CENTRAL VALLEY SPRING CHINOOK SALMON

Oncorhynchus tshawytscha

Critical Concern. Status Score = 1.7 out of 5.0. Vulnerable to extinction in the next 50-100 years, or less. Small, self-sustaining populations remain in only a few watersheds.

Description: All California Chinook salmon are similar in morphology and other characteristics. They are categorized into various Evolutionary Significant Units (ESUs) for management purposes. These "runs" are distinguished mainly by genetics and life history traits (e.g., run timing, maturation, and rearing patterns), although there are often statistical differences in size among Chinook salmon ESUs (see UKTR fall-run Chinook salmon account for a description of some minor differences). Central Valley spring-run Chinook salmon (CVS Chinook) are mainly differentiated by their late maturation and geographic and spatial separation from the more abundant Central Valley fall-run Chinook salmon, but also display considerable plasticity in their age at spawning and rearing and migration behavior.

Taxonomic Relationships: Chinook salmon are most closely related to coho salmon (*O. kisutch*), with which they occasionally hybridize (Moyle 2002). Chinook runs are named for the season in which they begin their freshwater spawning migration. Chinook populations are delineated phenotypically, genetically and geographically. In California's Central Valley, there are four distinct ESUs of Chinook: fall, late-fall, winter, and spring. While each run is distinct in timing of spawning and migration, location of spawning areas, and rearing strategies based on instream conditions, their juveniles that mix together in the Sacramento River are commonly differentiated by length-at-date size class projections by management agencies at rotary screw traps and salvaged at delta pumps, which can confound accurate accounting of returns from each run (Meek et al. 2016, M. Johnson, CDFW, pers. comm. 2017). Spring-run fish are distinguished in part by their delayed maturation, which enables them to delay spawning for 4-5 months after entering fresh water. Prince et al. (2016), using genomic techniques, showed that the delayed maturation life history arose as a single evolutionary event in Chinook salmon and spread throughout the species' range, primarily through straying. Where conditions favored this late-maturing life history strategy, reproduction by strays was followed by positive selection for the spring-run phenotype over time. Presumably the rare early possessors of this distinctive gene complex would have spawned with early-arriving fall-run Chinook salmon, but their offspring possessed the spring-run genetic mutation and the locally adapted genes of the dominant fall Chinook salmon. There would then have been strong selection for spring-run fish that could use streams at times and places unavailable to fall run Chinook (see life history section).

Based on molecular genetic techniques, there are two distinct self-sustaining populations of CVS Chinook salmon: Deer and Mill creeks (Tehama Co.), and Butte Creek (Tehama Co., Garza and Pearse 2008). Small populations of spring-run Chinook are consistently observed in Big Chico, Cottonwood, Antelope, Clear, and Battle creeks, but it is not known if these streams support self-sustaining populations or if these fish are strays from the Butte/Deer and Mill populations (M. Johnson, CDFW, pers. comm. 2017). In addition, there is a putative population of CVS Chinook in the Feather River, which is supported by releases of nearly 2 million juvenile fish from Feather River Fish Hatchery (FRFH) each year (www.rmpc.org, NMFS 2016). These fish are nearly identical genetically to fall-run Chinook salmon (Williams 2006), yet are included somewhat controversially in the ESU designation due to concerns of inbreeding and outbreeding

depression among other Chinook populations in the Central Valley. Feather River CVS Chinook have hybridized with hatchery fall-run Chinook in the watershed over decades due to operations at FRFH in mid-September that mixed fish of different run timings in the past (NMFS 2016). An alternative hypothesis is that spring-run salmon recently diverged from fall-run salmon that re-colonized the Feather River after hydraulic mining ended (J. Williams, pers. comm. 2008). Small runs of spring salmon in the Yuba River, tributary to the Feather River, are too data-deficient for conclusive analysis of origin (NMFS 2016), but are most likely derived from Feather River fish and partly supported by strays from the Feather River Hatchery.

Life History: CVS Chinook salmon get their name for their spring migrations upstream during high springtime runoff events that swell rivers. These seasonal flows allow passage into higher elevation, smaller tributaries that are generally inaccessible to salmon at other times of the year. Once in headwater streams, adults hold in deep pools and spawn in early fall. Juveniles exhibit three distinct emigration strategies: 1) emigrating either after a few months in fresh water; 2) emigrating after spending an entire year in fresh water; or 3) leaving spawning areas soon after hatching during high flows during winter. After emigrating, juvenile spring-run Chinook may rear in the Sacramento River and other downstream habitats, such as the Sutter or Yolo bypasses, and migrate to the ocean as smolts during the spring or remain in their natal stream for an entire year and outmigrate the following fall, winter, or spring as yearlings. CVS Chinook exhibit considerable plasticity in their life history strategies, and do not fit easily into the life history categories identified for most other Chinook salmon populations (Box 1).

CVS salmon begin their spawning migration in January-February and arrive in the Sacramento River primarily during April through June, with migrations peaking in mid-April in Butte Creek and in mid-May in Deer and Mill Creeks (Williams 2006, NMFS 2016). Johnson and Merrick (2012) found adult spring-run Chinook entering Deer and Mill creeks as early as late February and as late as July, with a peak in late April through early May, while historical documents indicate peak adult returns used to occur nearly a month later from late May to early June (M. Johnson, CDFW, pers. comm. 2017). They migrate as silvery, immature fish that only reach sexual maturity after reaching summer holding areas, which are generally higher in the watershed than those of other runs. They seek out deep pools with hyporheic flow, subsurface springs, or inlet streams that provide suitable cool summer water temperatures to allow them to survive high daytime summer temperatures. CVS Chinook often do not stay in the same pool for the duration of summer, but generally move upstream from pool to pool as stream flow conditions allow, often spawning in the tailwaters of their final holding pool (Moyle 2002). Spawning behavior is similar to that of coho salmon, with females digging redds in the appropriate substrate and large, dominant males fighting off other males prior to spawning. The gametes of the dominant males are often supplemented, however, by those from one or more jacks (two-year-old males) that spawn by sneaking into the nest with the mating pair from downstream and releasing their milt just as the female releases her eggs (Moyle 2002, Williams 2006). The "sneaker" male spawning strategy supports greater genetic diversity in the population by reducing one-male to one-female mating and contributes to variable life history strategies.

CVS Chinook maintain a high degree of plasticity in their age at spawning. A small proportion of the run can be made up of jacks, or small male fish that return to the rivers to spawn after only a single year or two in the ocean, instead of the more typical three or four years at sea for most Chinook in the Central Valley (NMFS 2014). Age at spawning for CVS Chinook salmon generally varies from age 2 to age 4 (NMFS 2014); approximately 69% of the spawners

returning to Butte Creek in 2005 were estimated to be age-4 adults (McReynolds et al. 2006), while in 2006, age 4 fish accounted for 75% percent of returning spawners to Butte Creek (McReynolds et al. 2007). Pre-spawn mortality studies on Butte Creek from 2001-2006 estimated average spring-run FL to be 735 mm and 785 mm for females and males, respectively (McReynolds et al. 2007). Observations of sexually mature 1-year old male California Chinook salmon parr (those never going to sea) have also been made in watersheds supporting spring-run life histories (C. Jeffres, UC Davis, unpubl. obs.). These fish spawn in much the same way as jacks (Quinn 2005). It is thought that some of these "precocious parr" - whose enormous testes account for ~21% of their body weight - may actually survive to spawn a second time (Moyle 2002). The variability in male reproductive strategies ensures that around 90% of eggs are fertilized and that genetic diversity of the population is maintained (Moyle 2002).

Box 1. Chinook salmon life history strategies

Chinook salmon have a variety of life history adaptations that allow them to persist through variable environmental conditions, but are most often divided into two main life-history strategies: 1) stream-type and 2) ocean-type. Initially, these types simply distinguished salmon that spent a few months or a winter in freshwater before migrating to sea, as revealed by growth patterns in their scales (large spaces between rings indicated fast growth while at sea, while closely-spaced rings indicate slower growth while in freshwater, Gilbert 1913). Later, other characteristics were associated with these types, which have been named based on their timing of maturation. Generally speaking, ocean-type refers to a population in which juveniles begin their migration to sea soon after emerging from redds, spend less than a year in fresh water, return as mature adults, and spawn soon after reaching spawning grounds. The overwhelming majority of CVS Chinook juveniles exhibit this life history strategy (F. Cordoleani, NMFS, pers. comm. 2017). Alternatively, stream-type Chinook stay in streams for over a year before initiating seaward migration, and re-enter fresh water in spring as sexually immature fish. These fish mature in the stream over summer before spawning in early fall.

While at sea, ocean-type Chinook tend to forage close to the coast, whereas stream-type Chinook tend to venture farther out to forage in the open ocean. Stream-type Chinook displaying these characteristics predominate north of 55º latitude (near the southern edge of Alaska), while ocean-type Chinook predominate south of 55° latitude (Healey 1991). However, Williams (2006) noted that juvenile CVS Chinook from populations south of the Columbia River, including in California, often migrate to sea in their first year, and tend to forage in coastal waters. This is consistent with the development of a stream-type life history from an ocean-type lineage, which Healey (1991) recognized as a possibility and which has been demonstrated with CV Chinook that were transported to New Zealand (Unwin et al. 2000). It is also consistent with experiments showing that normally stream-type juvenile Chinook will behave like ocean-type fish if they are exposed to a short day photoperiod when they emerge (Clarke et al. 1992; Williams 2006). Healey (1991) postulated that the steam-type life history represents an Asian or Beringian lineage that had been separated from a Cascadian ocean-type lineage during the last glaciation event. There remains some confusion in the literature over how to apply the stream-type/ocean-type nomenclature, but it seems safest to use it only in reference to juvenile migration patterns, because they are not necessarily linked to adult behavior (Williams 2006).

Embryos incubate in the gravel for 40-60 days (temperature dependent) and remain in the gravel as alevins for an additional 4-6 weeks until the yolk-sac is absorbed and fry begin to forage (Williams 2006). Juveniles feed mainly on zooplankton, benthic invertebrates, terrestrial drift, and larvae of other fishes, especially suckers (Moyle 2002). Rearing and migration timing is extremely variable in CVS Chinook, ranging from 3 to 15 months, presumably as a result of limited rearing habitat available in the upper watersheds and variable flow conditions (Stillwater 2006, McReynolds et al. 2007). Some juveniles begin their emigration as fry mere hours after emerging from the gravel; in Butte Creek, most juveniles have already migrated downstream as fingerlings by the end of February (McReynolds et al. 2007). Most begin smoltification after a few months of stream rearing and outmigrate as sub-yearlings. A third type remains in the stream

for a year, over-summering in natal streams before beginning downstream emigrations (Hill and Webber 1999, Stillwater 2006). This complex of life history strategies can generally be thought of as bet-hedging behavior. Fish that remain in freshwater habitats near where they were hatched may have a reduced food supply due to comparatively lower productivity or intraspecific competition, but may enjoy increased survival rates until emigration. They are also likely to be larger at smolting, resulting in increased survival in downstream habitats. Another option to increase size and survival while migrating downstream is to spend time on floodplains, where water is often slower, warmer and more turbid, and full of abundant prey (see below).

Outmigrating juveniles from Mill, Butte, and Deer creeks average approximately 40mm FL between December and April, and reflect a prolonged emergence of fry (Lindley et al. 2004). Conversely, Ward et al. (2003) found the majority of spring-run migrants to be fry moving downstream primarily during December through February in Butte Creek, and that these movements appeared to be influenced largely by flow. Small numbers of spring-run juveniles remained in Butte Creek to rear and migrate as sub-yearlings later in the spring. Juvenile emigration patterns in Mill and Deer creeks typically exhibit a later young-of-the-year migration and an earlier yearling migration than juveniles in Butte Creek (Lindley et al. 2004). There are generally more yearling juveniles in Mill and Deer creeks than in Butte Creek, which is probably due to the colder spring and summer water temperatures found there (F. Cordoleani, NMFS, pers. comm. 2017). By contrast, in the Feather River the bulk of juvenile emigration occurs during November and December (USACE 2012).

As they move downstream, young Central Valley Chinook use the lower reaches of non-natal tributaries and the shallow edges of the mainstem to seek relief from high flows, forage, and refuge from predators. Downstream migration serves not only to disperse juveniles to the ocean, but it gives them access to temporary habitats with warmer temperatures and abundant food, such as aquatic invertebrates and larval fish, that allow for rapid growth. Sommer et al. (2001), Jeffres et al. (2008), and Katz et al. (*In press*) indicate significantly higher growth rates for juvenile Chinook rearing on the floodplain as opposed to those rearing in riverine habitats. Floodplain production and temperatures are considerably higher in these lowland habitats and provide an important resource for outmigrating juveniles. The extensive levee building that has taken place along the Sacramento River over the last century has prevented Chinook juveniles from accessing these habitats, except in a few places such as the Yolo and Sutter bypasses, when high winter and spring flows provide access. Juveniles can rear for 1-3 months in the bypasses, putting on significant weight, which is directly tied to increased survival at sea (Williams 2006).

CVS Chinook apparently rear on available floodplains and tidal marsh habitat of the Sacramento-San Joaquin Delta and may also utilize the shallow habitats of San Pablo Bay (Williams 2006). Juvenile usage of tidal marshes, mudflats, and bays of the San Francisco Estuary is not well understood or studied (Williams 2006). There is considerable inter- and intra-annual variation in rearing habitat use that varies in part with fish size. Young-of-year juvenile spring-run Chinook are almost all ocean-type fish; these fish enter the estuary at a smaller size than do the much less common yearling, or stream-type juveniles that spend more time growing in the upper watershed (F. Cordoleani, NMFS, pers. comm. 2017). The smaller ocean-type juveniles need to spend more time foraging and exploit available resources in the estuary before migrating out to sea (Williams 2006). Food type and availability varies with habitat, but aquatic and drift insects, amphipods, copepods, and small crustaceans are generally available throughout the brackish regions of the estuary (MacFarlane and Norton 2002). Studies from the early part of the 20th century in the lower estuary indicate that young Chinook frequently appeared in trawls

and beach seines, but the San Francisco Bay has changed significantly since then and the current ecosystem does not resemble the historical ecosystem (Scofield 1913, Williams 2006). As a result, it is likely that smolt habitat usage in the San Francisco Estuary has changed correspondingly.

We can infer from other studies, such as from the Columbia River Basin, that estuaries can play an exceedingly important role in both salmon and steelhead smolt growth and survival; size of smolts upon ocean entry appears to be a strong determinant of survival in the first year at sea (Williams 2006). Juvenile CVS Chinook that rear on the Sutter Bypass floodplain will likely emerge from that habitat at sizes larger than 70 mm FL, nearly double their size at emigration from Butte, Mill, and Deer creeks, and can then proceed to the estuary quickly without needing to delay and rely on what rearing habitat may be available in the Delta (Hill and Webber 1999). Tagging data of spring-run Chinook smolts in Sutter Bypass in May indicate that floodplain-reared fish average around 107 mm, compared to the much smaller 70mm juveniles emigrating at the same time that had not reared on the floodplain from Mill Creek (NMFS *In prep.*). While there have been few studies of juvenile CVS Chinook use of estuarine habitats, the low numbers of juveniles encountered throughout the bays and lower tidal marshes and the lack of growth observed in those reaches since the turn of the century reflect the immense changes and habitat alteration that have taken place (e.g., MacFarlane and Norton 2002). MacFarlane and Norton (2002) studied CVS Chinook migration through the Delta and San Francisco Estuary, and documented average juvenile migration durations of approximately 40 days through the estuary, at an estimated rate of 1.6 km/day. The bulk of tidal marsh and creek habitats have been leveed and channelized for drainage, water deliveries, and navigation. Meanwhile, water transfers at the federal and state Delta pumps have drastically altered the hydrology, salinity, and turbidity of the lower Delta, impacting migration duration. Additionally, it is possible that predation from fish and birds affect Chinook survival and behavior in these habitats (NMFS 2014).

The majority of a salmon's life, including its growth and weight gain, now typically occurs in the ocean, whereas a significant portion of growth presumably historically occurred in the San Francisco Estuary (MacFarlane and Norton 2002). Once smolts arrive at sea in the late spring/early summer, they begin to feed on a variety of crustaceans, euphausiids, and small prey fishes and larvae (MacFarlane and Norton 2002, MacFarlane et al. 2005). As young Chinook grow larger, their diet shifts from crustaceans to predominantly fish, such as herring, anchovies, juvenile rockfish, and sardines (Moyle 2002). Smolt body condition (K), which is a ratio of weight to length of fish, after the first summer of foraging in the ocean is thought to be a good predictor of juvenile survival over their first winter (Williams 2006). It appears that a certain threshold of food abundance must be reached in order to ensure high survival, although in the warmer regions surrounding San Francisco Bay, this threshold may not be as absolute as in the more northerly regions, due to less variety and abundance of food resources (MacFarlane and Norton 2002). MacFarlane and Norton (2002) found that mean growth in length (0.18 mm/day) and weight (0.02 g/day) of juvenile Chinook in estuary habitat paled in comparison to estimated daily growth of 0.6 mm/day and 0.5 g/day observed while these fish were in the ocean ($p \leq 0.001$); at the same time, body condition declined while they were in the estuary, but improved markedly once these fish had a chance to feed in the ocean. This phenomenon can be accounted for by the California Current system that prevails outside San Francisco Bay, where upwelling, especially in the Gulf of the Farallones, creates a rich foraging area for young salmon. It is probably for this reason that newly arrived salmon mostly feed near shore, rather than farther out in the open ocean.

Size at ocean entry differs between stream-type and ocean-type fish, with stream-type fish generally being larger than their ocean-type counterparts due to their longer growth in freshwater. Once in the ocean, growth rates are similar, but the sizes at entry can determine ultimate lengths of adults returning to spawn at a given age (Moyle 2002). Commercial and sport fisheries also select for smaller size by removing larger and older fish from the population, as current regulations stipulate adults must measure > 51cm North of Point Arena, and > 61 cm from Point Arena South, which results in smaller and younger returning adults (CDFW 2017a). Thus natural factors may favor survival of larger CVS Chinook salmon, while fisheries may favor survival of smaller individuals.

Habitat Requirements: Chinook salmon use a variety of habitats during their lives. In general, water temperature determines their presence in a particular stream segment in freshwater. Preferred holding habitat is characterized by maximum weekly average temperatures less than 21ºC (Moyle 2002), although there is some evidence that CVS Chinook in some areas may tolerate slightly higher temperatures, such as in Butte Creek, tributary to the Sacramento River. The upper limit of temperature tolerance for adult CVS Chinook appears to be between 21 and 24ºC (Williams 2006). Evidence from Butte Creek indicates that consecutive days with daily mean temperatures >/= 21ºC increase adult mortality. Eggs are less tolerant, and thus adults wait until stream temperatures drop to around 13-15°C in the fall before spawning, while juveniles are more tolerant that eggs or juveniles (Williams 2006). Preferred spawning habitat seems to be at depths of 25-100 cm and at water velocities of 30-80 cm/sec, though CVS Chinook have been observed digging redds and spawning at depths from a few centimeters to several meters and at water velocities of 15-190 cm/sec (Williams 2006). Redds are constructed over 2-10m^2, where the loosened gravels permit steady access of oxygen-saturated water. Embryos are the most sensitive life stage, and have a narrow range of temperature tolerance, with considerable mortality occurring at temperatures above 14-16°C.

Adult CVS Chinook require deep pools with good cover for holding over the summer; most of this habitat lies at elevations between 150 and 500 m, but from 500-1,000 m for Deer and Mill creeks (NMFS 2016, M. Johnson, CDFW, pers. comm. 2017). Most spawners reach these areas by July and select deep (> 2m) pools with bedrock bottoms and moderate velocities (15-18 cm/sec) and with abundant hiding places such as rock ledges, bubble curtains, and woody debris (Moyle 2002). Spawning begins once water temperatures decrease to around 15°C. Spawning gravel varies in size. The most important factor for spawning site selection appears to be good hyporheic (subsurface) flow that provides relatively cooler, oxygen-saturated water to support embryos in gravels (Moyle 2002).

Ocean-type fry spend more time in the lower reaches of rivers and in the Sacramento-San Joaquin Delta than stream-type fish, foraging in the shallows and rearing on the floodplains of the Central Valley before undergoing smoltification before ocean migration (Williams 2006). Juveniles that emigrate as yearlings are more likely to become smolts on the downstream migration, and not spend as much time in the San Francisco Estuary. In the ocean, both stream-type and ocean-type fish from the Central Valley stay close to the coastal shelf, where upwelling provides rich foraging opportunities (Williams 2006).

Distribution: CVS Chinook salmon historically ranged throughout the Central Valley in both the Sacramento and San Joaquin watersheds. The National Marine Fisheries Service five-year status review for CVS Chinook (NMFS 2016) identified 18 or 19 independent historical

populations of CVS Chinook ranging from the Pit River in the north to the southern reaches of the upper San Joaquin. These populations inhabited five distinct geologic/hydrologic regions: 1) Basalt and Porous Lava, 2) Northern Sierra Nevada, 3) Northwestern California, 4) Southern Sierra Nevada, and 5) Central Valley domains. For now, the ESU boundary for CVS Chinook salmon contains the Sacramento River Basin downstream of impassible barriers; should a run of self-sustaining, CVS Chinook become re-established in the San Joaquin River, the boundaries could be updated to include this population (NMFS 2016).

In the Sacramento drainage, CVS Chinook once ranged into the Fall, Pit, McCloud, and upper Sacramento Rivers, from which they have been excluded since the 1940s by Shasta Dam. Western Sacramento River tributaries once inhabited by CVS Chinook include: Stony, Thomes, Cottonwood, and Clear creeks. Eastern tributaries that historically supported CVS Chinook include: Cow, Battle, Antelope, Mill, Deer, Big Chico, and Butte creeks as well as the Feather, Yuba, American, and Mokelumne rivers. Today, some CVS Chinook are still found in Battle Creek and in the Sacramento River below Keswick Dam, but current distribution of viable populations is limited to just a handful of streams in the northern Sierra Nevada Region (Lindley et al. 2016). This includes naturally reproducing populations in Mill, Deer, and Butte Creeks. CVS Chinook also occur on a regular basis in some of the smaller tributaries, such as Antelope, Big Chico, Little Chico, Beegum, and Clear creeks, but these populations are presumably not self-sustaining (Lindley et al 2007, Figure 1).

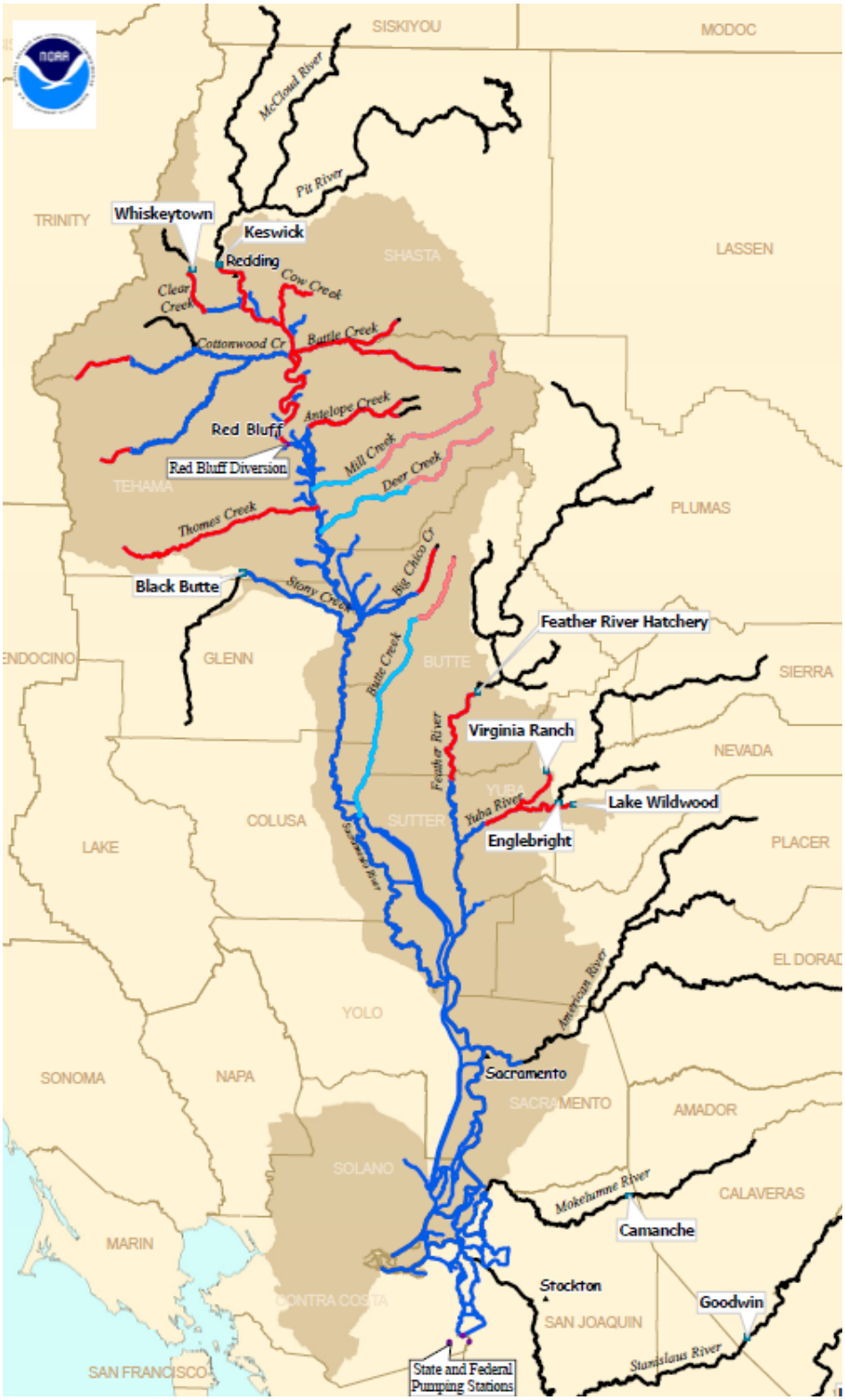

Figure 1. Historical and extant range of CVS Chinook salmon in the Sacramento Basin, California. Black = historical migration range; blue/light blue = current rearing or migration range; red/pink = current spawning range; blue squares = major dams, diversions, or hatcheries; purple squares = major pumping facilities. From NMFS 2014 Fig. 2-4, pg. 32.

In the San Joaquin drainage, lingering snow and glaciers at high elevations created a long spring hydrograph that favored CVS Chinook, making them the dominant run in the region. They apparently historically ascended the Kings, upper San Joaquin, Merced, Tuolumne, and Stanislaus Rivers, although pre-dam records for the latter three rivers are scarce (Yoshiyama et al. 1998). All San Joaquin drainage runs of CVS Chinook were thought to be extirpated as a result of a combination of factors including dam construction, water diversions for agriculture, and land use practices (NMFS 2014). More recent study (Franks 2015, FishBio 2015) has revealed Chinook exhibiting spring-run migration timing have been returning to the Stanislaus, Tuolumne, and Merced rivers, though their origin is unknown (Figure 2).

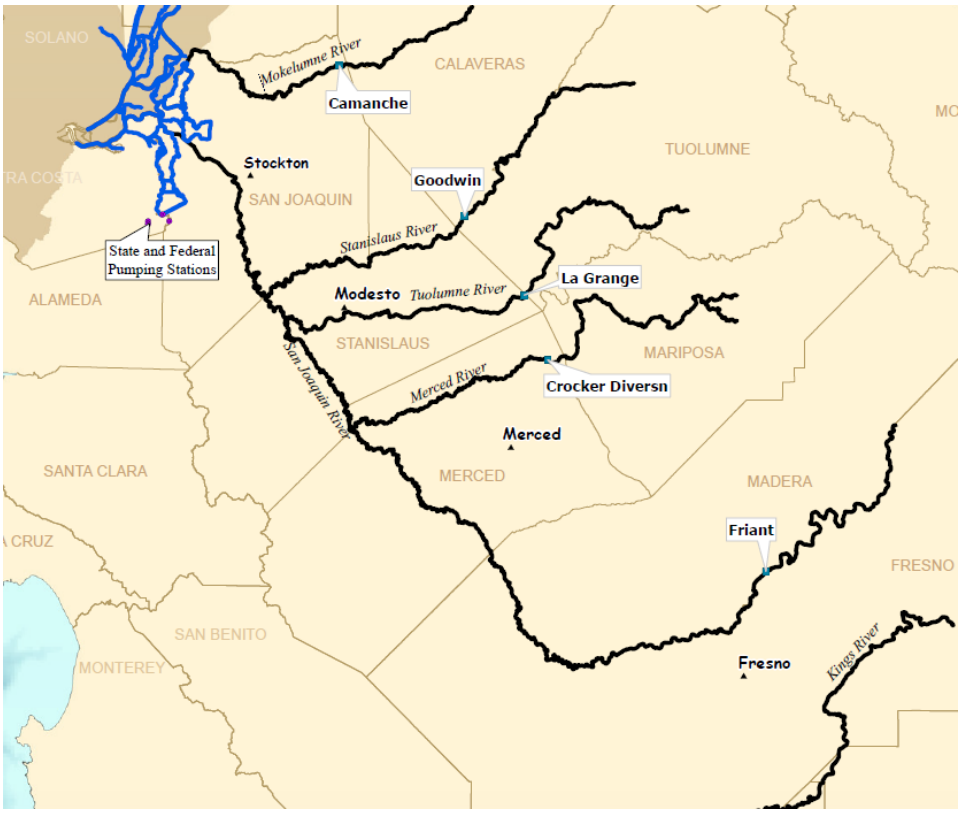

Figure 2. Historical and extant range of CVS Chinook salmon in the San Joaquin Basin. Black = historical migration range; blue = current rearing/migration range; blue squares = major dams, diversions, or hatcheries; purple squares = pumping facilities. From NMFS 2014 Fig. 2-4, pg. 32.

Within these regions, CVS Chinook distribution is limited significantly by both accessibility of habitat and water temperature. Many of the streams in the northern end of the ESU range are fed by springs, where precipitation falls mainly as rain rather than snow. These streams tend to have steady, year-round flows of cold water, which provided excellent habitat for oversummering CVS Chinook and decreased flow variability. Conversely, the bulk of the precipitation in the Sierra Nevada regions, especially in the south, falls as snow and spring-fed systems are less prevalent. This creates a sharp peak in the hydrograph during the late spring and early summer months when snowmelt is at its highest, then tapers off over the summer months into the early fall, when ambient and stream temperatures cool enough for spawning. The historical timing of high flows in the spring and early summer provided enough flow for CVS

Chinook to reach their summer holding areas. CVS Chinook upstream migrations were historically only truncated by natural impassible barriers, such as waterfalls and boulder fields that limited their access to higher-elevation, cooler reaches.

Trends in Abundance:

Overview. Annual abundance of CVS Chinook salmon populations has varied considerably from 1970 to 2012, from highs of around 31,000 to lows around 3,000 (NMFS 2014, Figure 3), including fish of hatchery origin in the Feather River. However, despite an upward trajectory in 2012, returns of fish from 2012-2014 again showed a downward trend, which carried over to very poor returns in 2015 (NMFS 2016).

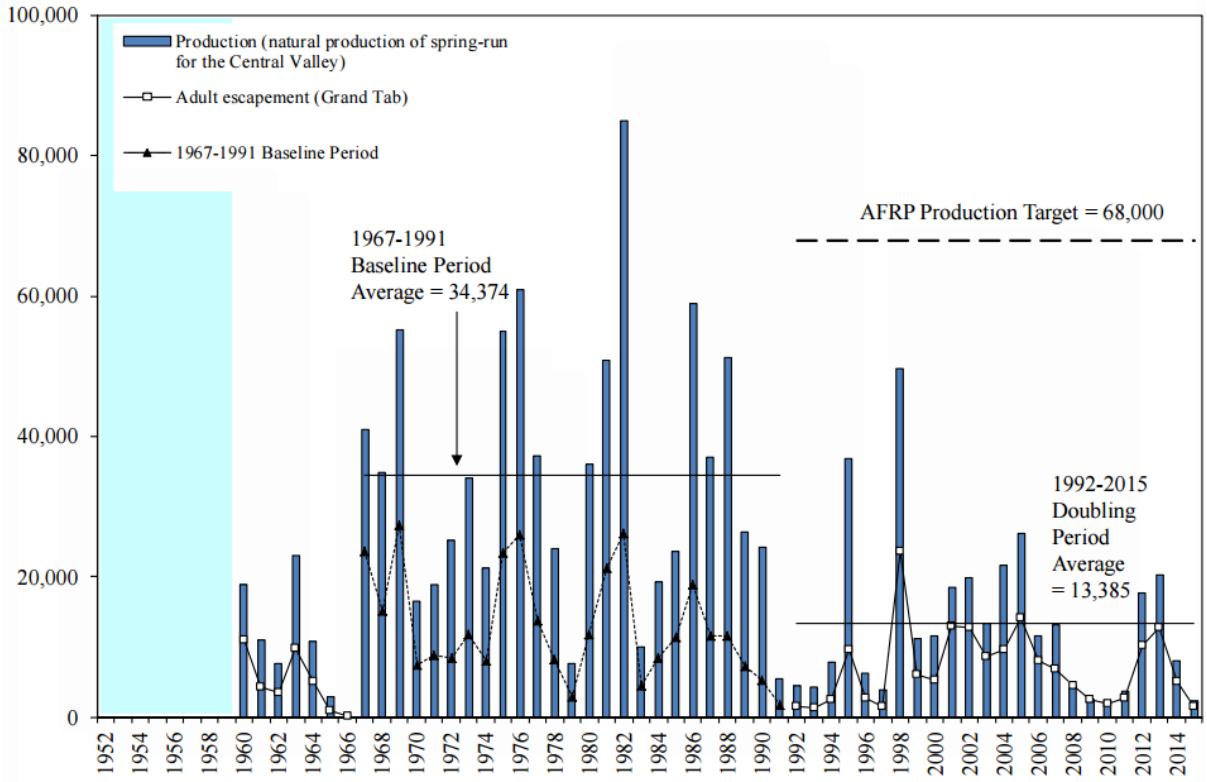

Figure 3. Estimated yearly adult natural production, and in-river adult escapement, of spring-run Chinook salmon in Central Valley rivers and streams, 1952-2015. Based on CDFW's Grandtab escapement estimates. From USFWS Anadromous Fish Restoration Program 2017, Fig. 5, pg. 5.

Sacramento Basin. CVS Chinook have been extirpated from the vast majority of their historical range in the Sacramento Basin due to habitat alteration. 19th century combined run sizes were probably in the range of 1 million fish per year, +\- 500,000 (Yoshiyama et al. 1998); CDFW (1998) estimated historical runs of around 600,000 CVS Chinook in the Central Valley from the 1880s to the 1940s. The three extant populations in Mill, Deer, and Butte creeks in the Northern Sierra Nevada diversity group saw an upward trend in abundance from 2010-2014. The Battle and Clear creek populations have been increasing recently and climbed into the moderate extinction risk category, (NMFS 2016) until ongoing drought brought significant declines across CVS Chinook populations (NMFS 2016, Figure 4), especially during 2015-16. The latest counts in 2016 (331 on Deer, 175 on Mill creeks) are likely the lowest ever recorded (M. Johnson,

CDFW, pers. comm. 2017). NMFS (2016) points out that once populations dip below 500 individuals over two generations, as is likely the case for Deer and Mill populations, the extinction risk becomes high.

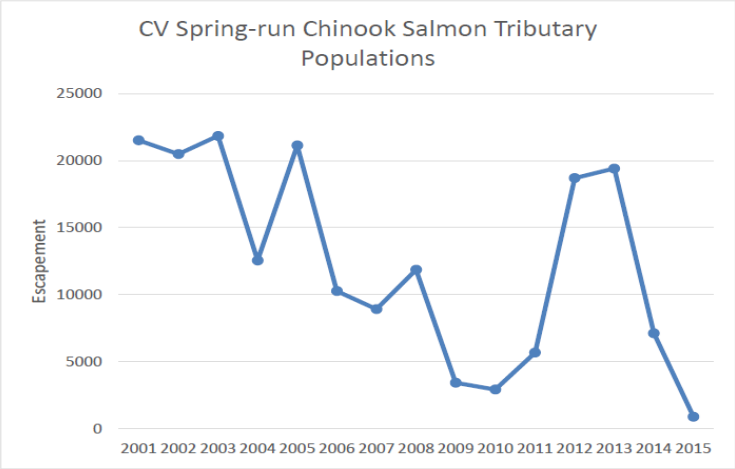

Figure 4. Combined escapement estimates for CVS Chinook salmon in Butte, Mill, Deer, Battle, and Clear creeks based on carcass surveys, 2001-2015. From NMFS 2016, Fig. 2, pg. 15.

Populations in Cottonwood, Antelope, and Big Chico creeks have remained at or near zero since 2007. Meanwhile, the Yuba River (with a few hundred to perhaps a few thousand fish) remains at high extinction risk as a result of FRFH influence. Aerial redd surveys conducted by CDFW indicate that a small number of CVS Chinook spawn in the mainstem Sacramento in September between Keswick Dam (Rkm 483) and Red Bluff Diversion Dam (Rkm 391) (NMFS 2016). In contrast, about 1,000-20,000 fish return to the Feather River annually, though these numbers are supported significantly by FRFH (NMFS 2016). The hatchery has been releasing about 2 million juvenile Chinook per year from 2006-2016 at various locations, including in-river and downstream locations in net pens within San Pablo and San Francisco bays (PSMFC 2017, Figure 5). These juveniles have been introgressed with Central Valley fall-run Chinook through hatchery practices over time (CHSRG 2012).

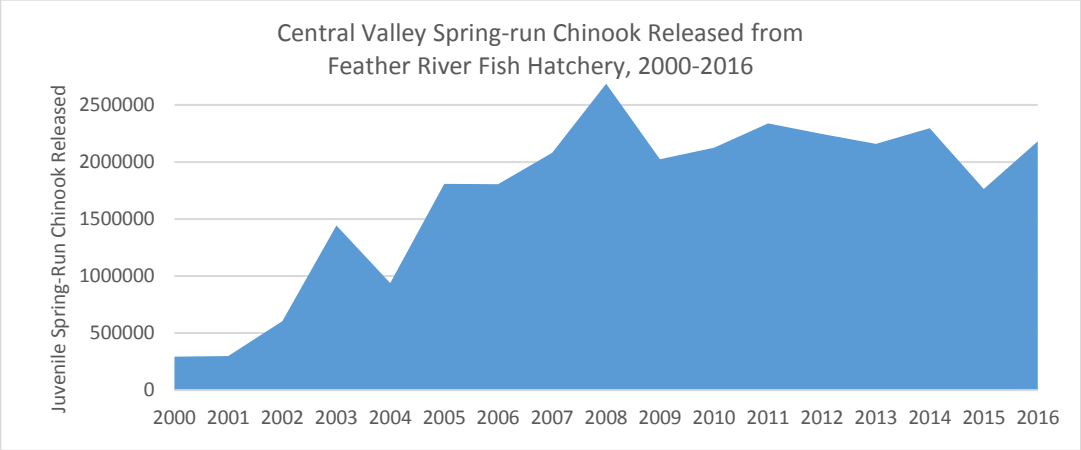

Figure 5. CVS Chinook salmon releases from Feather River Fish Hatchery, 2000-2016. Data from PSMFC 2017: http://www.rmpc.org/.

While hatchery releases show an increasing trend since 2000, returns of adults and jacks to the Feather River Fish Hatchery have remained fairly constant, ranging from about 1,000-4,000 fish per year (NMFS 2016). Since 2007, FRFH has adjusted their operations to tag and release fish that ascend the ladder from September 15 to June 30, ensuring that fish exhibiting spring run timing can be identified later when spawned. Nearly 1,000,000 juvenile fish are released into net pens in San Pablo Bay near Benicia, CA each year, which presumably increases in-river survival but leads to increased rates of straying to other Central Valley streams due to reduced opportunities for imprinting (NMFS 2016). From 2004-2010 on the Yuba River, hatchery-origin fish from FRFH accounted for an average of about 20% of the total annual run of CVS Chinook salmon passing upstream of Daguerre Point Dam (USACE 2012).

San Joaquin Basin. Fry (1961) estimated that approximately 50,000 CVS Chinook migrated up the San Joaquin River annually before completion of Friant Dam below Millerton Reservoir (Rkm 431) in 1942. By the 1950s, nearly the entire San Joaquin Basin run was extirpated, leaving only remnants in the Merced River (Yoshiyama at al. 1998). Since 2014, considerable investment has been made to attempt to re-establish a self-sustaining population of CVS Chinook in the San Joaquin River (www.rmpc.org). As part of the historic San Joaquin River Restoration Agreement, an average of 57,000 CVS Chinook originally from Feather River Fish Hatchery and raised at a temporary conservation hatchery facility at Friant Dam, have been released at the confluence with the Merced River (Rkm 189).

In addition, there have been reports of adult Chinook salmon returning from February through June to the Mokelumne, Stanislaus, and Tuolumne rivers that display spring-run life history strategies for holding and spawning (Franks 2014, Workman 2003, FishBio 2015, NMFS 2016). In 2013, 114 adult Chinook were counted on the video weir on the Stanislaus River between February and June, with only 7 fish (6%) without an adipose fin, indicating the majority are presumably natural-origin fish or offspring of natural-origin fish (FishBio 2015). The origins of these fish and viability of putative populations are unknown at this time.

Summary. Annual estimates of CVS Chinook salmon numbers in the past 25 years have varied from 3,000 to 30,000, including FRF Hatchery fish. Presumably such numbers would have large confidence intervals around them if the intervals could be calculated. If the FRFH component is ignored, numbers of wild CVS Chinook seem to range between 1,000 and 20,000 spawners, with a general downward trend.

Factors Affecting Status: Major factors affecting, or potentially affecting, the status of CVS Chinook in the Central Valley are discussed below. For a full discussion of more general factors, see Central Valley fall-run Chinook salmon.

Dams. Dams are the major cause of the widespread extirpation of CVS Chinook salmon. Currently, dams block access to over 90% of their historical spawning and summer holding areas, including almost all of the mainstem Sacramento, all of the San Joaquin drainage, the northern Sacramento basin, and central Sierra Nevada streams such as the Yuba, Feather, and American Rivers (Yoshiyama et al. 1998). All but three historical spawning areas are either behind impassable dams or are strongly impacted by dams (Mill, Deer, Butte creeks), and even these watersheds have been negatively affected over the last century by water diversions, small dams, and between-basin water transfers to support agricultural and urban water usage (Yoshiyama et al. 1998). Keswick (Rkm 483) and Shasta (Rkm 505) dams on the Sacramento River have fundamentally altered the hydrograph and character of the river downstream, significantly limiting the ability of the river to support salmon of any run timing (see winter-run

Chinook account). Historically, Red Bluff Diversion Dam (Rkm 391) utilized gates to divert water for agricultural and urban uses that created Lake Red Bluff and impediments to fish passage, but the gates have remained open since 2011 to allow passage for salmon, steelhead, and sturgeon in the river (USFWS 2014).

Large dams change the flow patterns of rivers, reducing the length of spring outflow events that help juveniles emigrate and attract adults upstream, and limit the ability of floodplains to properly function by providing opportunities for rapid growth of juvenile salmonids. Coldwater releases from dams provide cool temperatures to sustain CVS Chinook in some cases, but also facilitate easy hybridization with fall-run fish because of the loss of the historical geographic segregation between them. This relatively recent spatial overlap in spawning may drive the lack of genetic differentiation between fall- and spring-run Chinook in the Feather River.

The DeSabla-Centerville dams on Butte Creek operated by Pacific Gas & Electric Company are scheduled for relicensing in the near future, but PG&E has withdrawn their application. The future operation of these dams and associated diversions will have important consequences for the long-term persistence of CV spring-run Chinook.

Rural/ residential development. Development of all kinds along the Sacramento River and its tributaries impact CVS Chinook rearing in the main river and its tributaries through polluted run-off, sedimentation, loss of riparian habitat, and small diversions. The effects of such actions, however, are poorly documented.

Logging. Logging has and continues to be an important economic activity in the watersheds throughout the historical CVS Chinook range. Much of the headwaters of these watersheds lie within National Forest boundaries, including (from North to South) Shasta-Trinity, Lassen, Plumas, Tahoe, Eldorado, Stanislaus, and Sierra national forests. Legacy impacts to streams from logging and its associated road building have resulted in erosion, landslides, and loss of riparian vegetation and large woody debris inputs to streams that provide refuge for multiple life stages of salmonids across the ESU range (Meehan 1991).

Grazing. Cattle grazing occurs throughout most of the Central Valley watersheds where CVS Chinook reside. Basin-wide impacts from grazing include erosion from bank trampling, loss of meadow habitat, and loss of riparian vegetation with a resulting increase in water temperature and decrease in water quality. This in turn can alter the macroinvertebrate community relied on as food for both juveniles and over-summering spawners. Many of these impacts have been reduced in recent years (e.g., through the fencing of meadow streams such as in Deer Creek Meadows) by improved management of landowners and other partners, but livestock grazing is still a major land use throughout the ESU range.

*Agricultur*e. There are numerous diversions along the Sacramento River, mostly to support agricultural and urban uses, which can potentially entrain CVS Chinook fry and smolts. The larger diversions are all screened and presumably offer some degree of protection from entrainment, while smaller diversions on the main river do not need to be screened (Moyle and Israel 2006); the intakes in the main river also tend to be deeper than most salmon occur. The large State Water Project and the federal Central Valley Project pumps that divert Sacramento River water in the southern Delta to holding reservoirs and eventually to conveyances such as the California Aqueduct to supply southern California with water also have a major negative impact on CVS Chinook salmon populations. In 2009, the National Marine Fisheries Service issued its formal Biological Opinion on the impacts of this pumping in a jeopardy determination that triggered exploration and implementation of reasonable and prudent alternatives to business-as-

usual operations, which are the source of significant detrimental impacts to Central Valley salmon and steelhead, green sturgeon, and southern killer whales (NMFS 2017). See Central Valley fall Chinook account for further discussion of this factor. Finally, obsolete fish screens, diversions, dams, fish ladders, inadequate flows, levee construction, floodplain simplification, and hydroelectric projects on Battle and Butte creeks and the Feather and Sacramento rivers significantly limit spawning and rearing habitat for CVS Chinook by fragmenting and altering flow and habitat regimes (NMFS 2016). In addition, the variation of water operations deviates from natural hydrographs. In winter and spring, dams hold back flows to store water, then deliver it at artificially high flows for delivery to consumers downstream. These low springtime flows harm juvenile and adult spring-run Chinook by reducing water quality (higher water temperatures and contaminants) and increased predation (from lower velocity flows and warm water that favors alien species, M. Johnson, CDFW, pers. comm. 2017).

Historically, the biggest impact of agriculture on CVS Chinook salmon was construction of the massive levee system in the Central Valley in the 19th and early 20th centuries used to prevent flooding of agricultural fields and towns (Kelley 1989). Levees caused the lower river to down-cut as large sediment loads from hydraulic mining came downstream (which had raised historical river levels and exacerbated problems with flooding). The result was loss of floodplain and backwater habitat that was historically important for rearing juvenile Chinook salmon. Today this habitat is largely absent along the channelized Sacramento River and diked Sacramento-San Joaquin Delta. Patches of slow-moving rearing habitat are sparse outside the main river, where exposure to predators is high. In wet winters and springs when the Yolo Bypass is flooded, presumably some CVS Chinook take advantage of these favorable rearing conditions. The impact of loss of this historical rearing habitat on CVS Chinook is poorly documented, but the combination of fewer opportunities for rapid growth and more constant exposure to predators in the main river channels may greatly reduce out-migrant survival.

On Deer Creek, Stanford Vina Ranch Irrigation Company (SVRIC) and Deer Creek Irrigation District (DCID) draw enough water out of the creek for agriculture to prohibit upstream migration of adults, leaving less than 5cfs of flow during some intensive irrigation windows (CDFW 2014). On Mill Creek, Ward Diversion Dam reduces instream flows and increases stream temperatures, creating sub-optimal conditions for migrating and rearing spring-run Chinook (CDFW 2014b). Deer and Mill Creek spring-run juveniles out-migrate at later dates and smaller sizes compared to other CV Chinook stocks (Johnson and Merrick 2012). This likely puts Deer and Mill spring-run at greater risk to low flows and warm water temperatures in diverted stream sections and the mainstem Sacramento River during spring.

On the Feather River, water is diverted from Oroville Dam and warmed in a shallow reservoir (Thermalito Afterbay) for rice farming, with excess warm water returned to the river. The influx of warm water can raise instream temperatures to lethal levels for over-summering and juvenile CVS Chinook. Agricultural return waters also contain pesticides and other contaminants, which may negatively affect juvenile Chinook health and survival through reduced water quality.

On the San Joaquin River, diversion dams, levees, and similar water conveyance and control projects such as Chowchilla Bypass eliminated much of the rearing habitat for juvenile salmon that persisted through the summer by quickly draining coldwater flows from the high Sierra snowmelt and from artesian groundwater. These rearing habitats were found in the braided side channels and are still faintly visible on aerial photographs and in floodplains of the basin.

For more than sixty years, the mainstem San Joaquin has been dry as a result of overdraft of surface and groundwater in the region, especially in the vicinity of Chowchilla Bypass. This has effectively eliminated the migration and rearing capacity of the mainstem San Joaquin River altogether, significantly reducing CVS Chinook abundance by removing the southern half of their range. As a result of over eighteen years of lawsuits and a recent settlement agreement in September 2006, the San Joaquin River Restoration Program was adopted and has been implemented by NMFS, U.S. Fish and Wildlife Service, CDFW, water users, the U.S. Bureau of Reclamation, and other stakeholders. Under this program, flows have been secured from Friant Dam below Millerton Reservoir to provide access to spawning, rearing, and migration habitat for CVS Chinook. Using strategic releases of water from Friant Dam, the Settlement Parties aim to allow volitional migration possible once again for an experimental population of CVS Chinook from the Dam site downstream to the confluence with the Merced River.

CVS Chinook juveniles from broodstock at the Feather River Fish Hatchery are being raised at a temporary hatchery facility downstream of Friant Dam. NOAA Fisheries, the U.S. Fish and Wildlife Service, the U.S. Bureau of Reclamation, and the California Department of Fish and Wildlife currently jointly oversee this effort under section 10(j) of the Endangered Species Act. This major restoration project is the culmination of decades of negotiations and tireless work of numerous landowners, water users, managers, and other stakeholders, and represents the largest ever undertaken in the Central Valley. Additional information on this program can be found at (San Joaquin River Restoration Program 2017).

Mining. Hydraulic gold mining was presumably an initial factor in CVS Chinook decline in the late 19th century, which radically altered holding areas across most of the Sierra Nevada foothills (Merced to Feather rivers, as well as other areas). Historical mining during the California Gold Rush (1948-1952) resulted in the destruction of many of the streams used by all runs of Chinook, but especially CVS Chinook, which require high-quality habitat and cold water all year round. Hydraulic mining washed millions of tons of sediment into streams, covering spawning gravel and destroying habitat. Historical records indicate that runs in the rivers subjected to hydraulic mining were extirpated for some time until conditions improved and the salmon were able to re-colonize areas not blocked by dams (Williams 2006). Significant scarring and habitat alteration resulting from mining 150 years ago can still be seen today in streams and rivers throughout the southern and northern Sierra Nevada areas (e.g. Yuba River); high sediment loads in rivers after winter storms are a continuing legacy impact of these activities.

Toxic mining wastes, such as heavy metals like mercury, mainly from abandoned mines, also have legacy effects on CVS Chinook. The principal threat today associated with mining in the ESU range is the potential for a major spill of highly toxic waste from Iron Mountain Mine, a U.S. EPA superfund site about 14.5km Northwest of Redding (Shasta Co.). If the check dam on Spring Creek that currently contains the contaminants should fail, a plume of toxic water could be flushed down the Sacramento River, with lethal consequences for any fish.

Estuarine alteration. The San Francisco Estuary is a very different ecosystem today than it was when Central Valley Chinook salmon evolved, leaving few opportunities for foraging and rearing salmon and the kind of growth that historically prepared smolts for the rigors of ocean migration (MacFarlane and Norton 2002). Historically, juvenile CVS Chinook would have arrived in an estuary that was a complex of tidal marshes, with many shallow channels, rich in food and refuge. In this system, they could physiologically adjust to changing salinities slowly, while finding abundant food and cover to compensate for the stress of emigration. Today, most of the tidal marshes are gone, food resources are diminished, and exposure to predators,

especially in the form of invasive or alien species, is high. Thus, juvenile salmon move through estuary as rapidly as possible, at considerable cost in energy and vulnerability to predation (and the federal and state pumping facilities in the South Delta).

Harvest. In the nineteenth century, commercial fisheries decimated CVS Chinook populations statewide. The fisheries were reduced initially because numbers of salmon had become too small to make canning profitable, and then regulations helped to reduce harvest rates. There was some recovery in populations until the completion of major Central Valley rim dams blocked access to most spawning and rearing habitat for CVS Chinook.

The impacts of commercial and sport fisheries have been through incidental take in ocean fisheries, which largely depend on hatchery fish from FRFH. It is likely that such take has been a significant source of mortality for the diminished populations of CVS Chinook, but its impact is not well understood due to lack of a robust genetic stock identification program or marking of all hatchery fish, which would enable wild fish to be distinguished from hatchery fish at sea. Fisheries also select for younger, smaller, and less fecund fish as spawners, reducing resiliency of the populations over time.

Recent breakthroughs in sequencing specific segments of DNA to determine life history strategy and run assignment, called ancestry-informative markers (AIMs), shows promise for stock identification of Chinook caught at sea. Meeks and colleagues (2016) developed testing to reliably identify Central Valley Chinook salmon by run timing with an average accuracy rate of 96%. This and other experiments will be very important for monitoring and managing the health of individual populations, especially the imperiled spring-run ESU (Meeks 2016).

CVS Chinook salmon have a relatively broad ocean distribution from Central California to Cape Falcon, Oregon, that is similar to Central Valley fall-run Chinook salmon. However, they are thought to incur less fishing mortality and pressure than their fall-run counterparts since they migrate to freshwater in spring before the most intense fishing pressure occurs in the summer (NMFS 2016). Salmon fishing is prohibited on Mill, Deer, and Butte creeks (NMFS 2016), though low recoveries of coded wire tags from Butte Creek fish are inconclusive as to the harvest impacts on CVS Chinook.

Hatcheries. There appears to be little obvious hatchery influence on Mill Creek, Butte Creek, and Deer Creek populations, but Battle Creek (Rkm 534) and Feather River (Rkm 128) populations are strongly influenced by hatchery operations through straying and genetic introgression of fall-run and spring-run Chinook (NMFS 2016). Coleman National Fish Hatchery (Battle Creek) and Feather River Fish Hatchery are the two main hatcheries currently operating in the CVS Chinook ESU range. While Coleman National Fish Hatchery only raises and releases fall- and late-fall Chinook (USFWS 2017b), FRFH releases an estimated 2 million CVS Chinook smolts per year to prop up abundance in the Feather River. The millions of smolts are released in relatively close proximity to one another (Rkm 504-518), and have the potential to stray and spawn with fall- and late-fall Chinook in other watersheds. These releases significantly prop up the population; 78 percent of spawners in the 2010/2011 CVS Chinook salmon carcass survey on the Feather River were estimated to be from the FRFH (Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013). This facility has received criticism for mixing spring- and fall-run fish for broodstock in the past (Williams 2006). While Butte Creek and Feather River CVS Chinook appear genetically distinct, about 200,000 juvenile Feather River CVS Chinook were planted into Butte Creek in 1986 in response to extremely low numbers of returning fish. However, there is little evidence that this plant had any effect on Butte Creek populations.

In addition, until 2015, at least half of the CVS Chinook salmon production from FRFH has been trucked to release sites such as the San Francisco Bay, rather than releasing juveniles into the river. This practice has been shown to increase straying rates of returning adults to other watersheds, posing genetic risk to those other Central Valley salmon populations (Kormos et al., 2012, Palmer-Zwahlen and Kormos 2013). A prolonged influx of FRFH CVS Chinook salmon strays to other Central Valley salmon populations, even at levels of less than one percent, can increase extinction risk after only four generations (Lindley et al. 2007). The extent of interbreeding between hatchery-reared fall and CVS Chinook salmon in the Feather River is unknown due to the absence of spatial or temporal barriers to spawning in the river today, but is estimated to be significant (NMFS 2016). Also, a significant portion of the FRFH returning adults (~20%) have been recovered in the American (Cramer 1996) and Yuba rivers in recent years (USACE 2012). On Battle Creek, perhaps as much as 29% of CVS Chinook salmon in 2010 were estimated to have originated from the FRFH (USFWS 2014). In addition, a recent study suggests a high likelihood that FRFH Chinook may be interbreeding with natural-origin spring- or fall-run Chinook salmon in the Sacramento River after a fish trap below Keswick Dam captured dozens of FRFH-tagged Chinook in recent years (Rueth 2015). If such introgression occurs with fish in Mill, Deer, or Butte creeks, as seems likely, the negative consequences may be important because these fish retain unique genetic signatures among extant CVS Chinook salmon (NMFS 2016). A Hatchery and Genetics Management Plan that mandates in-river release of juveniles for imprinting and reducing straying, which began implementation in 2015, should reduce genetic impacts of hatchery fish on natural-origin CVS Chinook. See Central Valley fall Chinook salmon account for more discussion of hatcheries.

Alien species. Predation on juvenile salmon by predators such as striped bass (*Morone saxatilis*), smallmouth bass (*Micropterus dolomieu*), and largemouth bass (*M. salmoides*) may be limiting, especially in areas with man-made structures that alter the environment such as near the pumping and diversion stations in the highly altered Delta. For example, the striped bass spawning migration in the Sacramento River corresponds with the outmigration timing of spring-run and fall-run Chinook juveniles to the ocean, which may be a source of juvenile salmon mortality (F. Cordoleani, NMFS, pers. comm. 2017).

In addition to anthropogenic threats discussed above, forest fires, volcanic activity, drought, and climate change all have a high potential to affect CVS Chinook because three major populations are located closely together in the Mount Lassen foothill region. Catastrophic forest fire has become a major problem in the Sierra Nevada stemming from a century of fire suppression, fuel accumulation, and housing development in the urban-forest interface. All three of the extant spring-run Chinook creeks have their headwaters in public and private forestland that has high potential for large, destructive fires. Lindley et al. (2007) examined fire risk and demographics in the spring-run watersheds and determined that a fire of 30km width could simultaneously burn the headwaters of all three populations, leading to heavy potential impacts on CVS Chinook. Such a fire has a 10% chance of occurring in any given year, increasing the vulnerability of these populations to such catastrophic stochastic events (Lindley et al. 2007).

Likewise, all CVS Chinook populations are vulnerable to volcanic eruptions from Mount Lassen, an active volcano located at the headwaters of Mill, Butte, and Deer Creeks. All three streams are located within the estimated reach of pyroclastic and debris flows from a potential volcanic eruption. The USGS has classified Mt. Lassen as “highly dangerous” (Lindley et al. 2007).

Factor	Rating	Explanation
Major dams	High	Dams block access to over 90% of historical habitat and alter the quantity and quality of remaining habitat for CVS Chinook.
Agriculture	High	Diversions, mostly for agricultural uses, have reduced availability of cold, clean water throughout most of the ESU range.
Grazing	Low	Cattle grazing relatively common throughout the ESU, though impacts are likely small.
Rural /residential development	Low	Development at the forest-rural interface may reduce availability of cold water, especially during critical holding periods in summer and fall.
Urbanization	Low	Water diversion and groundwater pumping may negatively impact coldwater flows.
Instream mining	Low	Some legacy impacts from gravel mining possible.
Mining	Low	Legacy impacts are likely small; toxic spills from Iron Mountain Mine could be a major threat to all fish in the Sacramento River.
Transportation	Low	Watersheds have many logging or agricultural roads; impacts likely to be local and related to sedimentation.
Logging	Medium	Holding/spawning areas are within National Forests or private timberlands, which have been subjected to decades of heavy logging and associated road building.
Fire	Medium	Fish in adjacent watersheds (Mill, Deer, Butte creeks) are susceptible to depletion from a single large fire.
Estuary alteration	High	The San Francisco Estuary is heavily altered, to the detriment of all migratory fish.
Recreation	Low	Boating, swimming, and fishing may disturb holding CVS Chinook, but magnitude of impacts unknown.
Harvest	Low	Recent estimates of commercial fishing pressure on CVS Chinook are low and do not contribute to overutilization; recreational fishing in freshwater is banned for CVS Chinook.
Hatcheries	High	Feather River Fish Hatchery fall- and spring-run Chinook are closely related and stray to other watersheds, reducing genetic integrity of natural-origin stocks.
Alien species	Medium	Predation from fishes such as striped and smallmouth bass may be locally significant.

Table 1. Major anthropogenic factors limiting, or potentially limiting, viability of populations of Central Valley spring-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 for explanation.

Effects of Climate Change: CVS Chinook salmon are rated "critically vulnerable" to extinction by Moyle et al. (2012). This vulnerability is the result of the added effects of climate change on

top of restricted distribution and depressed annual abundance. Climate change represents a special conservation challenge for these fish due to their reliance on cold spring water and snowmelt to sustain them through warm summer months. Lindley et al. (2007) indicate that climate change will likely lead to elimination of suitable thermal habitat in much of the currently accessible extant range by 2100. In a detailed field and modeling study of Butte Creek, Thompson et al. (2012) found that CVS Chinook salmon will be extirpated from the creek in 50-100 years or less, as the result of loss of coldwater habitat from climate change. Less snowfall, and potentially reduced overall precipitation, is expected across California in the coming decades (Lindley et al. 2007). Reduced snowpack and snow water equivalents are expected to decrease over time, especially in Northern California, where snowpack is generally shallower than in the southern Sierra. Dettinger (2005) indicates that a 5°C rise in average temperatures is likely. Such higher temperatures, especially in lower elevation streams such as Butte, Cottonwood, and Big Chico creeks, will continue to stress CVS Chinook salmon. On top of decreased precipitation and warmer temperatures, more frequent and intense wildfires are expected statewide, which can burn riparian vegetation, lead to sedimentation and landslides, and reduce habitat for salmon. The chances of catastrophic fire under a warmer, dryer climate in California are very likely to increase over time (NMFS 2016).

This means CVS Chinook will need to spawn and hold higher in the watersheds than current infrastructure (dams and diversions, natural barriers) allows, making experimentation with trap-and-haul or other fish passage programs likely; this concept is currently being explored by the Yuba Salmon Partnership Initiative, a collection of agencies and other partner groups around Englebright Dam on the Yuba River (CDFW 2017b). Lusardi and Moyle (*In press*) however indicate that two-way trap and haul programs do not have a good record of success and that there are many uncertainties associated with the efficacy of such programs.

Restoration of former habitat is critical to maintaining long-term population stability, particularly in the face of future climate change. Enhancement of the Battle Creek population and restoration of the San Joaquin River population, in particular, are very important aspects of CVS Chinook conservation because both have good sources of cold water. In addition, the San Joaquin River is distant from other populations and could bolster spatial stability and increase genetic adaptation and diversity in putative San Joaquin tributary populations.

Habitat simplification and degradation have reduced the resiliency of CVS Chinook populations and rendered them more susceptible to additional environmental stressors, such as drought (NMFS 2016). Extended dry or drought periods are predicted in the future in California under most climate change models, and could easily render most existing CVS Chinook habitat unusable, either through temperature increases or lack of adequate flows (Williams et al. 2016). Increased frequency and/or intensity of drought will lead to less water available behind dams, reducing cold water pool available for releases to support adult fish in warmer summer months. These reduced flows will also limit the ability of groundwater aquifers to recharge and to supply the cold spring flows that are characteristic of the Basalt and Porous Lava Domain. The impacts of recent drought years (2012-2016) and warm ocean conditions on the juvenile life stage will only be realized in potential low returns of CVS Chinook adults from 2015 through 2018 (Williams et al. 2016). This is already being realized with very low returns of CVS Chinook in 2015 to almost all watersheds in the ESU. Lethal water temperatures in traditional and non-traditional CVS Chinook salmon holding habitat during the summer in Butte and Big Chico creeks have been documented since 2013, causing elevated pre-spawn mortality in some populations. A large number of adults (about 900 and 230, respectively) were estimated to have

died prior to spawning in the drought years of 2013 and 2014 (Garman 2015). Additionally, pre-spawn mortality in adult CVS Chinook salmon in Mill, Deer, Butte, and Battle creeks was observed in addition to longer duration of warm temperatures (Garman 2015). Thus, while NMFS (2016) considers CVS Chinook to be at moderate (Mill and Deer) or low (Butte Creek) risk of immediate extinction, these populations are likely to decline as impacts from the 2012-16 drought are realized in returning adults (NMFS 2016) and as climate change impacts become more severe (Thompson et al. 2012).

Status Score = 1.7 out of 5.0. Critical Concern. There is high likelihood of naturally spawning CVS Chinook going extinct in the next 50 years. Both state and federal governments list CVS Chinook as threatened. Our evaluation does not count fish from FRFH (and naturally spawning strays from the hatchery) that are currently included in the CVS Chinook ESU because of their hatchery dependence and hybridization with fall-run Chinook. However, the score would be only slightly higher if these fish were counted. Given the high likelihood of extirpation of the naturally spawning, independent populations, the spring-run life history strategy in the future may only exist in the Central Valley in rivers with cold water releases from dams, where natural reproduction is enhanced with fish from FRFH. We also recognize that some straying of CVS Chinook from FRFH into Deer, Mill, and Butte creeks probably occurs in most years, with unknown effects.

Recent management efforts and restoration projects have somewhat reduced their vulnerability to extinction, but the probability of populations plummeting in the future are high, especially considering recent downward trends (2014-2016). NMFS (2016) suggested CVS Chinook in Butte, Mill, and Deer Creeks were at low risk of extinction in the short term, but impacts of drought have caused populations to plummet. All three independent populations are in adjacent streams subject to natural and human-caused disasters, populations have been extremely small in the recent past, and all three streams are small and could become marginal for salmon as the climate continues to shift. The small populations in Battle and Clear creeks show increasing trends since 2011 and could potentially become sustainable populations, as could the experimental population in the San Joaquin River with active management and significant restoration, but drought impacts will likely reduce the number of returning adults in 2017-2018 (Williams et al. 2016, F. Cordoleani, NMFS, pers. comm. 2017).

While NMFS (2016) reports that the status of the ESU has probably improved since 2008 due to extensive restoration (e.g., Clear Creek) and increases in spatial structure of populations (Battle and Clear creeks), this evaluation does not take into account the more recent impacts of drought and climate change. A downward trend across Butte, Mill, and Deer creek populations has already been observed since 2014 (NMFS 2016). In general, low abundance, diversity, and poor spatial structure among independent populations of this ESU are troubling (NMFS 2016). The recent declines due to high pre-spawn and egg mortality, uncertain juvenile survival to smolting, and poor ocean conditions during the 2012 to 2016 drought are all causes for concern. In addition, straying of FRFH CVS Chinook salmon to other watersheds and introgression with other populations may also be working against the resiliency of remaining natural-origin populations (NMFS 2016).

Metric	Score	Justification
Area occupied	2	Self-sustaining populations are mainly in Deer, Mill, and Butte creeks, with potential for populations in Battle and Clear creeks, as the result of restoration.
Estimated adult abundance	2	Total numbers have periodically dropped below 5,000 fish even when FRH fish are counted. When FRH fish are not counted, most of the remaining fish are in Butte Creek.
Intervention dependence	2	Without significant restoration and intervention, CVS Chinook would likely already be extinct in the Central Valley.
Environmental tolerance	2	Narrow physiological tolerances in summer for both adults and juveniles considering streams they inhabit.
Genetic risk	2	Butte Creek and Deer-Mill Creeks populations appear to be distinct, but effect of hybridization with FRH fish unknown.
Climate change	1	Extremely vulnerable given small population sizes and range, as well as already high temperatures of streams.
Anthropogenic effects	1	Four High threats.
Average	1.7	12/7.
Certainty (1-4)	4	Well-studied.

Table 2. Metrics for determining the status of CVS Chinook salmon, where 1 is poor value and 5 is excellent. Scores 2-4 are intermediate values. Certainty of these judgments is high. See methods for explanation.

Management Recommendations: CVS Chinook declined from once being as abundant as fall-run Chinook salmon, to a few hundred to perhaps a few thousand fish in each population (NMFS 2014). The most recent annual population trends indicate pending extinction, and that past management efforts have not been sufficient to protect them from extinction. Climate change models show an increased need for large-scale management, with predicted increases in average air temperatures and more variable precipitation patterns expected by 2100. Lindley et al. (2007) found that at a minimum, California water temperatures are expected to increase 2°C by 2100, but perhaps as high as 8°C, which would remove all currently available thermal refuges for CVS Chinook in California. The largest independent run, in Butte Creek, already faces near-lethal temperatures in summer and has a high probability of being extirpated in the not-too-distant future from climate change effects alone (Thompson et al. 2012). These factors all need to be taken into account when managing CVS Chinook salmon.

Our management recommendations fall into three distinct categories: self-sustaining populations, hatchery-supported populations, and restored populations. Most of this account focuses on self-sustaining populations because the population supported by the Feather River Fish Hatchery is a hybrid stock genetically close to CV fall-run Chinook. However, a substantial part of this population does maintain the spring-run life history and so is worth continuing to manage for that life history, especially if the hatchery contribution can be effectively managed to reduce influence on selection, survival and behavior. Restored populations are works in progress, with recent work on the San Joaquin River, Clear and Battle creeks, the Yuba River, and the McCloud River.

Self-sustaining populations. The most important actions for preventing extinction of CVS Chinook salmon lie in protecting/enhancing coldwater habitat in Butte creek and restoring

unimpaired flows in the lower reaches due to diversions in Deer and Mill creeks. The fact that self-sustaining populations of CVS Chinook salmon have managed to persist in Mill and Deer creek is mostly a matter of luck: the streams were too small for economically feasible dams yet supplied cool water year round due to mainly to their geology and geography. The present limited current distribution of the 'independent' CVS Chinook makes them vulnerable to localized stochastic events (fire, volcanic eruption, etc.) in which the entire run may be jeopardized by a single incident. Fortunately, all three watersheds are the focus both of large-scale restoration projects (e.g. Deer Creek Meadows) and citizen groups that want to protect the fish and their streams.

Seizing an opportunity to protect an important source of diversity in Chinook life histories in the Central Valley, agencies and landowners in the Central Valley, in coordination with the Deer Creek and Mill Creek conservancies and Friends of Butte Creek, began protecting CVS Chinook salmon. For Deer and Mill Creeks, cooperative agreements among ranchers, lumber companies, agencies, and other partners to do business in a fish-friendly manner, while public agencies similarly managed their own lands and waters. The most important immediate actions involve reducing diversions and modernizing fish passage facilities on Mill, Deer and Antelope creeks to increase flows for adult and juvenile fish passage through water acquisition, conjunctive use of wells, and water use efficiency plans and improvements (NMFS 2016). In 2014 and 2015, NMFS and CDFW developed a Voluntary Drought Initiative program (NMFS 2017) to provide minimum flow protection in lower Deer and Mill Creeks. Where voluntary cooperation by diverters was not obtained, the California State Water Resources Control Board (SWRCB) provided a "back-stop" for flow protection by the adoption of emergency regulations (M. Johnson, CDFW, pers. comm. 2017). Similar Voluntary Drought Initiative cooperation or SWRCB flow regulation should be permanently secured for Mill, Deer, and Butte Creeks. Johnson (2016) lists other recommendations to benefit spring-run in these watersheds.

On Butte Creek, Pacific Gas and Electric (PG&E) has indicated (February 2017) that they will no longer operate their hydroelectric project or be responsible for implementing flows beneficial to CVS Chinook starting in about a decade. What impact this forfeiture of the operating license for the hydroelectric project and water operations will have on the state of Butte Creek and plight of CVS Chinook there remains to be seen. This may provide an opportunity for developing new approaches to protecting Butte Creek fish from predicted extirpation from climate change effects (Thompson et al. 2012).

Hatchery-supported populations. FRFH salmon express the spring-run life history, but are of a mixed genetic background. Many of these fish wind up spawning in the Feather River below the hatchery and contributing to returning salmon numbers, although there is only one population. In the hatchery itself, a genetic management program should be aimed at reducing domestication trends and to enhancing the spring-run life history, while hatchery operations should be focused on minimizing the potential for fall-run and spring-run fish to interbreed.

Restoration: Battle Creek. Restoration in many watersheds, such as Battle Creek, have begun to improve the spatial structure of the ESU overall and provide some hope of recovery (NMFS 2016). We therefore encourage the full implementation of a project on Battle Creek to turn it back into a major CVS Chinook stream. In 1999, 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. Under this arrangement, nearly 80km of habitat will be opened up for salmon spawning and rearing. The Battle Creek Salmon and Steelhead Restoration Project will remove dams, install

fish screens, and end the diversion of water from the North Fork to the South Fork specifically to benefit listed salmon runs (NMFS 2016), with full implementation expected by 2020.

Restoration: San Joaquin River. Restoration of the San Joaquin River to support CVS Chinook salmon is a heroic effort that should continue, given that the river was illegally dried up when it still supported a substantial run of CVS Chinook salmon. In 1948, virtually all water behind Friant Dam on the San Joaquin River was sent down the Friant-Kern and Madera canals to support agricultural uses, with a small release for riparian landowners immediately below the dam. CDFG officials attempted to rescue the 1948 run by trucking some 1,915 CVS Chinook around the dry stretch to the tailwaters at the base of Friant Dam. There the fish successfully over-summered and spawned, but the outmigrating smolts were stranded in the dry river downstream; in just a few years thereafter, the run was extirpated, as was the companion run in the Kings River (Moyle 2002).

In 2006, a settlement agreement was reached for the San Joaquin River, known as the San Joaquin River Restoration Program, to provide minimum instream flows to create a permanent flow of water all year round, plus additional water for migration, spawning, and rearing of an experimental population of CVS Chinook salmon. Among the project goals are extensive habitat restoration to riparian and instream habitats, necessary after 50+ years of complete neglect and abuse of the channel. Restoring continuous flows to the approximately 240km of often dry and heavily altered river channel will take place in a series of phases.

Toward that end, interim and experimental flows started in 2009 with the goal of establishing a self-sustaining population of CVS Chinook by 2025. Restoration flows designed to restore connectivity from Friant Dam to the Merced River began in January 2014; the first release of CVS Chinook salmon from the Feather River Fish Hatchery into the San Joaquin River occurred shortly thereafter in April, 2014. A second release occurred in 2015, and future releases are planned to continue annually in the spring. A conservation hatchery and captive broodstock program was initiated in 2012 to support the reintroduction with limited impact on source populations by utilizing excess broodstock from FRFH. The 2016 release included the first generation of CVS Chinook salmon reared entirely in the San Joaquin River in over 60 years (NMFS 2016). Such watershed-scale reconciliation and restoration actions are essential for keeping CVS Chinook from going extinct in the next 50 years. Barrier removal or some kind of trap and haul operation will also likely be a major part of CVS Chinook conservation in the near future, until more permanent solutions to restore passage to historical habitat can be found.

General recommendations. Dam and water conveyance operations throughout the salmonid migration corridor from rim dams to the valley floor and ocean must be re-thought and adjusted to help recover CVS Chinook and avoid local extirpations in the short-term. Instream flows must be restored to mimic natural hydrographs to the extent practicable on the Sacramento River and its tributaries. Additional cold water must be secured where practicable through shifts in land use practices and management, in cooperation with private and public entities, to help bolster populations in places such as Antelope, Clear, Deer, and Mill creeks (NMFS 2016). Oroville dam and related operations must be evaluated in the context of long-term salmonid persistence in the Central Valley. Fish passage improvements in all CVS Chinook watersheds should also be prioritized to foster increases in spawning success and abundance.

In February 2017, an unprecedented rainfall event caused catastrophic failure of the spillway at Oroville Dam, just upstream from the FRFH. About 200,000 people were evacuated from downstream cities including Oroville, Yuba City, and Marysville. Meanwhile, 6.5 million fall- and spring-run Chinook at FRFH were put into trucks and transported to the hatchery annex

near Thermalito Afterbay, several kilometers downstream (CDFW 2014b). The mobilization of large amounts of water, sediment, and large concrete structures associated with the ruptured spillway likely removed spawning and rearing habitat immediately downstream of the dam, but the effects of this event on CVS Chinook in the Feather River will not be known for years.

Third, floodplain management must be altered to restore ecologically based flows in the Sacramento River to allow breaching and volitional immigration and emigration of juvenile salmonids to floodplains such as Sutter and Yolo bypasses to help increase survival of smolts. At the same time, NMFS (2014) noted the need to explore alternative water operations and conveyance systems in the Delta to improve prospects for all Central Valley salmonids, including allowing more water to flow downstream to the Delta to enhance water quality and provide more suitable migration and rearing habitat that favors native fishes. Such a task will require an enormous investment of resources and novel ways of thinking to attempt to restore more natural hydrology and ecosystem function of the Delta. Such improvements will be essential to leveling the playing field for native fishes in the heavily altered Delta and San Francisco Estuary. Ongoing salt marsh restoration throughout Suisun, San Pablo, and Grizzly could be most effective only with concurrent changes to water operations and management of the Delta. Multi-benefit projects that benefit wildlife and water users and other stakeholders that leverage incentives for participation should be expanded where possible to help build momentum and scale up successful projects to region-wide initiatives. Many of these recommendations come directly out of the NMFS (2009) Biological Opinion on the continued operations of the state and federal pumping facilities in the Delta.

In addition to the specific restoration and reconciliation work occurring across the ESU, there is an important need for continued monitoring of watershed conditions and populations to gauge progress toward recovery of CVS Chinook. Drought impacts are likely to drive remaining populations again into the high extinction risk categories between 2015-2018, reinforcing the need to document changes that could impact viability and persistence of populations.

In addition to the actions discussed above, the NMFS (2014) Recovery Plan for Central Valley winter and CVS Chinook and steelhead identifies more specific actions that can be taken in the short term to benefit CVS Chinook:

1) Augmenting spawning gravel on Clear Creek
2) Enhancing riparian habitat and spawning gravel on the Yuba River
3) Restoring access to high elevation habitat in the Yuba River upstream of New Bullards Bar Dam and in the Sacramento River upstream of Shasta Dam
4) Reducing harvest of CVS Chinook in ocean salmon fisheries
5) Implementing temperature reduction at the DeSabla Forebay (Butte Creek)
6) Modernizing fish passage facilities at Weir 1 in the Sutter Bypass;
7) Finalizing and implementing the Hatchery and Genetics Management Plan for the FRFH to reduce interaction between hatchery and wild fish
8) Providing passage at Sunset Pumps weir (Feather River)
9) Implement fish passage improvements at Stanford Vina Irrigation Company and Deer Creek Irrigation District dams on Deer Creek and Upper Dam on Mill Creek
10) Increase instream flows between March 1 and July 15 to protect migrating spring-run Chinook salmon.

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