook is listed as a species of special concern by NMFS. The NMFS status review concluded that "…high hatchery production combined with infrequent monitoring of natural production make assessing the sustainability of natural production problematic, resulting in substantial uncertainty regarding this ESU (Myers et al. 1998)".

Metric	Score	Justification
Area occupied	2	Some indication of natural self-sustaining populations in the upper Sacramento River watershed
Estimated adult abundance	4	Annual spawning returns generally exceed 100,000 fish
Intervention dependence	2	The majority of remaining spawning and rearing habitat is dependent on instream flow releases from major dams, gravel augmentation and other ongoing efforts; population appears largely dependent on hatchery augmentation
Tolerance	3	Moderate physiological tolerance, multiple age classes
Genetic risk	2	High hatchery production has resulted in genetic homogenization of the run, reducing overall fitness

Climate change	3	The 'ocean' life history strategy makes them the least vulnerable of all CV Chinook runs to extirpation; however, models suggest dramatic changes to lower elevation CV rivers and streams
Anthropogenic threats	2	See Table 3
Average	2.7	19/7
Certainty	4	Well studied although high uncertainty about ocean stage

Table 4. Metrics for determining the status of Central Valley fall-run Chinook salmon, where 1 is a major negative factor contributing to status, 5 is a factor with no or positive effects on status, and 2-4 are intermediate values. See methods section for further explanation.

Management Recommendations: Before CV winter and spring-run Chinook salmon were listed, virtually all salmon conservation actions were focused on fall-run Chinook, because it was the most abundant run that supported fisheries. Prior to the passage of the Central Valley Project Improvement Act by Congress in 1992, which established the Anadromous Fish Restoration Program (AFRP), actions to protect fall-run salmon were either focused on hatchery production or initiating defensive actions to prevent further declines. Thus, minimum flow releases were established as dams were relicensed, the largest diversions were screened, efforts were made to salvage salmon entrained at the large pumping plants in the south Delta, barriers to passage were removed in some streams, and monitoring continued. The AFRP and its associated agencies began to take additional actions to enhance natural salmon populations, including evaluating the ocean fishery, improving management of diversions (such as Red Bluff Diversion Dam), investigating ways to improve passage through the Delta, and other measures. The AFRP is charged to plan "all reasonable efforts to at least double natural production of anadromous fish in California's Central Valley streams on a long-term, sustainable basis" http://www.delta.dfg.ca.gov/afrp). The final goal is to average 990,000 fish for all four runs combined, but predominately fall-run Chinook.

The listing of winter-run Chinook salmon as endangered (1989 by CDFW; 1994 by NMFS) and spring-run Chinook as threatened in 1998 (both State and federal listings) increased the urgency of salmon restoration efforts and actions to benefit these two runs have benefited fall-run Chinook salmon as well, at least in the Sacramento River. Funding for much of the recent restoration efforts, especially the more innovative projects (such as rehabilitating Clear Creek and Battle Creek), largely came through CALFED, established in 1994. Fall-run Chinook salmon should also benefit considerably from additional measures required by NMFS (e.g., http://swr.nmfs.noaa.gov/ocap.htm) to enhance winter and spring-run Chinook salmon populations in the river.

In the San Joaquin tributaries, considerable effort has been made to improve conditions for fall-run Chinook salmon, including modified flow regimes, better habitat management, reducing impacts of instream gravel pits and other actions. However, these actions have not prevented continued declines in fall-run Chinook numbers, presumably as the result of factors outside the San Joaquin basin, especially in the south Delta.

There are four general directions management actions could take: (1) improving population monitoring, (2) improving habitats, (3) adjusting water management, and (4) improving hatchery management practices.

Improving population monitoring. Expanded monitoring of fall-run Chinook salmon in Central Valley streams and the ocean is essential for improved management. At present, our understanding of the relationships between ocean conditions and salmon survival is largely unstudied, with studies and restoration actions implemented long (sometimes years) after a significant event affecting populations occurs. An investment in research on the effects of ocean conditions on survival of juvenile Chinook salmon would have large benefits for improved salmon management and population recovery.

In 2012, the CDFW completed the *Central Valley Adult Chinook Salmon In-stream Escapement Monitoring Plan*. The plan reviewed existing monitoring programs and made recommendations for program improvements. Implementation of the recommendations, already in progress, is expected to yield more accurate estimates of Chinook salmon escapement to the Central Valley for use in harvest management and restoration planning.

Additional emphases need to be given to where fish are naturally spawning and rearing, the relative importance of specific rivers to the run, the genetic diversity across the Central Valley and with the various hatchery stocks, and the genetic differences between fall-run and late-fall-run Chinook salmon.

Habitat improvement. In the Central Valley, recovery actions have focused on habitat restoration. Because habitat diversity is essential to maintaining life-history diversity, conservation strategies that restore and improve physical habitat quality, extent, and connectivity are essential tools in improving the resilience of salmon populations. For example, efforts should be made to reconnect river channels to floodplains. Infrastructure and operational changes needed to increase habitat value for salmon and other native fishes in the Yolo Bypass and other floodplains should be prioritized. Modification of flows below many dams could also improve habitat conditions for salmon. Improving habitat for rearing in the Delta and San Francisco Bay, reducing inputs of toxins to the estuary, continuing with improvements of upstream habitats, managing floodplain areas such as the Yolo Bypass for salmon, and restoring the mainstem San Joaquin River are all important management actions that need further attention and resources.

Adjusting water management. Water management from each major reservoir, in-river (both the Sacramento and San Joaquin rivers), and in the Delta greatly affects spawning, rearing, and migration of both juvenile and adult life stages. A comprehensive plan for the run as well as specific evaluation and planning for rivers where salmon spawn and rear would both directly benefit the run, as well as have important ramifications for habitat restoration and sustainability, response to climate change, and ensuring sustainable river and ocean fisheries.

Improving hatchery practices. In 2012, the California Hatchery Scientific Review Group completed a comprehensive review of California's anadromous fish hatcheries, including those hatcheries rearing Central Valley fall-run Chinook salmon (California HSRG 2012). Implementation of the review's recommendations over the next ten years will significantly reduce the genetic and ecological impacts of hatchery production on Central Valley fall-run Chinook salmon.

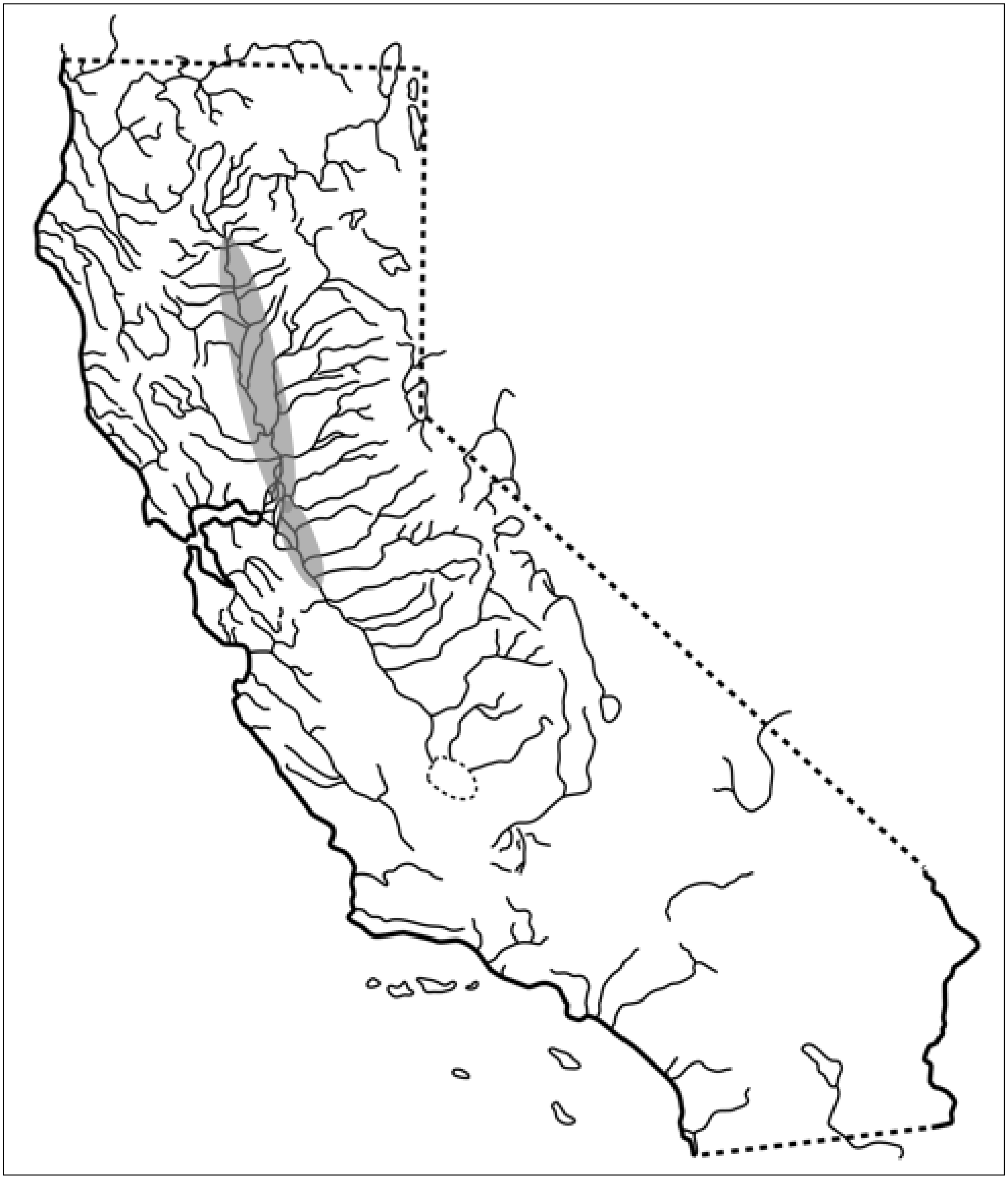

Figure 2. Distribution of Central Valley fall-run Chinook salmon, *Oncorhynchus tshawytscha* ESU, in the Sacramento and San Joaquin rivers of California.