Appendix 11A
Covered Fish Species Descriptions

"Covered Species" identified in the Bay Delta Conservation Plan (BDCP) are those that are Endangered or Threatened and whose conservation and management will be provided by the BDCP, as follows:

- Delta Smelt
- Longfin Smelt
- Sacramento River Winter-Run Chinook Salmon
- Central Valley Spring-Run Chinook Salmon
- Central Valley Fall- and Late Fall-Run Chinook Salmon
- Central Valley Steelhead
- Sacramento Splittail
- Green Sturgeon
- White Sturgeon
- Pacific Lamprey
- River Lamprey

The geographic distribution and timing of lifestages of the Covered Species within the San Francisco Bay-Delta Watershed are summarized in Table 11A-1.

11A.1 Delta Smelt (*Hypomesus transpacificus*)

11A.1.1 General

Delta smelt are a small, translucent fish endemic to the Sacramento–San Joaquin River Delta (Delta) (Moyle 2002). They inhabit open surface waters of the Plan Area, where they form loose aggregations. Their life history has been described as semi anadromous by Bennett (2005), reflecting a cycle of spawning in freshwater areas generally followed by juvenile migration to shallow, open-water areas of the West Delta and Suisun Bay subregions to feed and mature. More recent analyses suggest that year-round populations of delta smelt may exist in central locations (Lower Sacramento River to Suisun Marsh and in the Cache Slough and Deep Water Ship Channel regions) suggesting that they are not 100% obligatorily semi-anadromous or migratory, but may show several life history strategies (Merz et al. 2011; Baxter et al. 2010; Murphy et al. 2013). Delta smelt populations have shown a long-term decline in the upper estuary (the Delta and Suisun Bay), although the Fall Mid-Water Trawl index has fluctuated greatly from year to year, with change points detected in 1975–76, 1980–81 and 1998–99 by Manly and Chotkowski (2006). Using a different analytical method, a trend change was identified in 2000–2002, and a step decline in 2004 (Thomson et al. 2010).There has been extremely low abundance in recent years as part of the pelagic organism decline (POD) (Sommer et al. 2007; Baxter et al. 2010).

The low abundance of delta smelt since the early 1980s is hypothesized to relate to a number of interacting factors. These factors include larval advection during high flows in the winter and spring of 1982 and 1983 (Kimmerer 2002a); the prolonged drought from 1987 to 1992 (Baxter et al. 2010); entrainment in water diversions (although a small effect at population level) (Kimmerer 2008); increases in salinity, water clarity, and temperature constricting habitat for juveniles (Nobriga et al. 2008) and maturing individuals (Feyrer et al. 2007;Thomson et al. 2010); predation and competition from introduced species (Bennett 2005); a decline in food resources (Maunder and Deriso 2011, Miller et al. 2012); and changes in the foodweb due to changes in nutrients (Glibert et al. 2011; Dugdale et al. 2012; Parker et al. 2012a; Parker et al. 2012b). In its most recent review of the factors potentially threatening the delta smelt, the U.S. Fish and Wildlife Service (USFWS) determined that operation of upstream reservoirs, increased water exports, and upstream water diversions has altered the location and extent of the low-salinity zone. Upstream reservoirs and the increased presence of *Egeria densa* have reduced turbidity levels in rearing habitat, which may reduce foraging efficiency. Predation, deficiency of current regulatory processes, entrainment into water diversions, the presence of nonnative plant and animal species, contaminants, and the potential for effects related to small population size all are likely having an effect on the abundance of the delta smelt. The delta smelt is also highly vulnerable to climate change (Brown et al. 2013).

11A.1.2 Legal Status

The U.S. Fish and Wildlife Service (USFWS) determined that delta smelt warranted listing as a threatened species under the federal Endangered Species Act (ESA) effective April 5, 1993. The listing decision was based on a substantial reduction in delta smelt abundance within the Bay-Delta estuary in a variety of fishery sampling programs, threats to its habitat, and the inadequacy of regulatory mechanisms to protect delta smelt (58 *Federal Register* [FR] 12863). The delta smelt was listed as a threatened species under the California Endangered Species Act (CESA) on December 9, 1993. The *Sacramento-San Joaquin Delta Native Fishes Recovery Plan*, which includes delta smelt, was completed in 1996 (U.S. Fish and Wildlife Service 1996).

In response to several law suits, USFWS conducted a 5-year status review for delta smelt and, on March 31, 2004, concluded that delta smelt abundance remained relatively low compared to historical levels and that many of the threats to the species identified at the time of listing were still in existence, precluding delisting of the species (U.S. Fish and Wildlife Service 2004). Subsequent indices of delta smelt abundance based on results of California Department of Fish and Wildlife (CDFW) fishery sampling have shown that the abundance of delta smelt and other POD species has declined substantially in recent years, reaching record low levels of abundance.

In March 2006, the Center for Biological Diversity, the Bay Institute, and the Natural Resources Defense Council filed an emergency petition with USFWS requesting delta smelt be reclassified from threatened to endangered under the ESA (Center for Biological Diversity et al. 2006). Emergency status was not accorded the petition by USFWS. However, on July 10, 2008, USFWS announced in a 90-day finding that consideration for reclassification of delta smelt was warranted and, after an information collection stage, a status review would be initiated (73 FR 39639). On April 7, 2010, USFWS ruled that the change in status from threatened to endangered was warranted, but precluded by other higher priority listing actions (75 FR 17667).

An emergency petition was filed in February 2007 to the California Fish and Game Commission to elevate the status of delta smelt from threatened to endangered under CESA (The Bay Institute et al. 2007). On March 4, 2009, the California Fish and Game Commission elevated the status of delta smelt to endangered under CESA.

Critical habitat was designated by USFWS for the delta smelt under the ESA effective January 18, 1995 (59 FR 65256). The designated critical habitat extends throughout Suisun Bay (including Grizzly and Honker Bays), the length of Goodyear, Suisun, Cutoff, First Mallard (Spring Branch) and Montezuma Sloughs, and the contiguous waters of the legal Delta (59 FR 65256). Designation of critical habitat for delta smelt was intended to provide additional protection under Section 7 of the ESA with regard to activities that require federal agency action.

11A.1.3 Distribution and Abundance

The geographic distribution of delta smelt occurs primarily downstream of Isleton on the Sacramento River, in the Cache Slough subregion (Cache Slough-Liberty Island and the Deep Water Ship Channel), downstream of Mossdale on the San Joaquin River, and Suisun Bay and Suisun Marsh (Moyle 2002; Kimmerer 2004) (Figure 2A.1-1). Delta smelt also have been collected in the Petaluma and Napa Rivers (Bennett 2005). A delta smelt was caught just below Knights Landing on the Sacramento River, representing the highest known point of the distribution (Vincik and Julienne 2012). Over the last two decades, the center of the adult delta smelt abundance in the fall (September through December) has been the West Delta and Suisun Bay subregions (Sommer et al. 2011). There is evidence that delta smelt may remain in the Cache Slough subregion throughout their lives (Nobriga et al. 2008; Sommer et al. 2011; Lehman et al., possibly because turbidity and prey abundance are sufficient to support them (Sommer et al. 2004; Lehman et al. 2010). Merz et al. (2011) examined the recent (1995 to 2009) frequency of occurrence of delta smelt in various surveys in the species' range, including the Plan Area. They found that larval delta smelt (less than 15 millimeters) were most frequently found in the West Delta subregion (confluence of the Sacramento/San Joaquin Rivers and the lower San Joaquin River) and the Suisun Marsh subregion. Subjuveniles (15 to 30 millimeters) were most commonly found in the Cache Slough subregion, West Delta subregion (confluence and lower Sacramento River), and Suisun Marsh and Suisun Bay subregions. Juveniles (30 to 55 millimeters) were most frequently found in the Suisun Bay, Cache Slough, and West Delta subregions. Subadults (larger than 55 millimeters) were most commonly found in the West Delta and Suisun Bay subregions. Mature adults had their highest frequency of occurrence in the Suisun Bay subregion, whereas prespawning adults were most frequently collected in the Suisun Marsh, West Delta, and Suisun Bay subregions. Adults in spawning condition were most frequently sampled in the Suisun Marsh and Cache Slough subregions.

Although an unbiased estimate of the abundance of delta smelt is not presently available, indices of relative abundance have been developed using catch data from surveys conducted by the Interagency Ecological Program. Several of the program's surveys provide annual delta smelt abundance information, including the Spring Kodiak Trawl, the larva survey, the 20-millimeter survey, the Summer Townet Survey, and the Fall Midwater Trawl. Relative abundance information can also be obtained from count data on delta smelt entrained into the federal and state water export facilities. The Fall Midwater Trawl provides the best available long-term index of the relative abundance of delta smelt (Moyle et al. 1992; Sweetnam 1999). The indices derived from the Fall Midwater Trawl closely mirror trends in catch per unit effort (Kimmerer and Nobriga 2005), but do not, at present, support statistically reliable population abundance estimates, though substantial progress has recently been made (Newman 2008). Fall Midwater Trawl -derived data are generally accepted as providing a reasonable basis for detecting and roughly scaling interannual trends in delta smelt abundance. The Fall Midwater Trawl -derived indices have ranged from a low of 17 in 2009 to 1,673 in 1970. For comparison, Summer Townet Survey -derived indices have ranged from a low of 0.3 in 2005 and 2009 to a high of 62.5 in 1978. Although the peak high and low values have occurred in different years, the Fall Midwater Trawl and Summer Townet Survey indices show a similar pattern of delta smelt relative abundance that is higher prior to the mid-1980s and very low in the past decade. Smelt abundance is indexed from surveys at different locations and times that sample various life-history stages of delta smelt (Table 2A.1-1). Multiple permanent sites sampled by CDFW and USFWS using many different collection methods intended to sample various life history stages of delta smelt provide a basis for examining trends in abundance of delta smelt under different hydrologic conditions, as well as the temporal and geographic distribution of the species within and among years (Table 2A.1-2, Figure 2A.1-2, Figure 2A.1-3).

The surveys vary considerably in sampling methodology, life stage collected, spatiotemporal coverage, and methods used to expand sample data (Bennett 2005). Regardless, all sampling methods consistently have shown that the abundance of delta smelt inhabiting the Bay-Delta system has declined since the 1980s (Figure 2A.1-2). The observed decline in delta smelt abundance is consistent with declines of other pelagic species in the Delta (Sommer et al. 2007; Baxter et al. 2010). Indices of delta smelt abundance in the fall, as reflected in CDFW fall midwater trawl surveys, were the lowest on record in 2006 (Figure 2A.1-2). It should be noted that the CDFW Fall Midwater Trawl survey seems to catch fewer smelt than other methods like the Spring Kodiak Trawl. Significantly more delta smelt have been recorded in a sampling area on the flood tide as opposed to the ebb tide (Feyrer pers. comm.). Because the Fall Midwater Trawl does not take into account the tidal exchange when sampling, it may be under-reporting actual catch due to delta smelt movement out of channel sampling sites during the ebb tide.

Designated critical habitat is displayed in Figure 2A.1-4.

Table 2A.1-1. Average Annual Frequency of Delta Smelt Occurrence by Life Stage, Interagency Ecological Program Monitoring Program, and Region, with BDCP Subregion in Brackets

Region [BDCP Subregion]	**Average Annual Frequency (%)**										
Life Stage:	**Larvae (<15 mm)**	**Sub-Juvenile (≥15, <30 mm)**		**Juvenile (30–55 mm)**			**Sub-Adult (>55 mm)**	**Mature Adults (>55 mm)**		**Pre-Spawning[a]**	**Spawning[a]**
Monitoring Program:	20-mm	20m-mm	STN	20m-mm	STN	FMWT	FMWT	BS	BMWT	KT	KT
Years of Data Used:	1995–2009	1995–2009	1995–2009	1995–2009	1995–2009	1995–2009	1995–2009	1995–2009	1995–2006	2002–2009	2002–2009
Time Period:	Apr–Jun	Apr–Jul	Jun–Aug	May–Jul	Jun–Aug	Sep–Dec	Sep–Dec	Dec–May	Jan–May	Jan–Apr	Jan–May
San Francisco Bay	NS	NS	NS	NS	NS	NS	NS	0.0	0.0	NS	NS
West San Pablo Bay	NS	NS	NS	NS	NS	0.2	0.0	0.0	1.2	NS	NS
East San Pablo Bay	0.0	1.0	0.0	2.8	3.6	0.7	0.6	NS	2.7	NS	NS
Lower Napa River	7.3	7.7	3.3	13.3	14.0	1.7	0.8	NS	NS	14.3	11.8
Upper Napa River	11.6	21.2	NS	12.0	NS	NS	NS	NS	NS	NS	NS
Carquinez Strait	5.7	9.3	1.1	24.4	33.7	1.9	3.3	NS	5.4	16.7	0.0
Suisun Bay (SW) [Suisun Bay]	17.8	18.3	1.3	17.5	26.9	4.3	4.3	NS	4.3	23.3	5.6
Suisun Bay (NW) [Suisun Bay]	2.2	8.9	1.1	21.7	34.8	7.3	10.0	NS	8.7	23.3	5.6
Suisun Bay (SE) [Suisun Bay]	19.5	24.9	11.0	20.9	45.7	11.0	12.1	NS	6.5	28.3	6.9
Suisun Bay (NE) [Suisun Bay]	17.8	19.2	33.6	29.7	66.7	20.3	29.3	NS	28.3	48.3	13.9
Grizzly Bay [Suisun Bay]	16.3	27.6	17.9	42.9	72.8	15.0	19.6	NS	30.4	30.0	5.6
Suisun Marsh [Suisun Marsh]	21.4	33.6	14.2	18.5	19.2	22.8	27.2	NS	NS	62.0	23.1
Confluence [West Delta]	35.7	41.6	25.7	29.2	36.1	20.2	24.5	1.8	17.4	30.0	10.4
Lower Sacramento River [West Delta]	16.5	37.0	43.3	26.2	55.5	22.9	37.1	NS	18.8	54.4	17.8
Upper Sacramento River [North Delta]	10.8	8.2	1.3	0.0	0.0	2.7	8.0	5.8	16.7	21.7	15.3
Cache Slough and Ship Channel [Cache Slough]	17.2	47.3	NS	54.3	NS	9.8	26.7	NS	NS	33.9	21.1

Region [BDCP Subregion]	**Average Annual Frequency (%)**										
Life Stage:	**Larvae (<15 mm)**	**Sub-Juvenile (≥15, <30 mm)**		**Juvenile (30–55 mm)**			**Sub-Adult (>55 mm)**	**Mature Adults (>55 mm)**		**Pre-Spawning[a]**	**Spawning[a]**
Monitoring Program:	20-mm	20m-mm	STN	20m-mm	STN	FMWT	FMWT	BS	BMWT	KT	KT
Years of Data Used:	1995–2009	1995–2009	1995–2009	1995–2009	1995–2009	1995–2009	1995–2009	1995–2009	1995–2006	2002–2009	2002–2009
Time Period:	Apr–Jun	Apr–Jul	Jun–Aug	May–Jul	Jun–Aug	Sep–Dec	Sep–Dec	Dec–May	Jan–May	Jan–Apr	Jan–May
Lower San Joaquin River [West Delta]	28.0	24.5	4.1	5.1	5.6	2.6	3.5	0.9	12.6	30.6	9.7
East Delta [East Delta]	14.6	8.8	0.0	1.2	0.0	0.0	0.0	1.6	NS	5.7	2.3
South Delta [South Delta]	18.4	10.8	0.0	1.4	0.3	0.0	0.0	0.3	NS	7.1	1.1
Upper San Joaquin River [South Delta]	NS	NS	NS	NS	NS	NS	NS	0.2	NS	NS	NS
Sacramento Valley [Sacramento River: North Delta to RM 143]	NS	NS	NS	NS	NS	NS	NS	0.2	NS	NS	NS

Source: Merz et al. 2011.

20-mm = 20-millimeter Townet.
BMWT = Bay Midwater Trawl.
BS = Beach Seine.
FMWT = Fall Midwater Trawl.
KT = Kodiak Trawl.
NS = indicates no survey conducted in the given life stage and region.
SKT = Spring Kodiak Trawl.
STM = Summer Tow-Net.

[a] Gonadal stages of male and female delta smelt found in Spring Kodiak Trawl database were classified by California Department of Fish and Wildlife following Mager (1996). Descriptions of these reproduction stages are available at: <http://www.dfg.ca.gov/delta/data/skt/eggstages.asp>.
Mature adults, pre-spawning: Reproductive stages[a]: females 1–3; males 1–4.
Mature adults: spawning: Reproductive stages[a]: females 4; males 5.

Table 2A.1-2. Sampling Methods Used to Index the Abundance of Delta Smelt

Sampling Program	Sampling Period	Life-Stage Focus	Target Species
Summer Townet Survey	July–August	Juveniles	Striped bass juveniles
Fall Midwater Trawl	September–December	Preadults	Striped bass juveniles
20 millimeter Townet	March–June	Larvae–juveniles	Delta smelt larvae
Kodiak Trawl	January–May	Juvenile–adult	Delta smelt pre-spawning adults

11A.1.4 Life Stages

The life cycle of delta smelt has been reviewed by Moyle et al. (1992), Moyle (2002), and Bennett (2005) and summarized by Nobriga and Herbold (2009). The life cycle generally spans a single year that ends with spawning in the early spring, although a small proportion of the population survives to spawn a second time.

Bennett (2005) describes seven life stages of delta smelt. These seven life stages were reduced to four in Nobriga and Herbold (2009). For purposes of the BDCP analysis, a fifth life stage, spawners, has been added to those of the Nobriga and Herbold (2009) scheme. *Spawners* was added to recognize that adults include adult delta smelt in nearshore spawning areas (spawners) as well as adults in open water (feeding adults, which may be staging prior to spawning). Table 2A.1-3 compares the delta smelt life stages of Bennett (2005) and Nobriga and Herbold (2009).

Table 2A.1-3. Delta Smelt Life Stages

Bennett 2005	Nobriga and Herbold 2009	BDCP
Eggs	Eggs	Eggs
Yolk-sac larvae	Eggs	Eggs
Feeding larvae	Larvae	Larvae
Post larvae	Larvae	Larvae
Juveniles	Juveniles	Juveniles
Adults	Adults	Feeding adults
Maturity	Adults	Spawners

Distribution of delta smelt life stages appears to be based largely on salinity and temperature (Bennett 2005). Larvae, in particular, distribute themselves in relation to the two-parts-per-thousand (2ppt) salinity isohaline, usually about 10 km upstream of it (Dege and Brown 2004). The Summer Tow-Net Survey and the Fall Midwater Trawl survey indicate that over 70% of juveniles and 60% of preadults are collected at salinities less than 2 practical salinity units (psu), with over 90% occurring at salinities less than 7 psu (Bennett 2005). Abundance is centered near or slightly upstream of 2 psu in the entrapment or low-salinity zone (LSZ) (Dege and Brown 2004). Water temperatures above 25°C are above delta smelt tolerance and can constrain available habitat especially in late summer and fall (Swanson et al. 2000). The LSZ, or the entrapment zone, is an area just seaward of the extent of salinity intrusion and is an area of high retention of fishes and zooplankton. It is determined by the interaction of Delta outflow and tidal inflow of marine water from San Francisco and San Pablo Bays. The downstream location of the LSZ typically is in Suisun Bay, extending farther to the west in response to higher Delta outflows and farther to the east in response to lower Delta outflows. Delta smelt have been collected in Carquinez Strait, the Napa River, and even as far downstream as the East Bay Shoreline in wet years (Bennett 2005; Merz et al. 2011). Smaller larvae and spawning activity are distributed away from the LSZ, while prespawning adults and juveniles are distributed along the edge of the LSZ, as indicated by the position of X2 (i.e., the location of the 2-psu bottom salinity isohaline; Jassby et al. 1995). Juvenile delta smelt are most abundant at the upstream edge of the LSZ where salinity is less than 3 psu, water transparency is low (Secchi disk depth less than 0.5 meter), and water temperatures are cool (less than 24°C) (Feyrer et al. 2007; Nobriga et al. 2008). The association with the LSZ may be related to distribution of food as well as abiotic factors such as salinity.

Migrating, staging, and spawning delta smelt reportedly require low-salinity and freshwater habitats, turbidity, and water temperatures less than 20°C (68°F) (Sommer et al. 2011; Grimaldo et al. 2009). Subadult and adult delta smelt densities are positively correlated with turbidity (Feyrer et al. 2007; Nobriga et al. 2008). Several hypotheses have been suggested for the observed positive correlation with turbidity.

- Greater feeding ability because of the contrast of prey against a more visible background.
- A lower risk of predation.

Turbidity has declined in the Delta in the past few decades in part due to trapping of sediment in reservoirs and depletion of the erodible sediment pool from hydraulic mining in the late 1800s, and to increases of submerged aquatic vegetation that traps sediment (Wright and Shoellhamer 2004; Shoellhamer 2011; Hestir et al. 2008). Declining turbidity has been hypothesized as one factor in the long-term decline of delta smelt (Baxter et al. 2010).

11A.1.5 Life History

Sommer et al. 2011 suggest that, from December to March, mature delta smelt move upstream from brackish rearing areas in and around Suisun Bay and the confluence of the Sacramento and San Joaquin Rivers). Murphy et al. (2013) propose that the observed change in distribution is an expansion of smelt distribution using fresher waters throughout their range. The initiation of migration is associated with pulses of freshwater inflow, which are turbid, cool, and less saline (Grimaldo et al. 2009). Spawning has not been observed in the wild; timing and locations may be inferred from the collection of gravid females and larvae. Preferred substrates have been inferred from laboratory observations and other smelt species. From collection of larval smelt, it appears that delta smelt spawn from February to June at water temperatures ranging from approximately 10°C to 20°C, with most spawning in mid-April and May (California Department of Fish and Game 2007; Bennett 2005; Moyle 2002). Recent (2002 to 2009) sampling data showed that individuals in spawning condition were collected in the Suisun Marsh and Cache Slough subregions, and were also collected in upper portions of the West Delta subregion and lower portion of the North Delta subregion (Table 1 in Merz et al. 2011). Sampling of larval smelt in the Delta suggests spawning occurs in the Sacramento River; Barker, Lindsey, Cache, Georgiana, Prospect, Beaver, Hog, Miner, Steamboat and Sycamore Sloughs; in the San Joaquin River off Bradford Island, including Fisherman's Cut; False River along the shore zone between Frank's and Webb Tracts; and possibly other areas (Wang 1991). CDFW sampling has suggested that spawning is often centered in Cache Slough and the lower end of the Sacramento Deep Water Ship Channel (California Department of Fish and Game 2007). In winters with high Delta outflow, the spawning range of delta smelt extends west and includes the Napa River (Hobbs et al. 2005; 2007), as indicated an average of nearly 12% of Kodiak trawl samples containing spawning-condition delta smelt (Table 1 in Merz et al. 2011).

Mager (1996) reported a length/fecundity range spanning 1,196 eggs for a 56-millimeter female to 1,856 eggs for a 66-millimeter female. Captive-reared females may be more fecund than a wild female of the same size; however, the variability in the length-fecundity relationship also appears to be greater for captive females (Bennett 2005). The abrupt change from a single-age, adult cohort during spawning in spring to a population dominated by juveniles in summer suggests strongly that most adults die after they spawn (Radtke 1966; Moyle 2002).

Based on laboratory observations, it is thought that the adhesive, demersal eggs of delta smelt attach by means of a chorion stalk to hard substrates like sand or gravel that are washed by gentle currents adjacent to river channels (Moyle 2002). Spawning occurs mainly at night when females broadcast their eggs while swimming against the current. Eggs incubate from 8 to 15 days, depending on water temperature (Bennett 2005). Temperatures that are optimal for survival of embryos and larvae have not yet been determined, although survival of newly spawned larvae and older delta smelt appears to peak at temperatures about 16°C (Bennett 2005). Postlarval delta smelt of all sizes are found in the main channels of the Delta and Suisun Marsh and the open waters of Suisun Bay, where the waters are well-oxygenated and temperatures are relatively cool, usually lower than 20°C to 22°C (68°F to 72°F) in summer. Delta smelt tolerate a wide range of temperatures, from less than 6°C to approximately 25°C (Swanson et al. 2000). More than 90% of juvenile and preadult delta smelt caught in the CDFW Summer Townet Survey and Fall Midwater Trawl Survey were collected at water temperatures lower than 20°C (Bennett 2005).

Larvae emerge near where they are spawned, and mainly inhabit tidal fresh water at temperatures between 10°C to 20°C (Bennett 2005). The center of distribution (1995 to 2001) for delta smelt larvae less than 20 millimeters is usually 5 to 20 kilometers upstream of X2, but most larvae move closer to X2 as the spring progresses into summer (Dege and Brown 2004). Survival during the larval period is linked to the minimum density of zooplankton prey (Maunder and Deriso 2011; Miller et al. 2012). The effects of outflow are complex, affecting not only abundance, but also patterns of distribution, and possibly the timing of spawning events (Moyle 2002). The lowest numbers of smelt generally occur in years of either low or extremely high outflow, but outflow and smelt numbers show no relationship at intermediate flows where abundance is highly variable (Moyle 2002; Bennett 2005). Feeding success is highly dependent upon prey densities (Nobriga 2002) and turbidity (Baskerville-Bridges et al. 2004; Mager et al. 2004). Juveniles grow to 40 to 50 millimeters total length by early August (Erkkila et al. 1950; Ganssle 1966; Radtke 1966). Delta smelt reach 55 to 70 millimeters standard length in 7 to 9 months (Moyle 2002). Growth during the next 3 months slows down considerably (only 3 to 9 millimeters total), presumably because most of the energy ingested is directed toward gonadal development (Erkkila et al. 1950; Radtke 1966).

In a near-annual fish like delta smelt, maximizing recruitment success is vital to the long-term persistence of the population. There is some evidence that density-dependent (preferred food resources) and density-independent (turbidity, salinity and temperature) factors may affect the population (Bennett 2005; Maunder and Deriso 2011; Miller et al. 2012).

Figures 2A.1-5 and 2A.1-6 show the distribution of adult and larval/juvenile delta smelt in a typical above-normal water year.

11A.1.6 Threats and Stressors

Threats can be defined as conditions or events that change an organism's probability of survival. Stressors are conditions or events that change an organism's behavior or physiology. There are multiple threats and stressors to delta smelt that appear to act in complicated and synergistic ways to influence their distribution and abundance (Moyle 2002). Delta smelt are particularly vulnerable to these threats and stressors because of their short life span, low fecundity, low current abundance, and limited geographic range. Stressor rankings and the certainty associated with these rankings are provided in Chapter 5, *Effects Analysis,* of the BDCP. The discussion below outlines some of the main threats and stressors to delta smelt.

11A.1.6.1 Water Diversions

Despite the number of delta smelt that have been entrained by the State Water Project (SWP) and Central Valley Project (CVP) export facilities and over 2,200 smaller diversions in the Delta (Herren and Kawasaki 2001), the direct effects of water diversions on the overall population dynamics of delta smelt are not well understood and there is disagreement among experts about the magnitude of these effects (Bennett 2005; Kimmerer 2008; Kimmerer 2011; Miller 2011).

Entrainment risk for delta smelt has largely been based on analyses of SWP/ CVP fish salvage data and Delta hydrodynamics. At least one analysis seemed to suggest a correlation between SWP/ CVP exports and indices of delta smelt abundance, suggesting that entrainment may negatively affect delta smelt abundance (Kimmerer 2011). These relationships do not establish causality, but they are an indicator that entrainment as indexed by salvage is a contributing factor in delta smelt population dynamics. Kimmerer (2008) estimated that entrainment losses of adult delta smelt had a median value of 15% (range 1 to 50%) while seasonal losses for juvenile delta smelt had a median value of 13% (range of 0 to 25%). In response to criticism from Miller (2010), Kimmerer (2011) reexamined his analysis in 2008 and revised his adult delta smelt entrainment losses down by 24%. In his reexamination of juvenile numbers, Kimmerer concluded that Miller was mistaken about his conclusion of high bias and, if anything, his (Kimmerer 2008) estimates were probably biased low. Kimmerer (2008) concluded that the effect of these losses on population abundance of delta smelt was obscured by a 50-fold variation in the overall survival of delta smelt between summer and fall. Kimmerer (2011) also found that, even when entrainment loss appeared to be moderate, it could still be significant in terms of its effects on abundance in some years. Thomson et al. (2010) found that water clarity and the volume of winter water exports statistically significant predicators of the long-term abundance of delta smelt and other fish, but could not explain the recent record low levels of delta smelt. Mac Nally et al. (2010) found that winter and spring export volumes showed some evidence for a negative association with delta smelt abundance in the subsequent fall. Miller et al. (2012) found that combined winter/spring entrainment of adult and larval-juvenile delta smelt was included in the best-fitting equation describing survival from fall to summer, although they did not find entrainment to be one of the important predictors of survival from fall to fall.

The risk of entrainment to delta smelt varies seasonally and among years. The most important entrainment risk has been hypothesized to occur during winter, when prespawning adults migrate into the Delta in preparation for spawning (Moyle 2002; Sommer et al. 2007). Bennett (2005) has hypothesized that delta smelt that spawn earlier in the winter are more vulnerable to entrainment by the south Delta export facilities. Fish that hatch earlier can grow larger prior to spawning than fish that hatch later. Larger females may be more fecund, spawn repeatedly, and produce more offspring with higher fitness than smaller females. As a result, Bennett hypothesized that entrainment during winter months may have a disproportionately large impact on the overall population dynamics of delta smelt than entrainment during other periods of the year.

A 2007 federal court decision regarding interim operational restrictions on SWP/CVP exports (Wanger decision). The 2007 decision on the Occupational Criteria and Plan (OCAP) litigation centered on the District Court's finding that the biological opinion (BiOp) did not provide reasonable certainty that mitigation would occur, and was therefore inadequate to protect the species. The Interim Remedies and subsequent BiOp (2008) used the Old and Middle River relationship to both better assess the effects of SWP/CVP operations and to design a more effective means of addressing the impacts. (U.S. Fish and Wildlife Service 2008b.) The analyses indicated that delta smelt salvage remained relatively low when reverse flows in Old and Middle Rivers were below approximately -5,000 cubic feet per second (cfs), but salvage increased substantially as reverse flows increased above 5,000 cfs.

Several limitations of current fish salvage operations are recognized. First, the salvage facilities were designed primarily for salmonids; the overall facility efficiency of delta smelt salvage is relatively poor (Bowen et al 2004; Castillo et al 2012). Further, while it is assumed that salvage is proportional to entrainment, the relationship is likely to vary with both operations and fish densities. Another limitation of the salvage operation is due to the inherent difficulty of identifying larval fishes by species in real time, thus it only identifies and counts fish greater than 20 millimeters in length. As a result, smaller larval delta smelt are not included in fish salvage estimates. Until now, estimates of entrainment losses for larval delta smelt and estimates of population abundance have been based on extrapolations from results of the CDFW 20-millimeter delta smelt survey. However, those estimates have been criticized because some of the assumptions supporting the population and entrainment loss estimates have not been tested or validated. Recognizing that larval delta smelt are vulnerable to SWP/ CVP entrainment that may vary in magnitude and potential effect on the population among years, the federal district court ordered that a study be conducted beginning in 2008 to monitor the densities of larval delta smelt vulnerable to SWP/CVP entrainment to determine whether or not protective measures are needed for larvae.

Delta smelt are not believed to be threatened by small agriculture diversions. Nobriga and Matica (2000) and Nobriga et al. (2004) found low and inconsistent entrainment of juvenile delta smelt by small agricultural diversions near Sherman Island; the low entrainment rates were hypothesized to be the result of juvenile delta smelt occurring offshore of the intake location and in the upper portions of the water column. Cook and Buffaloe (1998) also reported that unscreened agricultural diversions entrained low numbers of delta smelt. Larvae may have higher entrainment losses than juveniles and adults because they are planktonic, with poor swimming ability.

Power plants located in the Plan Area at Pittsburg has the potential to entrain large numbers of fish, including delta smelt and other covered fish species, particularly because these species may be located near these facilities for much of the year (Matica and Sommer 2005). However, use of cooling water is currently low because of the retirement of older units. According to recent regulations, units at these two plants must be equipped with a closed cycle cooling system by 2017 that eliminates fish entrainment.

11A.1.6.2 Habitat Loss

11A.1.6.2.1 Reduced Spawning Habitat

Although delta smelt spawning has not been observed in the Bay-Delta, it is generally thought that spawning occurs in shallow, low-salinity areas with sand or gravel substrate on which to deposit adhesive egg sacs (Bennett 2005). The extent of these areas is dependent on the spatial distribution of fresh water in the estuary (Hobbs et al. 2005; 2007). Such habitat could occur in Cache Slough or in shallow shoals located in the Deep Water Ship Channel (Bennett 2007) and may be reduced because of land reclamation, channelization, and riprapping of historical intertidal and shallow subtidal wetlands. The extent to which such habitat loss may be limiting the population is unknown (Bennett 2005; Miller et al. 2012); however, spawning substrates are not thought to be a limiting factor for delta smelt.

11A.1.6.2.2 Reduced Rearing Habitat

There is evidence that the availability and suitability of delta smelt rearing habitat varies with salinity and the location of the LSZ (Moyle et al. 1992; Hobbs et al. 2006; Feyrer et al 2007; Kimmerer et al. 2009). The Suisun Marsh salinity control gates function to decrease salinity in managed wetlands of Suisun Marsh to support crops that attract waterfowl to duck clubs located throughout the marsh. When in operation, generally from October through May, the control gates near Collinsville divert up to 2,500 cubic feet per square inch (cfs) of fresh water from upstream flows into the marsh. Because the minimum outflow standard during fall months is 5,000 cfs, a significant proportion of total Delta outflow (up to 50%) does not flow through the eastern Suisun Bay region. This diversion moves the LSZ upstream resulting in a measurable increase in salinity in eastern Suisun Bay, which may correspond to a decrease in low salinity habitat for delta smelt. The LSZ also moves in response to gross hydrology (e.g., precipitation in the watershed) and SWP/CVP diversions. Outflow objectives in the State Water Resources Control Board Decision 1641 recognize the importance of the location of the LSZ, and are intended to protect beneficial uses for fish and wildlife. Recent assessments conducted by mandate of the Delta Reform Act indicate that current Delta flow criteria may not be sufficient to protect public trust resources (State Water Resources Control Board and California Environmental Protection Agency 2010). The BDCP delta smelt conceptual model includes a submodel for fall X2, as discussed in Chapter 5, *Effects Analysis*.

11A.1.6.3 Water Temperature

Delta smelt are members of the cold water fish family (Osmeridae) and it is adapted to cold to cool water temperatures like many other California fish species (Moyle 2002). Delta smelt are sensitive to exposure to elevated water temperatures, and high temperatures are known to reduce delta smelt survival (Swanson et al. 2000) and interfere with spawning (Bennett 2005). During the late spring, summer, and early fall months water temperatures in the central and southern regions of the Delta typically exceed 25°C (77°F), which has been found to be close to the incipient lethal temperature for delta smelt. During these warmer periods, results of fishery sampling have shown that delta smelt avoid inhabiting the central and south Delta and are typically located downstream in Suisun Bay and Suisun Marsh. Although water temperatures are cooler in Suisun Bay during the summer months, water temperatures in excess of 20°C (68°F) are typical in July (Nobriga et al. 2008). Under these warm summer conditions, delta smelt rearing in Suisun Bay and Suisun Marsh would be stressed by exposure to elevated water temperatures and would experience higher metabolic demands and a greater demand for food supplies to maintain individual health and a positive growth rate. Stresses experienced by rearing delta smelt during the warmer summer months, which include the synergistic effects of salinity and seasonally elevated water temperatures, have been hypothesized to be a potentially significant factor affecting delta smelt survival, abundance, and subsequent reproductive success in the Bay-Delta estuary (Baxter et al. 2010; Mac Nally et al. 2010; Miller et al. 2012).

Recent climate change analyses have examined the potential implications of climate warming for delta smelt (Wagner et al. 2011; Brown et al. 2013). Modeling results projected increases in the number of days with lethal and stressful water temperatures (especially along the Sacramento River) and a shift in thermal conditions for spawning to earlier in the year, upstream movement of the LSZ, and decreasing habitat suitability.

11A.1.6.4 Turbidity

Turbidity is a significant predictor of delta smelt occurrence in the Delta (Feyrer et al. 2007; Resources Agency 2007; Nobriga et al. 2008; Grimaldo et al. 2009). Delta smelt require turbidity for both successful foraging (Feyrer et al. 2007; Nobriga et al. 2008) and predator escape (Feyrer et al. 2007), and turbidity is an important cue for delta smelt spawning movements (Grimaldo et al. 2009). Thompson et al. (2010) found fall water clarity to be a significant covariate associated with changes in delta smelt abundance over time.

Turbidity levels have declined in the Bay-Delta estuary since the 1970s as a result of numerous factors (Kimmerer 2004):

- Upstream sediment inputs have declined because of a range of anthropogenic actions, including river bank protection, trapping of sediments by dams and reservoirs, levee construction that has reduced floodplain inundation and channel meanders, and changes in land use (Wright and Shoellhamer 2004; Shoellhamer 2011). Wright and Shoellhamer (2004) estimated that the yield of suspended sediments from the Sacramento River declined by approximately 50% from 1957 to 2001.
- There has been a dramatic increase over the past 20 years in the distribution and abundance of nonnative aquatic plant species, particularly Brazilian waterweed (*Egeria densa*) and water hyacinth (*Eichhornia crassipes*) (Nobriga et al. 2005; Brown and Michniuk 2007). Both species can reduce turbidity by reducing local water velocities and trapping fine suspended sediments (Grimaldo and Hymanson 1999; Nestor et al. 2003; Hobbs et al. 2006).
- The high filtering efficiency of invasive clams has dramatically reduced phytoplankton and zooplankton abundance in the western Delta and Suisun Bay (Kimmerer and Orsi 1996; Jassby et al. 2002; Kimmerer 2002b, 2004). The reduction in phytoplankton in the water column may contribute to increased water clarity and reduced turbidity in the Delta.
- Hydraulic residence time in the Delta has declined because of increased channelization and the movement of water from the Sacramento River into the interior Delta channels to improve water quality and provide increased supplies to the SWP/CVP exports. Reduced hydraulic residence time reduces the ability of phytoplankton and bacteria to incorporate nutrients and carbon, ultimately reducing the abundance of these organisms in the water column, and increasing water clarity (Jassby et al. 2002; Kimmerer 2002a, 2004; Resources Agency 2007).
- The creation of large, shallow open water areas makes it likely that turbidity inside and near several of the restoration opportunity areas will increase seasonally due to wind-wave sediment

resuspension. There is evidence that declining wind speeds may be a factor in declining turbidity throughout the Plan Area (Fullerton pers. comm.). A dynamic suspended sediment model of the Plan Area would be required to take into account the many interacting factors that may influence water clarity and to reduce uncertainty regarding the potential effects of the BDCP on water clarity.

11A.1.6.5 Food Resources

Reduced food availability in the Bay-Delta estuary has been identified as a major stressor on delta smelt. Recent analyses by Maunder and Deriso (2011) and Miller et al. (2012) indicated that prey density was the most important environmental factor explaining variations in delta smelt abundance from 1972 to 2006 and over the recent period of decline. Delta smelt feed primarily on calanoid copepods, cladocerans, amphipods, and, to a lesser extent, on insect larvae (Moyle et al. 1992; Lott 1998; Nobriga 2002). Larger delta smelt may also feed on the mysid shrimp, *Neomysis* (Moyle et al. 1992). Mac Nally et al. (2010) found evidence for a relationship between summer calanoid copepod biomass and changes in delta smelt abundance. The most important food organism for all sizes of delta smelt appears to be the euryhaline copepod, *Eurytemora*, although the nonnative *Pseudodiaptomus* has become a major part of the diet since its introduction in 1988 (Kimmerer and Orsi 1996; Nobriga 2002; Hobbs et al. 2006). In recent years, heavy grazing by introduced clams has depleted phytoplankton standing stock, limiting food supplies for the zooplankton prey of delta smelt and other fish species. The overbite clam, *Potamocorbula amurensis*, found in brackish areas, has had a dramatic effect on food resources in the western Delta, Suisun Bay, and Suisun Marsh (Kimmerer and Orsi 1996), while the effect of the freshwater Asian clam, *Corbicula fluminea*, are mainly limited to freshwater flooded island areas (Lucas et al. 2002; Lopez et al. 2006). By filtering large quantities of phytoplankton from the water column and increasing water clarity, the clams may also reduce delta smelt foraging efficiency.

The following factors may contribute to the observed reductions in zooplankton prey densities.

- Historically, a significant reduction in tidal and shallow-water subtidal habitat caused a reduction in emergent vegetation, nutrient cycling, and the production of phytoplankton, zooplankton, macroinvertebrates, and other aquatic organisms that provide food resources for delta smelt. These changes were in place when delta smelt abundance was much higher than it is today.
- Historical loss of seasonally inundated floodplains reduces food exports. Upstream reservoirs and levees have reduced the seasonal inundation of floodplains in the Delta (Moyle et al. 2010). Floodplains are highly productive due to their shallow, warm, and low velocity water (Sommer et al. 2001a, 2001b; Harrell and Sommer 2003) and the input of organic material and nutrients from the terrestrial community (Booth et al. 2006). Floodplains provide benefits to the larger estuary by exporting food resources to downstream systems, providing increased production for pelagic species such as delta smelt (Schemel et al. 2004; Ahearn et al. 2006; Lehman et al. 2008).
- The historical loss of complex dendritic channel morphology and water operations has reduced hydraulic residence time, which reduces phytoplankton production (Jassby et al. 2002; Kimmerer 2002a, 2004; Resources Agency 2007).
- SWP/ CVP exports and the over 2,200 in-Delta agricultural diversions (Herren and Kawasaki 2001) exports has changed system energetics of a low productivity system by removing organic

material biomass including phytoplankton equivalent to 30% of the Delta's primary productivity (Jassby et al. 2002; Cloern and Jassby 2012).

- High concentrations of ammonia[1] from municipal wastewater treatment plants inhibit sdiatom production, reducing the food available for the zooplankton prey of delta smelt and other fish species (Wilkerson et al. 2006; Dugdale et al. 2007; Glibert 2010; Cloern et al. 2011; Glibert et al. 2011; Parker et al. 2012; Dugdale et al. 2012). Changes in nitrogen and phosphorus ratios and ammonia and nitrate ratios may have enhanced phytoplankton and zooplankton species that are less beneficial as food resources for delta smelt (Glibert et al. 2011). Nitrogen to phosphorus ratios may also affect several metabolic pathways in phytoplankton, including growth, cell membrane thickness, chemical makeup, toxin production, fecundity, and eventual outcome of the population (Mitra and Flynn 2005; Jeyasingh and Weider 2005, 2007). High concentrations of ammonia may also be directly toxic to organisms. Teh et al. (2011) found that total ammonium at levels commonly found in the Sacramento River significantly affects the recruitment of new adult copepods (*Pseudodiaptomus forbesis*) and the number of newborn nauplii surviving to 3 days.

11A.1.6.6 Contaminants and Exposure to Toxins

Exposure of delta smelt to toxic substances can result from point and nonpoint sources associated with agricultural, urban, and industrial land uses. Delta waters contain a wide variety and large volume of toxic substances, including agricultural pesticides, herbicides, endocrine disruptors, heavy metals, and other agricultural and urban products (Thompson et al. 2000; Brooks et al. 2012). There is some indication that the ammonia discharged from municipal wastewater treatment plants may contribute to localized toxicity in delta smelt, but results are highly variable (Werner et al. 2008). Toxics may affect delta smelt indirectly by reducing food resources (Luoma 2007; Werner 2007; Teh et al. 2011), but the short life span (1 to 2 years) and location of their food sources in the food web (zooplankton are primary consumers) reduce the ability of toxic chemicals to bioaccumulate in the tissue of delta smelt (Moyle 2002). Exposure to environmentally relevant pyrethroid concentrations resulted in significant swimming abnormalities in delta smelt. Kuivila and Moon (2004) found that the exposure to multiple pesticides for an extended period could pose potential lethal or sublethal effects on delta smelt, particularly during the larval development stage. This scenario occurred at the confluence of the Sacramento and San Joaquin Rivers with pesticide concentrations and fish densities coinciding for several weeks.

Exposure to copper contamination also results in significant sublethal effects on Delta fish species, with implications for their vulnerability to other stressors (Hetrick et al. 1979; Sandahl et al. 2006; Little and Finger 1990; Oros and Werner 2005). Dissolved copper causes acute toxicity to the calanoid copepod, *Eurytemora affinis*, in the north and south Delta (Teh et al. 2009). Additionally, negative synergistic effects have been documented such that the presence of copper in combination with ammonia is more toxic to aquatic organisms than either toxicant individually (Herbert and Vandyke 1964). Copper concentrations 32 times higher than background have been found in the Sacramento River delta smelt (Bennett et al. 2001)

The short life span and location of their food source in the food web (zooplankton are primary consumers) reduce the ability of toxic chemicals to bioaccumulate in the tissue of delta smelt (Moyle

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[1] Ammonia in water generally forms some amount of ammonium. Therefore, the use of the term *ammonia* implies that both ammonia and ammonium may be present.

2002). Their location in the water column may further reduce the probability of some toxic impacts by those chemicals that are sequestered quickly by sediments (e.g., pyrethroids). However, Weston and Lydy (2010) found sufficient concentration of the pyrethroid bifenthrin to cause water column toxicity in two urban creeks, over at least a 30-kilometer reach of the American River, and at one site in the San Joaquin River. It is unknown to what extent these effects were evident when these chemical levels were diluted in the much larger Sacramento and San Joaquin River systems. Additional research is needed to investigate the potential risk of exposure to toxic chemicals at concentrations and exposure durations typical of Bay-Delta conditions on various life stages of delta smelt. Brooks et al. (2012) presented a conceptual model of potential contaminant effects on delta smelt, including elements such as acute toxicity to larvae and juveniles, direct or indirect food limitation, impaired behavior and disease susceptibility, harmful algal blooms, migratory release of toxins from fat reserves, and temperature effects on toxic thresholds.

11A.1.6.7 Predation and Competition

The importance of predation on delta smelt relative to others is uncertain. Statistical analyses have shown some evidence for links between delta smelt abundance or survival and predation (Mac Nally et al. 2010; Maunder and Deriso 2011). Silversides may consume delta smelt eggs and larvae (Bennett 2005). In a pilot study, genetic testing found that 41% of 37 silversides caught in the channel of Cache Slough contained delta smelt DNA in their guts, while none of 614 silversides from nearshore areas contained delta smelt DNA (Baerwald et al. 2012). Silversides are highly abundant throughout the delta smelt geographic range, their diet range encompasses that of delta smelt, and because they spawn repeatedly throughout late spring, summer, and fall, they have a competitive advantage over delta smelt (Bennett 1998, 2005).

In an experiment where delta smelt were released into Clifton Court Forebay, recapture rates were very low due to prescreen losses attributed to increased residence time, which increased exposure to predators and other sources of potential mortality (Castillo et al. 2012).

Wakasagi can occur in the delta smelt geographic range and have similar life requirements. Wakasagi have a higher tolerance to salinity and temperature and a wider geographic range than delta smelt, suggesting that they have a competitive advantage over delta smelt. The two species are not closely related genetically and, although first generation hybrids have been collected, all of them have been sterile (Stanley et al. 1995; Trenham et al. 1998). However, if wakasagi abundance in delta smelt habitat were to increase dramatically, the risk of genetic introgression would be enhanced (Bennett 2005). The recent decline in delta smelt abundance has likely made the species vulnerable to inbreeding and genetic drift, leading to decreased genetic variation and reduced evolutionary fitness (Center for Biological Diversity et al. 2006). However, no estimates currently exist for the minimum viable population size of delta smelt, nor have studies been conducted to evaluate changes in genetic diversity.

11A.1.6.8 Invasive Aquatic Vegetation

Egeria and water hyacinth are fast-growing and abundant aquatic plants that have had detrimental effects on the Bay-Delta aquatic ecosystem, including competition with native vegetation and reducing dissolved oxygen concentrations and turbidity within their immediate vicinity (Grimaldo and Hymanson 1999; Brown and Michniuk 2007; Feyrer et al. 2007). These nonnative plant species grow in dense aggregations and can indirectly affect delta smelt by reducing dissolved oxygen levels and nearby flow rates, thus reducing suspended sediment concentrations and turbidity within the water column. Furthermore, because of the three-dimensional structure and shade they provide, these aquatic plants likely create excellent habitat for nonnative predators of delta smelt, primarily centrarchids (Nobriga et al. 2005). Mac Nally et al. (2010) found some evidence for a negative association between delta smelt abundance and the abundance of largemouth bass.

11A.1.7 Relevant Conservation Efforts

Pursuant to the CALFED objective of ecosystem restoration, the CALFED agencies developed the Ecosystem Restoration Plan and the Environmental Water Account for the purpose of restoring habitat and recovering at-risk populations like delta smelt in the Bay-Delta estuary (CALFED Bay-Delta Program 2000).

In January 2005, the Interagency Ecological Program established the POD work group to investigate the causes of the observed rapid decline in populations of pelagic organisms, including delta smelt, in the upper San Francisco Bay estuary (Armor et al. 2006, Baxter et al. 2008, 2010). The Resources Agency prepared the *Pelagic Fish Action Plan* in March 2007 to address POD (Resources Agency 2007). The action plan identifies 17 actions that are being implemented or that are under active evaluation to help stabilize the Delta ecosystem and improve conditions for pelagic fish.

The USFWS recovery strategy for delta smelt is contained in the *Sacramento-San Joaquin Delta Native Fishes Recovery Plan* (U.S. Fish and Wildlife Service 1996). The basic strategy for recovery is to manage the estuary in such a way that it provides better habitat for native fish in general and delta smelt in particular. Since 1996, new significant findings regarding the status and biology of and threats to delta smelt have emerged, prompting development of an updated recovery plan.

In 2007, the Federal District Court, Eastern District of California, Fresno Division (Judge Wanger) issued a court order for interim actions to protect delta smelt pending completion of a new BiOp by USFWS on SWP/CVP operations. The court ruling remained in effect until the new BiOp was approved in December 2008. The 2008 BiOp indicated that "coordinated operations of CVP and SWP diversion facilities, as proposed, are likely to jeopardize the continued existence of delta smelt" (U.S. Fish and Wildlife Service 2008b). The new opinion detailed "reasonable and prudent" alternative actions to reduce the likelihood of jeopardy that include improvements to flow conditions, restoration of tidal marsh and associated subtidal habitat in the Delta and Suisun Marsh, and a comprehensive monitoring plan. However, specific portions of the new BiOp were found arbitrary and capricious by the Federal District Court and the BiOp has been partially remanded.

11A.1.8 References Cited

11A.1.8.1 Literature Cited

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11A.1.9 Personal Communications

Feyrer, Fred. October 1–3, 2013—Presentation at State Water Resources Control Board, Phase II Comprehensive Review of the Bay Delta Plan, Workshop 2. Discussion regarding data from the smelt camera count. General presentation available at: <http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/wrkshp2/dfullerton.pdf>.

Fullerton, Dave. October 1–3, 2013—Presentation at State Water Resources Control Board, Phase II Comprehensive Review of the Bay Delta Plan, Workshop 2, regarding evidence of declining turbidity in the Plan Area. Available at: <http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/wrkshp2/dfullerton.pdf>.

11A.2 Longfin Smelt (*Spirinchus thaleichthys*)

11A.2.1 General

Longfin smelt is a small, euryhaline, anadromous, and semelparous fish with a life cycle of approximately 2 years (Rosenfield 2010). Longfin smelt reach 90 to 110 millimeters standard length, with a maximum size of 120 to 150 millimeters standard length (Moyle 2002; Rosenfield and Baxter 2007). Young longfin smelt occur from the estuary's low-salinity zone (LSZ), where brackish and fresh waters meet, seaward and into the coastal ocean. Longfin smelt can be distinguished from other California smelt by their long pectoral fins (which reach or nearly reach the bases of the pelvic fins), their incomplete lateral line, weak or absent striations on the opercular bones, low number of scales in the lateral series (54 to 65), and long maxillary bones (which in adults extend just short of the posterior margin of the eye) (Moyle 2002). Populations of longfin smelt occur along the Pacific Coast of North America, from Hinchinbrook Island, Prince William Sound, Alaska to the San Francisco Bay estuary (Lee et al. 1980:25). Although individual longfin smelt have been caught in Monterey Bay (Moyle 2002), there is no evidence of a spawning population south of the Golden Gate. Small and perhaps ephemeral longfin smelt spawning populations have been documented or suspected to exist in Humboldt Bay, the Klamath River estuary, the Eel River estuary and drainage, and the Russian River (Moyle 2002; Pinnix et al. 2004). The San Francisco Bay/Sacramento–San Joaquin River Delta (Bay-Delta) population is the southernmost and largest spawning population in California (Figure 2A.2-1). Longfin smelt have been historically sampled at numerous locations in the Sacramento–San Joaquin River Delta (Delta) (Figure 2A.2-2). The population has shown extremely low abundance in recent years as part of the pelagic organism decline (POD) (Sommer et al. 2007; Baxter et al. 2010).

11A.2.2 Legal Status

The Bay-Delta population of longfin smelt was petitioned for threatened status under the federal Endangered Species Act (ESA) in 1992, but the petition was denied because the population was surviving well in areas outside the Bay-Delta estuary. Subsequent research indicated that the Bay-Delta population is more geographically isolated from other west coast longfin smelt populations than previously thought (Moyle 2002). In 2007, the Bay Institute, Center for Biological Diversity, and Natural Resources Defense Council (2007a, 2007b) petitioned to have the Bay-Delta longfin smelt population listed as a threatened species under both the California Endangered Species Act (CESA) and the ESA. On May 6, 2008, the U.S. Fish and Wildlife Service (USFWS) found that a status review for longfin smelt was warranted (73 *Federal Register* [FR] 24911). On April 9, 2009, USFWS determined that the Bay-Delta population did not meet the legal criteria for protection as a species subpopulation under the ESA (74 FR 16169). However, this determination was challenged legally and resulted in a settlement agreement to review the criteria for listing the Bay-Delta longfin smelt population as a distinct population segment (DPS) under ESA. The review resulted in a finding that listing of the Bay-Delta DPS of longfin smelt is warranted (77 FR 19755). Currently, however, listing the Bay-Delta DPS of longfin smelt is precluded by higher priority actions to amend the Lists of Endangered and Threatened Wildlife and Plants.

In December 2007, CDFW completed a preliminary review of the longfin smelt petition (California Department of Fish and Game 2007) and concluded that there was sufficient information to warrant further consideration by the California Fish and Game Commission. On February 7, 2008, the California Fish and Game Commission designated the longfin smelt as a candidate for potential listing under the CESA. On June 26, 2009, the California Fish and Game Commission ruled to list the status of longfin smelt as threatened under the CESA.

11A.2.3 Distribution and Abundance

In the Plan Area, longfin smelt occur primarily in the lower Sacramento River (downstream of Rio Vista) up into the Cache-Liberty Island area and the Deep Water Ship Channel, lower San Joaquin River, and west Delta and Upper Suisun Bay and Montezuma Slough in Suisun Marsh. Longfin smelt occur in relatively low abundance in the south Delta as reflected in results of CDFW fishery sampling and fish salvage monitoring at the State Water Project (SWP) and Central Valley Project (CVP) export facilities. During nonspawning periods, individuals are most often concentrated in Suisun, San Pablo and north San Francisco Bays (Baxter 1999; Moyle 2002). The species is also common in nearshore coastal marine waters outside the Golden Gate Bridge in late summer and fall (Baxter 1999). Longfin smelt are periodically caught in the nearshore ocean, suggesting that some individuals emigrate from or immigrate into the estuary.

Longfin smelt abundance in the Bay-Delta estuary has been highly variable and generally declining, as reflected in the CDFW fall midwater trawl surveys and Bay Study surveys (Figure 2A.2-3). The CDFW fall midwater trawl samples approximately 100 locations throughout the Bay-Delta system during the period from September through December each year. The survey has been conducted since 1967 and is considered to represent the best long-term record of the index of longfin smelt abundance in the Bay-Delta estuary. Additional information on trends in abundance of longfin smelt inhabiting the estuary is available from the CDFW Bay fishery surveys that have sampled monthly since 1980 at a wide range of locations using both an otter trawl and midwater trawl. Because the fall midwater trawl surveys and Bay fishery surveys show similar trends in abundance of longfin smelt (Hieb et al. 2005), the following description of trends in the status of longfin smelt is based on results of the long-term CDFW fall midwater trawl surveys.

Correlations between longfin smelt abundance indices and various environmental parameters suggest that freshwater outflow from the Delta during the longfin smelt spawning, larval, and early juvenile period (January to June) has a strong influence on longfin smelt abundance (Figure 2A.2-4) (Moyle 2002). Abundance indices were greatest in 1967 and 1969 followed by a second peak in 1980 and 1982. High abundance indices are associated with years when spring Delta outflow is high, and low abundance indices are associated with low Delta outflow in the spring, such as the drought conditions that occurred in 1976 and 1977 and during the early 1990s. Longfin abundance also showed a general decline from 1967 through 2009. In recent years, longfin smelt abundance was greatest in 1995, and then declined between 1998 and 2009. The abundance index based on the CDFW fall midwater trawl survey conducted in 2007 was the lowest on record. Fall midwater trawl abundance indices suggest that abundance of longfin smelt within the Bay-Delta estuary has declined by over 95% since the survey began.

There was a four-fold decline in longfin smelt abundance after the 1987 invasion of the overbite clam, *Potamocorbula amurensis*, which resulted in a dramatic drop in food resources for the Delta's fish species because of heavy clam grazing. However, there was no change in the slope of the relationship between freshwater outflow and longfin smelt abundance (Figure 2A.2-4) (Kimmerer 2002a; Sommer et al. 2007; Thomson et al. 2010). Furthermore, although Delta outflow conditions were relatively high in 2003, 2005, and 2006, reflecting wet and above-normal hydrologic conditions, longfin smelt abundance did not increase as much as would be expected based on the 1987 to 2000 relationship (Sommer et al. 2007). There appears to be a further reduction in the elevation of the abundance-flow relationship since 2001 (Baxter et al. 2010), although the slope of the relationship remains unchanged (Figure 2A.2-4). This finding suggests that an additional factor or factors may now be limiting the Bay-Delta population response. Recently, Thomson et al. (2010) hypothesized that the simultaneous, abrupt declines in the abundances of multiple species during the POD are more likely to have been caused by a common but unknown factor than by different factors for each species.

Distribution of longfin smelt may be influenced by the position of the LSZ. For example, in drier years, spawning adults are further upstream and larvae are more susceptible to entrainment (reviewed by Baxter et al. 2010). Some long-term changes in distribution appear to have occurred, e.g., a shift downstream to higher salinities in summer and fall following the invasion of the clam *Potamocorbula* that resulted in lower abundance of zooplankton prey for longfin smelt (Baxter et al. 2010; Contreras et al. 2012).

An unknown fraction of the longfin smelt population migrates to the marine environment during the species' first and second years of life; some may remain in the marine environment from their first year until they return to the estuary to spawn near the end of their second year (rarely their third). It is not known if marine residence is necessary for proper egg development, but the extremely limited number of age 1 smelt captured upstream of central San Francisco Bay during fall suggests that salinity during high-outflow years or, more likely, higher temperatures may be a factor affecting the seasonal distribution of smelt within the estuary.

11A.2.4 Life Stages

Rosenfield (2010) described five life stages of longfin smelt. CDFW (California Department of Fish and Game 2009) also described five life stages, although CDFW discerned between two larval stages, whereas Rosenfield (2010) discerned between two adult stages. For purposes of the BDCP analysis, five life stages recognize the unique requirements of both the larval stages and the adult stages in terms of food resources and habitat. Table 2A.2-1 compares the longfin smelt life stages of Rosenfield and CDFW.

Table 2A.2-1. Life Stages of Longfin Smelt

Rosenfield 2010	California Department of Fish and Game 2009	BDCP
Eggs	Eggs	Eggs
Larvae	Yolk-sac larvae	Larvae
Juvenile	Post-yolk-sac larvae	Juvenile
Subadult	Juvenile	Subadult
Sexually mature adult	Adult	Adult

11A.2.5 Life History

Longfin smelt generally spawn at age 2 in fresh water in the Delta from December to April (Moyle 2002; Rosenfield and Baxter 2007), with some individuals possibly spawning at age 1 and some at age 3 (reviewed by California Department of Fish and Game 2009). Spawning occurs at temperatures that range from 7.0 to 14.5°C, with larvae hatching in 40 days at 7°C (Moyle 2002). Movement patterns based on catches in CDFW fishery sampling suggest that longfin smelt actively avoid water temperatures greater than 22°C (72°F) (California Department of Fish and Game 2009). Longfin smelt do not occupy areas with temperatures greater than 22°C (72°F) in combination with salinities greater than 26 parts per thousand (ppt). These conditions occur between August and September almost annually in south San Francisco Bay and periodically in shallower portions of San Pablo Bay.

Collections of larval and juvenile longfin smelt smaller than 50-millimeter fork length in the Bay-Delta showed that 90% of the individuals inhabited areas with salinities lower than 18 ppt (Baxter 1999). However, other populations of longfin smelt inhabiting west coast waters are present in coastal estuaries or may complete their entire life cycle in fresh water (Dryfoos 1965; Moulton 1974), indicating that there is no lower limit to salinity tolerance for any life stage. Healthy individuals 20-millimeter fork length and larger have been captured in salinities of 32 ppt (ocean water) and along the open coast, suggesting that high salinity may be limiting the geographic distribution for only a small portion of their lifecycle. However, larvae are not known to tolerate salinities greater than 8 ppt (77 FR 19755).

Longfin smelt have not been observed spawning in the Bay-Delta, so the exact location of spawning sites is not well understood, but location in the Plan Area can be inferred by CDFW surveys that collect adult and larval longfin smelt. Based on the distribution of gravid females (Spring Kodiak Trawl Study) the spawning habitat of longfin smelt probably includes the Cache Slough subregion (Sacramento Deep Water Ship Channel, Cache-Liberty Island Complex), the West Delta subregion (lower Sacramento River), the eastern Suisun Bay subregion including upper Grizzly Bay, and Montezuma Slough in the Suisun Marsh subregion. Spawning rarely occurs in the San Joaquin River in the West Delta/South Delta subregions, but when it occurs, it is usually below Twitchell Island (Moyle 2002). CDFW data indicate that spawning longfin smelt were also once common in Suisun Marsh, but in recent years, very few adult, spawning-age longfin smelt have been collected there. Adult and subadult longfin smelt aggregate in deep water in channels, but it is not clear that spawning occurs there; spawning may occur on shoals adjacent to deep channels similar to delta smelt (Rosenfield and Baxter 2007). Spawning locations in the Plan Area are unknown, but spawning in the Lake Washington population occurred primarily on sand substrate in low velocity habitat of lake tributaries (California Department of Fish and Game 2009). Collection of small larvae in the Interagency Ecological Program 20-millimeter tow-net surveys suggests spawning regularly occurs in the Napa River.

Larval longfin smelt have been found concentrated off the mouth of Coyote Creek, indicating that spawning can take place in tributaries of south San Francisco Bay when runoff and Delta outflow are high, such as conditions that occurred in 1982 and 1983 (Baxter 1999).

Upon hatching from adhesive eggs (primarily January to April), buoyant longfin smelt larvae rise toward the surface and are transported downstream by surface currents resulting from both river flow and tidal mixing of fresh and marine waters. Larval longfin smelt remain in the upper part of the water column until they reach 10 to 15 millimeters, after which they move to the middle and bottom parts of the water column (Hieb and Baxter 1993; Bennett et al. 2002; Moyle 2002). The larvae are distributed broadly into all open water habitats and into marsh sloughs (Baxter 1999; Meng and Matern 2001).

The geographic distribution of larval and early juvenile life stages of longfin smelt may be influenced by freshwater inflows to the Delta during the late winter and spring, possibly influencing larval planktonic transport rates from the upstream spawning habitat to the downstream estuarine portions of the Delta. Studies indicate that flow rates are positively related to downstream transport (Hieb and Baxter 1993; Baxter 1999; Dege and Brown 2004). Larval longfin smelt are typically collected in the region of the estuary extending from the west Delta into San Pablo Bay, but their distribution shifts upstream or downstream in response to Delta outflow (Baxter 1999; Dege and Brown 2004). In years when winter-spring Delta outflow is low, few larvae are transported to San Pablo Bay. In years when winter-spring Delta outflow is high, few larvae remain in the west Delta, but are abundant in San Pablo Bay and may reach northern San Francisco Bay (Baxter 1999; Dege and Brown 2004). When Delta inflows are high, the location of the LSZ is further west (downstream) and larval and early juvenile delta smelt are frequently observed further downstream in Suisun Bay. The center of larval distribution is closely tied to the location of the LSZ, as indicated by the position of X2 (the 2 ppt isohaline) at all Delta outflows (Rosenfield and Baxter 2007; Dege and Brown 2004).

The initial distribution of young juveniles correlates positively with that of larvae, both vertically in the water column and geographically. During their first year, juveniles disperse broadly downstream, eventually inhabiting Suisun, San Pablo, and central and south San Francisco Bays and moving into nearshore coastal marine habitats in most years (Figure 2A.2-5) (Baxter 1999; Dege and Brown 2004; Hieb and Baxter 1993; Moyle 2002). Juveniles move from offshore shoals into channels during summer and fall (Rosenfield and Baxter 2007). This movement, and the late summer emigration from south San Francisco Bay, may be a response to increasing water temperatures (greater than 20°C [68°F]) (Baxter 1999).

Longfin smelt in their second year of life (age 1) are typically distributed from the west Delta through south San Francisco Bay from January through March. Their distribution then moves toward the central San Francisco Bay, such that by August and September few, if any, are collected outside of central San Francisco Bay (Baxter 1999).

During the summer, longfin smelt occur in nearshore coastal waters. Migration out of the San Francisco Bay estuary into the marine environment is indicated by the persistent decline of longfin abundance throughout the estuary through summer and then the reappearance of part of the population during the late fall and winter (Rosenfield and Baxter 2007). There is an upstream trend in migration by subadults and adults toward Suisun Bay, Suisun Marsh and the west Delta before a protracted spawning period that can occur from late November into June (Moyle 2002). As longfin smelt begin to mature in the fall, they reinhabit the entire estuary and begin migrating upstream toward fresh water (Baxter 1999; Rosenfield and Baxter 2007).

11A.2.6 Threats and Stressors

A number of threats and stressors exist for longfin smelt. Stressor rankings and the certainty associated with these rankings for longfin smelt are provided in Chapter 5, *Effects Analysis,* of the BDCP. The discussion below outlines some of the main threats and stressors to longfin smelt.

11A.2.6.1 Water Diversions

The effect of entrainment on the population dynamics and abundance of longfin smelt has been examined less than the studies of entrainment effects on delta smelt. Because longfin smelt tend to be mostly estuarine, they likely spend most of their life (approximately 1.5 years) downstream of the influence of the SWP/CVP south Delta export facilities (Figure 2A.2-5). Appreciable numbers of longfin smelt were historically found in salvage at the export facilities and entrainment tends to be higher in years with less outflow (reviewed by California Department of Fish and Game 2009). Recent analyses did not find statistical associations between trends in longfin smelt abundance and the volume of water exported in either winter (December to February) or spring (March to May) (Mac Nally et al. 2010; Thomson et al. 2010). Implementation of south Delta export pumping restrictions to protect delta smelt under the USFWS' biological opinion and as part of CDFW's incidental take permit for the operation of the south Delta export facilities has likely reduced entrainment risk to longfin smelt and to a very low level in most years.

There are over 2,200 small agricultural diversions in the Delta (Herren and Kawasaki 2001). Although these diversions generally take water from the deepest part of the channel, the intakes may obtain water near the surface at low tide; therefore, the vulnerability of a pelagic species such as juvenile and adult longfin smelt may be reduced. Planktonic larval longfin smelt may have a greater vulnerability to entrainment into diversions because of their poor swimming ability. However, entrainment of larvae at agricultural diversions is likely to be low because diversions are low during the winter-spring larval period (Appendix 5.B *Entrainment,* Section 5B.4.7, *Agricultural Diversions*). The impact of entrainment mortality at these diversions on the longfin smelt population abundance has not been quantified.

The power plant in Pittsburg historically entrained appreciable numbers of longfin smelt (reviewed by California Department of Fish and Game 2009), particularly because juvenile longfin smelt may be located near this facility for much of the year (Matica and Sommer 2005). However, use of cooling water is currently low with the retirement of older units. According to recent regulations by the State Water Resources Control Board, units at this plant must be equipped with a closed-cycle cooling system by 2017 that eliminates fish entrainment.

11A.2.6.2 Habitat Loss

11A.2.6.2.1 Reduced Spawning Habitat

Spawning of longfin smelt in California has not been observed, but is most likely similar to other populations of longfin smelt. Sand is the preferred substrate in Lake Washington (Moulton 1974). The supply of sand for longfin smelt spawning substrate has likely been reduced as a result of the construction and/or operation of dams (Wright and Schoellhamer 2004), sand mining, and other activities that alter the flux of sediment or that change the availability of nearshore sandy habitat (e.g., bank stabilization with revetment). The possibility of spawning habitat availability affecting the longfin smelt population is also a possible stressor on delta smelt (Bennett 2005; Miller et al. 2012), suggesting that both species may use similar spawning habitats.

11A.2.6.2.2 Reduced Rearing Habitat

Access to suitable rearing habitat, which for larvae is centered in the LSZ of the West Delta and Suisun Bay subregions (Dege and Brown 2004), may be linked to the magnitude of net downstream flows, which have undergone long-term decreases (Cloern and Jassby 2012). The LSZ, when positioned over shallow shoal areas in Suisun Bay in response to high Delta outflows, is more productive (Moyle et al. 1992; Bennett et al. 2002; Hobbs et al. 2006). When located upstream, the LSZ is confined to the deep river channels, is smaller in total surface area, contains very few shoal areas, may have swifter, more turbulent water currents, and may lack high zooplankton productivity. Hobbs et al. (2006) found evidence that the health and survival of juvenile longfin smelt were greater in habitats associated with shallow water. The documented strong correlation between the abundance of longfin smelt in the fall midwater trawl and the location of X2 (indicating changes in Delta outflow) in the winter and spring months (December to May) (Kimmerer 2002; Kimmerer et al. 2009) may be related to the transport of larval longfin smelt out of the Delta to rearing habitats downstream, and there are other potential mechanisms such as volume of habitat, retention of larvae/early juveniles related to gravitational circulation, or changes in food consumption either because of differences in co-occurrence with prey items or changes in food availability in areas where turbidity changes with changing flow (Kimmerer and Bennett 2005). Kimmerer et al. (2009) did not find strong evidence for the extent of rearing habitat being related to changes in longfin smelt abundance. The importance of spring outflow to longfin smelt is the subject of the spring X2 decision tree and is discussed further in the conceptual model for longfin smelt found in Chapter 5, *Effects Analysis.*

11A.2.6.3 Turbidity

Based on the similarities in life history, seasonal and geographic distribution, pelagic foraging and diet, it has been hypothesized that longfin smelt may have a similar relationship to turbidity as that observed for delta smelt (Feyrer et al. 2007; Resources Agency 2007; Nobriga et al. 2008; Grimaldo et al. 2009). Delta smelt require turbidity for successful foraging (Baskerville-Bridges et al. 2004) and predator escape (Feyrer et al. 2007). Longfin smelt larvae hatch coincident with annual peak Delta outflows, which typically coincide with high turbidity. Also, larval and older life stages of longfin smelt possess a well-developed olfactory system, suggesting that they are well adapted to high turbidity during foraging. As a result, longfin smelt may lose their competitive advantage in foraging to other zooplanktivores when turbidity is low. Kimmerer et al. (2009) found that abundance or frequency of occurrence of longfin smelt sampled by fall midwater trawling and spring 20-millimeter surveys was associated with salinity and Secchi depth. Thomson et al. (2010) found that variations in long-term fall abundance of longfin smelt were most correlated with fall water clarity (and spring X2).

Turbidity levels have declined in the Bay-Delta estuary since the 1970s as a result of numerous factors (Kimmerer 2004) such as upstream sediment trapping by dams, proliferation of invasive aquatic vegetation, and changes in hydraulic residence time, as outlined in the delta smelt species account.

11A.2.6.4 Food Resources

Larval and small juvenile longfin smelt feed on copepods and other small crustaceans, while juveniles and adults feed primarily on mysids (Moyle 2002; Feyer et al. 2003). Slater (2008) concluded from diet studies that young longfin smelt rely heavily on *Eurytemora* in spring. Longfin smelt, along with other POD species, have experienced a significant decline in food resources in recent decades. Efficient filter feeding and high abundance of *Potamocorbula* have dramatically reduced phytoplankton and zooplankton abundance in Suisun Bay, the west Delta, and Suisun Marsh since its introduction in the mid-1980s (Kimmerer and Orsi 1996). The introduced freshwater Asian clam, *Corbicula fluminea*, has reduced the abundance of phytoplankton in the Delta, although its effect is mainly limited to island areas flooded by fresh water (Lucas et al. 2002; Lopez et al. 2006). In Suisun Bay, the copepods *Pseudodiaptomus* and *Acanthocyclops* now dominate the diet of small juvenile smelt at low salinities in summer (Hobbs et al. 2006).

Since the decline of the native mysid *Neomysis* following the clam invasion, subadult and adult longfin smelt have fed on a broader variety of organisms, but mysids remain their primary food item (Moyle 2002; Feyrer et al. 2003). CDFW data indicate that in fall 2006, longfin smelt fed predominantly on the introduced mysid *Acanthomysis*, but consumed other mysids, as well as the copepod *Pseudodiaptomus* and amphipod *Corophium*. Baxter et al. (2010) noted that the POD coincided with lower spring abundance of mysids. Statistical analyses by Mac Nally et al. (2010) found some evidence for a positive association between longfin smelt abundance and calanoid copepod biomass in the low-salinity zone during summer. The same authors also found stronger negative associations between longfin smelt abundance and summer biomass of calanoid copepods and mysids, i.e., indications of longfin smelt limiting the abundance of these key prey species.

The changes in the zooplankton species composition have affected the quality of food resources available to longfin smelt (Resources Agency 2007; Sommer 2007). A decrease in foraging efficiency and/or the availability of suitable prey for various life stages of longfin smelt may result in reduced growth, survival, and reproductive success, contributing to observed lower population abundance (Kimmerer 2002a; Thomson et al. 2010).

A number of other factors may contribute to reduced food resources, including loss of shallow-water tidal and floodplain habitat, changes in hydraulic residence time, water diversions including SWP/CVP south Delta exports, and changes in nutrient balance caused by anthropogenic sources (Lucas et al. 2002; Lehman et al. 2008; Glibert et al. 2011; Jassby 1994; Jassby and Cloern 2000).

11A.2.6.5 Exposure to Toxins

Exposure of longfin smelt to toxic substances can result from point and nonpoint sources associated with agricultural, urban, and industrial land uses. Longfin smelt can potentially be exposed to these toxic materials, including pesticides, herbicides, endocrine disrupting compounds, and metals, during their period of residence within the Bay-Delta. No studies directly link mortality of longfin smelt with exposure to toxic chemicals in the Bay-Delta estuary, although longfin smelt spawn during winter months when nonpoint runoff of pesticides tends to be the greatest (Resources Agency 2007). The pesticide diazinon is known to reduce growth and increase spinal deformities in Sacramento splittail (Teh et al. 2004), but effects of diazinon on longfin smelt have not been investigated.

No formal risk assessment has been performed on the potential lethal and sublethal effects of toxics on longfin smelt population dynamics. However, there is growing evidence that toxics may have indirect effects on longfin smelt. For example, invertebrate prey of longfin smelt are affected by toxics (Luoma 2007; Werner 2007), reducing food availability for longfin smelt. There is also evidence that toxics may cause sublethal impacts that make fish species more vulnerable to other sources of mortality (Werner 2007). Most, if not all, pyrethroids are potent neurotoxicants (Shafer and Meyer 2004) and have immunosuppressive effects (Madsen et al. 1996; Clifford et al. 2005). In addition, these compounds and their breakdown products can act as endocrine-disrupting compounds (Tyler et al. 2000; Sun et al. 2007).

Exposure to copper contamination can result in significant sublethal effects on Delta fish species, with implications for their vulnerability to other stressors (Hetrick et al. 1979; Sandahl et al. 2006; Little and Finger 1990; Oros and Werner 2005). Dissolved copper causes acute toxicity to the calanoid copepod, *Eurytemora affinis*, in the north and south Delta (Teh et al. 2009). Additionally, negative synergistic effects have been documented such that the presence of copper in combination with ammonia is more toxic to aquatic organisms than either toxicant individually (Herbert and Vandyke 1964).

The short life span of longfin smelt (less than 3 years) and location of their food source in the foodweb (zooplankton are primary food sources) may limit the ability of toxic chemicals to bioaccumulate in their tissue (Moyle 2002). Their location in the water column may further reduce the probability of some toxic impacts by those chemicals that are sequestered quickly by sediments (i.e., pyrethroids). Additional research is needed to investigate the potential risk of exposure to toxic chemicals at concentrations and exposure durations typical of Bay-Delta conditions on various life stages of longfin smelt. A recent conceptual model by Brooks et al. (2012) suggested that adult longfin smelt might be vulnerable to the effects of contaminants in winter and spring through release of toxins from fat reserves during upstream migration to the Delta from San Francisco Bay and the Pacific Ocean. The conceptual model also noted the potential for contaminant effects in winter and spring during occupation of the freshwater Delta, including acute toxicity to larvae and juveniles, direct or indirect food limitation (spring only), impaired behavior and disease susceptibility, and temperature effects on toxic thresholds (spring only).

11A.2.6.6 Predation and Competition

The effect of nonnative predators, such as inland silversides, largemouth bass, striped bass, and centrarchids, has been identified as a potential stressor on longfin smelt populations (Sommer et al. 2007; Rosenfield 2010), but the potential effect of predation on longfin smelt remains largely unknown (Moyle 2002). Inland silversides and juvenile Chinook salmon are believed to prey on larval longfin smelt, and predation by striped bass adults likely results in mortality for the juvenile and adult life stages (Rosenfield 2010). Larval longfin smelt are not strong swimmers, and are thus particularly vulnerable to predation (Wang 1986). Predation has been implicated as an important factor affecting production of juvenile longfin smelt, in part because of the correspondence between freshwater flows, the volume of turbid habitat, and the young-of-year class size for longfin smelt (Rosenfield 2010). The coincidence of the increase in inland silverside abundance and decline in longfin smelt abundance also provides hypothetical evidence of the potential importance of predation as a stressor to longfin smelt. However, increases in predation are not believed to be responsible for the most recent decline in the longfin smelt population. Striped bass are hypothetically a major predator of longfin smelt, although their populations have declined substantially in recent years and any impact they have on longfin smelt populations is expected to have declined (Rosenfield 2010). Studies on the diets of striped bass (Stevens 1966; Thomas 1967) and largemouth bass (Nobriga and Feyrer 2007) in Suisun Marsh and the Sacramento-San Joaquin

Delta have rarely identified longfin smelt in the contents of their stomachs. In addition, though inland silversides are predatory, they prefer shallow-water habitats where juvenile and subadult longfin smelt are rare. Consequently, their impact as predators of juvenile longfin smelt is likely limited (Rosenfield 2010). As noted in the delta smelt species account, predation of the early life stages of delta smelt by silversides has been confirmed by DNA testing of silverside stomach contents (Baerwald et al. 2012). However, delta smelt DNA was only found in the stomachs of in the relatively few silversides captured by trawling away from shore, whereas there was no delta smelt DNA in the stomachs of the more numerous silversides captured inshore by beach seining. As noted above, this may indicate relatively little overlap in silversides and larval smelts, making the importance of predation uncertain.

Nonnative zooplanktivores, including threadfin shad, inland silversides, and wakasagi, may compete for limited food resources with longfin smelt.

11A.2.6.7 Invasive Aquatic Vegetation

Egeria and water hyacinth are invasive aquatic plants that grow in dense aggregations and can reduce dissolved oxygen and turbidity in their immediate vicinity (Grimaldo and Hymanson 1999; Brown and Michniuk 2007; Feyrer et al. 2007). In addition, because of the three-dimensional structure and shade they provide, these aquatic plants likely create excellent habitat for nonnative predators primarily centrarchids (Nobriga et al. 2005). Longfin smelt may be indirectly affected by invasive aquatic vegetation (decreased water quality and increased predation) if present in areas where *Egeria* and water hyacinth are prevalent.

11A.2.7 Relevant Conservation Efforts

Pursuant to the CALFED objective of ecosystem restoration, the CALFED agencies developed the Ecosystem Restoration Plan and the Environmental Water Account for the purpose of restoring habitat and recovering at-risk fish populations in the Bay-Delta estuary (CALFED Bay-Delta Program 2000). The CALFED Multi-Species Conservation Strategy (CALFED Bay-Delta Program 2000) designates longfin smelt as an "R" species and states that the goal is to "achieve recovery objectives identified for longfin smelt in the recovery plan for the Sacramento/San Joaquin Delta native fishes" (U.S. Fish and Wildlife Service 1996). However, no conservation efforts in the recovery plan specifically target longfin smelt; all are referenced to delta smelt.

In January 2005, the Interagency Ecological Program established the POD work group to investigate the causes of the recently observed rapid decline in populations of pelagic organisms, including longfin smelt, in the upper San Francisco Bay estuary (Baxter et al. 2010). The Resources Agency prepared the *Pelagic Fish Action Plan* in March 2007 to address POD (Resources Agency 2007). The action plan identifies 17 actions that are being implemented or that are under active evaluation to help stabilize the Delta ecosystem and improve conditions for pelagic fish.

Longfin smelt is included in the *Sacramento-San Joaquin Delta Native Fishes Recovery Plan* (U.S. Fish and Wildlife Service 1996), which also includes delta smelt, Sacramento splittail, green sturgeon, Sacramento perch, and three races of Chinook salmon. In addition, the 2008 SWP/CVP biological opinion (BiOp) includes conservation measures that would be protective of longfin smelt (U.S. Fish and Wildlife Service 2008b).

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11A.3 Sacramento River Winter-Run Chinook Salmon (*Oncorhynchus tshawytscha*)

11A.3.1 Legal Status

The Sacramento River winter-run Chinook salmon evolutionary significant unit (ESU) was originally listed as a threatened species in August 1989, under emergency provisions of the federal Endangered Species Act (ESA), and was formally listed as threatened in November 1990 (55 *Federal Register* [FR] 46515). The ESU consists of only one population confined to the upper Sacramento River in California's Central Valley. The ESU was reclassified as endangered under the ESA on January 4, 1994 (59 FR 440), because of to increased variability of run sizes, expected weak returns as a result of two small year classes in 1991 and 1993, and a 99% decline between 1966 and 1991. The Sacramento River winter-run Chinook salmon ESU includes all naturally spawned winter-run Chinook salmon in the Sacramento River and its tributaries, as well as two artificial propagation programs: winter-run Chinook salmon produced from the Livingston Stone National Fish Hatchery and released as juveniles into the Sacramento River and winter-run Chinook salmon held in a captive broodstock program maintained at Livingston Stone National Fish Hatchery (70 FR 37160, June 28, 2005) (Figure 2A.3-1).

The National Marine Fisheries Service (NMFS) reaffirmed the listing of the Sacramento River winter-run Chinook salmon ESU as endangered on June 28, 2005 (70 FR 37160), and included the Livingston Stone National Fish Hatchery population in the listed population. The major concerns were that there is only one extant population, which is spawning outside of its historical range, in artificially maintained habitat that is vulnerable to drought. Another concern was the rising levels of hatchery fish spawning in natural areas.

On August 15, 2011, after a second 5-year review (76 FR 50447), NMFS determined that the ESU had continued to decline since 2005, with a negative point estimate for the 10-year trend. However, the current population size still falls within the low-risk criterion, and the 10-year average introgression rate of hatchery fish (about 8%) is below the low-risk threshold for hatchery influence (National Marine Fisheries Service 2011). Winter-run Chinook salmon was listed as endangered under the California Endangered Species Act (CESA) on September 22, 1989.

11A.3.2 Species Distribution and Status

11A.3.2.1 Range and Status

The distribution of winter-run Chinook salmon spawning and rearing was limited historically to the upper Sacramento River and tributaries, where cool spring-fed streams supported successful adult holding, spawning, egg incubation, and juvenile rearing (Slater 1963; Yoshiyama et al. 1998). The headwaters of the McCloud, Pit, and Little Sacramento Rivers and Hat and Battle Creeks, provided clean, loose gravel, cold, well-oxygenated water, and year-round flow in riffle habitats for spawning and incubation (Figure 2A.3-1). These areas also provided the cold, productive waters necessary for egg and fry survival and juvenile rearing over summer. Construction of Shasta Dam in 1943 and Keswick Dam in 1950 blocked access to all of these upstream waters except Battle Creek, which is blocked by a weir at the Coleman National Fish Hatchery and other small hydroelectric facilities (Moyle et al. 1995; National Marine Fisheries Service 1997). Approximately 299 miles of tributary spawning habitat in the upper Sacramento River are inaccessible to winter-run Chinook salmon (National Marine Fisheries Service 2012).

Primary spawning and rearing habitats for winter-run Chinook salmon are now confined to the cold water areas between Keswick Dam and Red Bluff Diversion Dam. The lower reaches of the Sacramento River, Sacramento–San Joaquin River Delta (Delta), and San Francisco Bay serve as migration corridors for the upstream migration of adult and downstream migration of juvenile winter-run Chinook salmon.

Estimates of the Sacramento River winter-run Chinook salmon population (including both male and female salmon) reached nearly 100,000 fish in the 1960s before declining to under 200 fish in the 1990s (Good et al. 2005). Abundance of returning adult spawners generally increased between the mid-1990s and 2006 (Figure 2A.3-1). However, recent population estimates of winter-run Chinook salmon spawning upstream of the Red Bluff Diversion Dam have dropped off since the 2006 peak (California Department of Fish and Game 2010). The escapement estimate for 2010 was 1,533 adults, while the 2011 estimate (824 fish) was the lowest total since the 880 fish escapement estimate in 1997 (National Marine Fisheries Service 2012).

Two methods are used to estimate the juvenile production of Sacramento River winter-run Chinook salmon: the juvenile production index method (using rotary screw traps) and the juvenile production estimate method (using carcass surveys). Average juvenile population of Sacramento River winter-run Chinook salmon inhabiting the upper Sacramento River at the Red Bluff Diversion Dam is 4,230,378 juveniles per year, using the juvenile production index method between 1995 and 2007 (excluding 2000 and 2001 when rotary screw trapping was not conducted) (Poytress and Carillo 2010). Using the juvenile production estimate method, average production is estimated to be 5,034,921 juveniles exiting the upper Sacramento River at the Red Bluff Diversion Dam between 1996 and 2007 (Poytress and Carillo 2010).

Although the abundance of the Sacramento River winter-run Chinook salmon population has, on average, been growing since the 1990s (despite recent declines since 2007), there is only one population and it depends heavily on coldwater releases from Shasta Dam (Good et al. 2005). Lindley et al. (2007) consider the Sacramento River winter-run Chinook salmon population at a moderate risk of extinction primarily because of the risks associated with only one existing population. The viability of an ESU that is represented by a single population is vulnerable to changes in the environment through a lack of spatial geographic diversity and genetic diversity that result from having only one population. A single catastrophic event with effects persisting for 4 or more years could extirpate the entire Sacramento River winter-run Chinook salmon ESU, which puts the population at a high risk of extinction over the long term (Lindley et al. 2007). Such potential catastrophes include volcanic eruption of Mount Lassen; prolonged drought, which depletes the coldwater pool in Lake Shasta or some related failure to manage coldwater storage; a spill of toxic materials with effects that persist for 4 years; regional declines in upwelling and productivity of near-shore coastal marine waters resulting in reduced food supplies for juvenile and sub-adult salmon, reduced growth, and/or increased mortality; or a disease outbreak. Another vulnerability to an ESU that is represented by a single population is the limitation in life history and genetic diversity that would otherwise increase the ability of individuals in the population to withstand environmental variation.

Although NMFS proposed that this ESU be downgraded from endangered to threatened status, NMFS decided in its Final Listing Determination (June 28, 2005; 70 FR 37160) to continue to list the

Sacramento River winter-run Chinook salmon ESU as endangered because the population remains below the draft recovery goals established for the run (National Marine Fisheries Service 1997) and the naturally spawned component of the ESU is dependent on one extant population in the Sacramento River. NMFS reconfirmed this listing status in 2011, based on a 10-year negative trend in abundance and the continued influence of hatchery fish on the single spawning population in the ESU (National Marine Fisheries Service 2011).

11A.3.2.2 Distribution and Status in the Plan Area

The entire population of the Sacramento River winter-run Chinook salmon must pass through the Plan Area as migrating adults and emigrating juveniles. Because winter-run Chinook salmon use only the Sacramento River system for spawning adults are likely to migrate upstream primarily along the western edge of the Delta through the Sacramento River corridor. Because juvenile winter-run salmon have been collected at various locations in the Delta (including the State Water Project [SWP] and the Central Valley Project [CVP] south Delta export facilities), juveniles likely use a wider range of the Delta for migration and rearing than adults. Studies using acoustically tagged juvenile and adult Chinook salmon are ongoing to further investigate the migration routes, migration rates, reach-specific mortality rates, and the effects of hydrologic conditions (including the effects of SWP/CVP export operations) on salmon migration through the Delta (Lindley et al. 2008; MacFarlane et al. 2008a; Michel et al. 2009; Perry et al. 2010). Juvenile winter-run Chinook salmon likely inhabit Suisun Marsh for rearing and may inhabit the Yolo Bypass when flooded, although use of these two areas is not well understood.

Results of fishery monitoring using a combination of adult counts at the Red Bluff Diversion Dam fish ladder and carcass surveys have been used to estimate annual adult escapement of winter-run Chinook salmon on the mainstem Sacramento River. The estimated annual adult escapement from 1970 through 2009 is shown in Figure 2A.3-2. During the late 1960s and throughout the 1970s, winter-run Chinook salmon abundance declined significantly from a peak of approximately 120,000 adults to several thousand adults. Population abundance remained very low through the mid-1990s, with adult abundance in some years less than 500 fish. Beginning in the mid-1990s and continuing through 2006, adult escapement has shown a trend of increasing abundance, approaching 20,000 fish in 2005 and 2006.

The following factors have contributed to this increasing trend in adult abundance.

- Improved water temperatures and temperature management in the Shasta Reservoir and the mainstem river downstream of Keswick Dam.
- Improvements in the operations of the Red Bluff Diversion Dam (keeping holding gates open for a longer period).
- Favorable hydrological and ocean rearing conditions.
- Habitat enhancements, reductions in loading of toxic chemicals.
- Improved fish screens on major water diversions.
- Changes in ocean commercial and recreational angling to reduce harvest mortality.

Based on recent escapement data, NMFS concluded that the Central Valley winter-run Chinook salmon ESU has continued to decline from a recent peak in 2006 of over 17,000 fish to less than 2,000 fish in 2010 (National Marine Fisheries Service 2011). Overall, the recent 10-year trend in abundance is negative. Adult winter-run Chinook salmon escapement to the Sacramento River declined substantially in 2007, with an estimated 2,542 adults returning to spawn (Figure 2A.3-2). As discussed below, the substantial decline in adult winter-run Chinook salmon escapement was the likely result of reduced productivity of near-shore coastal waters and reduced prey availability resulting in poor juvenile salmon growth and high mortality during the juvenile ocean rearing phase (MacFarlane et al. 2008b). A similar substantial decline in abundance of returning fall-run Chinook salmon (and other salmon populations in California) was observed in 2007. Adult escapement remained low during 2008 and 2009. In response to the low numbers of adult Chinook salmon returning to the Central Valley, commercial and recreational fishing for salmon has been curtailed since 2007, but was resumed in 2010 and full seasons were restored in 2011 and 2012.

11A.3.3 Habitat Requirements and Special Considerations

Critical habitat for the winter-run Chinook ESU was designated under the ESA on June 16, 1993 (58 FR 33212). Designated critical habitat includes the Sacramento River from Keswick Dam (river mile 302) to Chipps Island (river mile 0) at the westward margin of the Delta, all waters from Chipps Island westward to Carquinez Bridge, including Honker, Grizzly, and Suisun bays, and Carquinez Strait, all waters of San Pablo Bay westward of the Carquinez Bridge, and all waters of San Francisco Bay (north of the San Francisco/Oakland Bay Bridge) from San Pablo Bay to the Golden Gate Bridge (59 FR 440, January 4, 1994) (Figure 2A.3-3). In the Sacramento River, critical habitat includes the river water column, river bottom, and adjacent riparian zone used by fry and juveniles for rearing. In the areas westward of Chipps Island, critical habitat includes the estuarine water column and essential foraging habitat and food resources used by Sacramento River winter-run Chinook salmon as part of their juvenile emigration or adult spawning migration.

Habitat of Sacramento River winter-run Chinook salmon is also protected under the Magnuson-Stevens Fishery Conservation and Management Act as essential fish habitat (EFH). Those waters and substrate necessary to support Sacramento River winter-run Chinook salmon spawning, breeding, feeding, or growth are included as EFH (Figure 2A.3-4). Critical habitat and EFH are managed differently from a regulatory standpoint, but are biologically equivalent with regard to conservation.

The designated critical habitat includes primary constituent elements (PCEs) considered essential for the conservation of Sacramento River winter-run Chinook salmon. The identified PCEs are spawning habitat, freshwater rearing habitat, freshwater migration corridors, estuarine habitat, and nearshore and offshore marine habitats.

11A.3.3.1 Spawning Habitat

Spawning habitat for Sacramento River winter-run Chinook salmon is restricted to the Sacramento River primarily between Red Bluff Diversion Dam and Keswick Dam. Spawning sites include those stream reaches with water movement, velocity, depth, temperature, and substrate composition that support spawning, egg incubation, and larval development. Water velocity and substrate conditions are more critical to the viability of spawning habitat than depth. Incubating eggs and embryos buried in gravel require sufficient water flow through the gravel to supply oxygen and remove metabolic wastes (Resources Agency et al. 1998). Spawning occurs in gravel substrate in relatively fast-moving, moderately shallow riffles or along banks with relatively high water velocities. The gravel must be clean and loose, yet stable for the duration of egg incubation and the larval development.

Substrate composition has other key implications to spawning success. The embryos and alevins (newly hatched fish with the yolk sac still attached) require adequate water movement through the substrate; however, this movement can be inhibited by the accumulation of fines and sand. Generally, the redd should contain less than 5% fines (Resources Agency et al. 1998).

Water velocity in Chinook salmon spawning areas typically ranges from 1.0 to 3.5 feet per second and optimum velocity is 1.5 feet per second (Resources Agency et al. 1998). Spawning occurs at depths between 1 to 5 feet with a maximum observed depth of 20 feet. A depth of less than 6 inches can be restrictive to Chinook salmon movement.

11A.3.3.2 Freshwater Rearing Habitat

Freshwater salmon rearing habitats contain sufficient water quantity and floodplain connectivity to form and maintain physical habitat conditions that support juvenile growth and mobility; suitable water quality; availability of suitable forage species that support juvenile salmon growth and development; and cover such as shade, submerged and overhanging large wood, log jams, beaver dams, aquatic vegetation, large rocks and boulders, side channels, and undercut banks. Both spawning areas and migratory corridors also function as rearing habitat for juveniles, which feed and grow before and during their outmigration. Nonnatal, intermittent tributaries also may be used for juvenile rearing. Rearing habitat value is strongly affected by habitat diversity and complexity, food supply, and fish and avian predators. Some of these more complex and productive habitats with floodplains are still found in the system (e.g., the lower Cosumnes River, Sacramento River reaches with setback levees [i.e., primarily located upstream of the City of Colusa]). The channeled, leveed, and riprapped river reaches and sloughs are common along the Sacramento River and throughout the Delta; however, they typically have low habitat complexity, have low abundance of food organisms, and offer little protection from predation by fish and birds. Freshwater rearing habitat has a high conservation value as the juvenile life stage of salmonids is dependent on the function of this habitat for successful survival and recruitment into the adult population.

11A.3.3.3 Freshwater Migration Corridors

Freshwater migration corridors for winter-run Chinook salmon, including river channels, floodplains, channels through the Delta, and the Bay-Delta estuary support mobility, survival, and food supplies for juveniles and adults. Migration corridors should be free from obstructions (passage barriers and impediments to migration), provide favorable water quantity (instream flows) and quality conditions (seasonal water temperatures), and contain natural cover such as submerged and overhanging large wood, native aquatic vegetation, large woody debris, rocks and boulders, side channels, and undercut banks. Migratory corridors for winter-run Chinook salmon are located downstream of the spawning areas and include the lower Sacramento River, Yolo Bypass, the Delta, and the San Francisco Bay complex extending to coastal marine waters. These corridors allow the upstream passage of adults and the downstream emigration of juvenile salmon. Migratory corridor conditions are strongly affected by the presence of passage barriers, which can include dams, unscreened or poorly screened diversions, and degraded water quality. For freshwater migration corridors to function properly, they must provide adequate passage, provide suitable migration cues, limit false attraction, provide low vulnerability to predation, and not contain impediments and delays in both upstream and downstream migration.

Results of mark-recapture studies conducted using juvenile Chinook salmon (typically hatchery-reared late fall-run Chinook salmon that are considered to be representative of juvenile winter-run salmon) released into the Sacramento River have shown high mortality during passage downstream through the rivers and Delta (Brandes and McLain 2001; Newman and Rice 2002; Hanson 2008). Mortality is typically greater in years when spring flows are reduced and water temperatures are increased. Results of survival studies have shown that closing the Delta Cross Channel gates to reduce the movement of juvenile salmon into the Central Delta, contributes to improved survival of emigrating juvenile Chinook salmon (Brandes and McLain 2001; Manly 2004; Low and White n.d.). Observations at the SWP/CVP fish salvage facilities have shown that very few of the marked salmon (typically less than 1% [Hanson 2008]) are entrained and salvaged at the export facilities. Results of estimating incidental take of juvenile winter-run Chinook salmon at the SWP/CVP fish salvage facilities based on comparison of the juvenile production estimates for winter-run emigrating from the upper Sacramento River rearing areas (e.g., estimated based on results of spawning carcass surveys and environmental conditions and/or fishery monitoring at Red Bluff Diversion Dam) show a similar low magnitude to direct losses of juvenile winter-run Chinook salmon at the fish salvage facilities. Although the factors contributing to the high juvenile mortality have not been quantified, results of acoustic tagging experiments and anecdotal observations suggest that exposure to adverse water quality leading to mortality (e.g., elevated water temperatures, potentially toxic chemicals) and vulnerability to predation mortality are two of the factors contributing to the high juvenile mortality observed in the Sacramento River and Delta.

11A.3.3.4 Estuarine Habitat

Estuarine migration and juvenile rearing habitats should be free of obstructions (i.e., dams and other barriers) and provide suitable water quality, water quantity (river and tidal flows), and salinity conditions to support juvenile and adult physiological transitions between fresh and salt water. Natural cover, such as submerged and overhanging large wood, native aquatic vegetation, and side channels, provide juvenile foraging habitat and cover from predators. Tidal wetlands and seasonally inundated floodplains have also been identified as high-value foraging and rearing habitats for juvenile salmon migrating downstream through the estuary. Estuarine areas contain a high conservation value because they function to support juvenile Chinook salmon growth, smolting, and avoidance of predators, as well as provide a transition to the ocean environment.

11A.3.3.5 Marine Habitats

Although ocean habitats are not part of the critical habitat listings for Sacramento River winter-run Chinook salmon, biologically productive coastal waters are an important habitat component for the species. Juvenile Chinook salmon inhabit near-shore coastal marine waters for a period of typically 2 to 4 years before adults return to Central Valley rivers to spawn. During their marine residence, Chinook salmon forage on krill, squid, and other marine invertebrates and a variety of fish such as northern anchovy, sardines, and Pacific herring. These features are essential for conservation because, without them, juveniles cannot forage and grow to adulthood.

The variation in ocean productivity off the West Coast can be high both within and among years. Changes in ocean currents and upwelling have been identified as significant factors affecting nutrient availability, phytoplankton and zooplankton production, and the availability of other forage species in near-shore surface waters. Ocean conditions during a salmon's ocean residency period can be important, as indicated by the effect of the 1983 El Niño on the size and fecundity of Central Valley fall-run Chinook salmon (Wells et al. 2006). Although the effects of ocean conditions on Chinook salmon growth and survival have not been investigated extensively, recent observations since 2007 have shown a significant decline in the abundance of adult Chinook and coho salmon returning to California rivers and streams (Pacific Fishery Management Council 2008). The decline has been hypothesized to be the result of decreased ocean productivity and associated high mortality rates during the period when these fish were rearing in near-shore coastal waters (MacFarlane et al. 2008b; Pacific Fishery Management Council 2008). The importance of changes in ocean conditions on growth, survival, and population abundance of Sacramento River Chinook salmon is currently undergoing further investigation.

11A.3.4 Life History

Chinook salmon exhibit two generalized freshwater life history types (Healey 1991). Stream-type adults enter fresh water months before spawning and juveniles reside in fresh water for a year or more following emergence, whereas ocean-type adults spawn soon after entering fresh water and juveniles migrate to the ocean as fry or parr in their first year. Winter-run Chinook salmon are somewhat anomalous in that they have characteristics of both stream- and ocean-type races (Healey 1991). Adults enter fresh water in winter or early spring, and delay spawning until spring or early summer (stream-type). However, juvenile winter-run Chinook salmon migrate to sea after only 4 to 7 months of river life (ocean-type). Adequate instream flows and cool water temperatures are more critical for the survival of Chinook salmon exhibiting a stream-type life history due to over-summering by adults and/or juveniles.

Sacramento River winter-run Chinook salmon adults enter the Sacramento River basin between December and July; the peak occurring in March (Table 2A.3-1) (Yoshiyama et al. 1998; Moyle 2002). Spawning occurs from mid-April to mid-August, peaking in May and June, in the Sacramento River reach between Keswick Dam and Red Bluff Diversion Dam (Vogel and Marine 1991). The majority of Sacramento River winter-run Chinook salmon spawners are 3 years old. Adult winter-run Chinook salmon tend to enter fresh water as sexually immature fish, migrate far upriver, and delay spawning for weeks or months. Prespawning activity requires an area of 200 to 650 square feet. The female digs a nest, called a redd, with an average size of 165 square feet, in which she buries her eggs after they are fertilized by the male (Resources Agency et al. 1998).

Sacramento River winter-run Chinook salmon fry begin to emerge from the gravel in late June to early July and continue through October (Fisher 1994), with emergence generally occurring at night. Fry then seek lower velocity nearshore habitats with riparian vegetation and associated substrates important for providing aquatic and terrestrial invertebrates, predator avoidance, and slower velocities for resting (National Marine Fisheries Service 1996). Emigrating juvenile Sacramento River winter-run Chinook salmon pass the Red Bluff Diversion Dam beginning as early as mid-July, typically peaking in September, and can continue through March in dry years (Vogel and Marine 1991; National Marine Fisheries Service 1997). Many juveniles apparently rear in the Sacramento River below Red Bluff Diversion Dam for several months before they reach the Delta (Williams 2006). From 1995 to 1999, all Sacramento River winter-run Chinook salmon outmigrating as fry passed the Red Bluff Diversion Dam by October, and all outmigrating presmolts and smolts passed the Red Bluff Diversion Dam by March (Martin et al. 2001).

Table 2A.3-1. Temporal Occurrence of Adult and Juvenile Sacramento River Winter-Run Chinook Salmon in the Sacramento River and Delta

Location	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Adult																								
Sacramento River basin[1]	▒	▒	▒	▒	■	■	▒	▒	▒	▒	▒	▒	▒	▒									▒	▒
Sacramento River[2]	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒									▒	▒	▒	▒
Juvenile																								
Sacramento River at Red Bluff[3]	░	░											░	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
Sacramento River at Red Bluff[2]	▒	▒	▒	▒									░	░	■	■	■	■	■	■	▒	▒	▒	▒
Sacramento River at Knights Landing[4]	▒	▒	▒	▒	▒	▒	░	░							░	░	░	░	░	░	■	■	■	■
Lower Sacramento River (seine)[5]	■	■	■	■	▒	▒	░										░	░	░	░	▒	▒	■	■
West Sacramento River (trawl)[5]	▒	▒	■	■	■	■	■	■	░												░	░	▒	▒
Chipps Island (trawl)[5]	▒	▒	▒	■	■	■	■	■	░	░													░	░

Relative Abundance: ■ = High ▒ = Medium ░ = Low

Note: Darker shades indicate months of greatest relative abundance.

Sources:

[1] Yoshiyama et al. 1998; Moyle 2002.

[2] Myers et al. 1998.

[3] Martin et al. 2001.

[4] Snider and Titus 2000.

[5] U.S. Fish and Wildlife Service 2006.

Juvenile Sacramento River winter-run Chinook salmon occur in the Delta primarily from November through early May based on data collected from trawls in the Sacramento River at West Sacramento (river mile 55) (U.S. Fish and Wildlife Service 2006), although the overall timing may extend from September to April (National Marine Fisheries Service 2012). The timing of migration varies somewhat because of changes in river flows, dam operations, seasonal water temperatures, and hydrologic conditions (water year type). Winter-run Chinook salmon juveniles remain in the Delta until they reach a fork length of approximately 118 millimeters and are between 5 and 10 months of age. It has been hypothesized that changes in habitat conditions in the Delta over the past century have resulted in a reduction in extended juvenile salmon rearing when compared to periods when habitat for juvenile salmon rearing was more suitable. The reduction of floodplain habitat may have significant negative impacts on winter-run Chinook salmon. The shallow water habitat occurring in floodplains provide for higher abundances of food and warmer temperatures, which promotes rapid growth. Presumably resulting in larger out-migrants which have higher survival rates in the ocean (Sommer et al. 2001). Emigration to the ocean begins as early as November and continues through May (Fisher 1994; Myers et al. 1998). The importance of the Delta in the life history of Sacramento River winter-run Chinook salmon is not well understood.

Data from the Pacific States Marine Fisheries Commission Regional Mark Information System database indicate that Sacramento River winter-run Chinook salmon adults are not as broadly distributed along the Pacific Coast as other Central Valley Chinook salmon runs and concentrate in the region between San Francisco and Monterey. This localized distribution may indicate a unique life history strategy related to the fact that Sacramento River winter-run Chinook salmon also mature at a relatively young age (Myers et al. 1998). Sacramento River winter-run Chinook salmon remain in the ocean environment for 2 to 4 years.

11A.3.5 Threats and Stressors

NMFS issued a final listing determination on June 28, 2005, concluding that the ESU was still "in danger of extinction" due to risks associated with its reduced diversity and spatial structure. The major concerns were that there is only one extant population, and it is spawning outside of its historical range, in artificially maintained habitat that is vulnerable to drought, climate change, and other catastrophes. There was also a concern over the increasing number of Livingston Stone National Fish Hatchery fish spawning in natural areas, although the duration and extent of this possible introgression was still consistent with a low extinction risk as of 2004 (National Marine Fisheries Service 2011). Since 2000, the proportion of hatchery-origin fish spawning in the Sacramento River has generally ranged between 5–10% of the total population, except for in 2005 when it reached approximately 20% of the population, which is consistent with the goals of the hatchery program (National Marine Fisheries Service 2011).

The following conditions have been identified as important threats and stressors to winter-run Chinook salmon.

11A.3.5.1 Reduced Staging and Spawning Habitat

Access to much of the historical upstream spawning habitat for winter-run Chinook salmon (Figure 2A.3-1) has been eliminated or degraded by artificial structures (e.g., dams and weirs) associated with water storage and conveyance, flood control, and diversions and exports for municipal, industrial, agricultural, and hydropower purposes (Yoshiyama et al. 1998). The construction and operation of Shasta Dam reduced the winter-run Chinook salmon ESU from four independent populations to just one. The remaining available habitat for natural spawners is currently maintained with cool water releases from Shasta and Keswick dams, thereby significantly limiting spatial distribution of this ESU in the reach of the mainstem Sacramento River immediately downstream of the dam.

Issues resulting from dam operation for water storage arise when flows are suddenly dropped back to baselines after water has been released to make room in Shasta Reservoir for floodwater storage. If 10,000 cubic feet per second (cfs) are being delivered during a spawning period, which then dropped to 3,500 cfs, there would be a 29.5% redd dewatering (U.S. Fish and Wildlife Service 2006). Upstream diversions and dams have decreased downstream flows and altered seasonal hydrologic patterns, which have been identified as factors resulting in delayed upstream migration by adults and increased mortality of out-migrating juveniles (Yoshiyama et al. 1998; California Department of Water Resources 2005). Dams and reservoir impoundments and associated reductions in peak flows have blocked gravel recruitment and reduced the flushing of sediments from existing gravel beds, reducing and degrading natal spawning grounds. Furthermore, reduced flows can lower attraction cues for adult spawners, causing straying and delays in spawning (California Department of Water

Resources 2005). Adult salmon migration delays can reduce fecundity and increase susceptibility to disease and harvest (McCullough 1999).

The Red Bluff Diversion Dam, located on the Sacramento River, has been identified as a barrier and impediment to adult winter-run Chinook salmon upstream migration. Although the Red Bluff Diversion Dam is equipped with fish ladders, migration delays occur when the dam gates are closed. Mortality, as a result of increased predation by Sacramento pikeminnow on juvenile salmon passing downstream through the fish ladder, has also been identified as a factor affecting abundance of salmon produced on the Sacramento River (Hallock 1991). The construction and operation of the Red Bluff Diversion Dam has been identified as one of the primary factors contributing to the decline in winter-run Chinook salmon abundance that lead to listing of the species under the ESA.

The Battle Creek Salmon and Steelhead Restoration Project will eventually remove five dams on Battle Creek, install fish screens and ladders on three dams, and end the diversion of water from the North Fork to the South Fork. When the program is completed, about 48 miles of additional habitat will be accessible to winter-run Chinook salmon. While a reintroduction plan has not been developed, a few adult spawners have already been observed returning to Battle Creek (National Marine Fisheries Service 2011).

11A.3.5.2 Reduced Rearing and Out-Migration Habitat

Juvenile winter-run Chinook salmon prefer natural stream banks, floodplains, marshes, and shallow water habitats for rearing during out-migration. Channel margins throughout the Delta have been leveed, channelized, and fortified with riprap for flood protection and island reclamation, reducing and degrading the value of natural habitat available for juvenile Chinook salmon rearing (Brandes and McLain 2001). Artificial barriers further reduce and degrade rearing and migration habitat and delay juvenile out-migration. Juvenile out-migration delays can reduce fitness and increase susceptibility to diversion screen impingement, entrainment, disease, and predation. Modification of natural flow regimes from upstream reservoir operations has resulted in dampening and altering the seasonal timing of the hydrograph, reducing the extent and duration of seasonal floodplain inundation and other flow-dependent habitat used by migrating juvenile Chinook salmon (70 FR 52488; Sommer et al. 2001; California Department of Water Resources 2005).

Recovery of floodplain habitat in the Central Valley has been found to contribute to increased production in fall-run Chinook salmon (Sommer et al. 2001), but little is known about the potential benefits of recovered floodplains during the migration period for winter-run fish, although Sommer et al. (2001) noted that the reduction of floodplain habitat might have significant negative impacts on winter-run Chinook salmon. Reductions in flow rates have resulted in increased seasonal water temperatures. The potential adverse effects of dam operations and reductions in seasonal river flows, such as delays in juvenile emigration and exposure to a higher proportion of agricultural return flows, have all been identified as factors that could affect the survival and success of winter-run Chinook salmon inhabiting the Sacramento River in the future.

Tidal areas form important rearing habitat for foraging juvenile salmonids. Studies have shown that foraging salmonids may spend 2 to 3 months in the Delta (e.g., fall-run Chinook salmon [Kjelson et al. 1982], winter-run Chinook salmon [Del Rosario et al. in review]). Loss of tidal habitat because of land reclamation facilitated by levee construction is considered to be a major stressor on juvenile salmonids in the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) conceptual model (Williams 2009).

Channel margins have been considerably reduced because of the construction of levees and the armoring of their banks with riprap (Williams 2009). These shallow-water habitat areas provide refuge from unfavorable hydraulic conditions and predation, as well as foraging habitat for out-migrating juvenile salmonids. Recent research has focused on the use of channel margin habitat by Chinook salmon fry (McLain and Castillo 2009; H.T. Harvey & Associates with PRBO Conservation Science 2010). Benefits for larger Chinook salmon migrant juveniles and steelhead may be somewhat less than for foraging Chinook salmon fry, although the habitat may serve an important function as holding areas during downstream migration (Burau et al. 2007), thereby improving connectivity along the migration route.

11A.3.5.3 Predation by Nonnative Species

Predation on juvenile salmon by nonnative fish has been identified as an important threat to winter-run Chinook salmon in areas with high densities of nonnative fish (e.g., small, and largemouth bass, striped bass, and catfish) that prey on out-migrating juveniles (Lindley and Mohr 2003). On the main stem Sacramento River, high rates of predation are known to occur at the Red Bluff Diversion Dam, the Anderson-Cottonwood and Glenn Colusa Irrigation District diversion facilities, areas where rock revetment has replaced natural river bank vegetation, and at South Delta water diversion structures (e.g., Clifton Court Forebay) (California Department of Fish and Game 1998). Predation at Red Bluff Diversion Dam on juvenile winter-run Chinook salmon is believed to be higher than normal because of flow dynamics associated with the operation of this structure. Because of their small size, early emigrating winter-run Chinook salmon may be highly susceptible to predation in Lake Red Bluff when the Red Bluff Diversion Dam gates remain closed in summer and early fall. In passing the dam, juveniles are subject to disorienting conditions, making them highly susceptible to predation by fish or birds (National Marine Fisheries Service 2012). However, Red Bluff Diversion Dam operations, established in the 2009 Operations Criteria and Plan (OCAP) Biological Opinion (BiOp), are expected to reduce these predation levels by having the gates open year-round.

Water temperatures are generally lower during out-migration of winter-run compared to other salmonids, and may ameliorate predation pressures that can increase with increasing water temperature. In addition, nonnative aquatic vegetation, such as Brazilian waterweed (*Egeria densa*) and water hyacinth (*Eichhornia crassipes*), provide suitable habitat for nonnative predators (Nobriga et al. 2005; Brown and Michniuk 2007). Predation risk may also vary with increased temperatures. Metabolic rates of nonnative, predatory fish increase with increasing water temperatures based on bioenergetic studies (Loboschefsky et al. 2009; Miranda et al. 2010). The low spatial complexity and reduced habitat diversity (e.g., lack of cover) of channelized waterways in the Sacramento River and Delta reduces refuge space of salmon from predators (Raleigh et al. 1984; Missildine et al. 2001; 70 FR 52488).

Increased predation mortality by native fish species, such as Sacramento pikeminnow at the Red Bluff Diversion Dam, has also been identified as a factor affecting the survival of juvenile salmon in the Sacramento River and Delta.

11A.3.5.4 Harvest

Commercial and recreational harvest of winter-run Chinook salmon in the ocean and inland fisheries has been a subject of management actions by the California Fish and Game Commission and the Pacific Fishery Management Council. The primary concerns focus on the effects of harvest on wild Chinook salmon produced in the Central Valley, as well as the incidental harvest of winter-run

Chinook salmon as part of the fall- and late fall-run salmon fisheries. Naturally reproducing winter-run Chinook salmon are less able to withstand high harvest rates when compared to hatchery-based stocks. This intolerance is attributed to differences in survival rates for incubating eggs and rearing and emigrating juvenile salmon produced in streams and rivers (relatively low survival rates) compared to Central Valley salmon hatcheries (relatively high survival rates) (Knudsen et al. 1999). As a result of recent changes in fishing regulations and restrictions on harvest, commercial and recreational fishing does not appear to have a significant impact on winter-run Chinook salmon populations, but continued assessment is warranted.

Commercial fishing for salmon in west coast ocean waters is managed by the Fishery Management Council and is constrained by time and area closures to meet the Sacramento River winter-run ESA consultation standard and restrictions that require minimum size limits and the use of circle hooks for anglers. Ocean harvest restrictions since 1995 have led to reduced ocean harvest of winter-run Chinook salmon (i.e., Central Valley Chinook salmon ocean harvest index, ranged from 0.55 to nearly 0.80 from 1970 to 1995, and was reduced to 0.27 in 2001). Major restrictions in the commercial fishing industry in California and Oregon were enforced to protect Klamath River coho salmon stocks. Because the fishery is mixed, these restrictions have likely reduced harvest of winter-run Chinook salmon as well. The California Department of Fish and Wildlife (CDFW), NMFS, and Pacific Fishery Management Council continually monitor and assess the effects of the harvest of winter-run Chinook salmon, such that regulations can be refined and modified as new information becomes available. However, previous harvest practices are the likely cause of the predominance of 3-year-old spawners, with few (if any) 4- and 5-year-old fish surviving the additional years in the ocean to return as spawners (National Marine Fisheries Service 2012).

Since 2005, NMFS has issued a new biological opinion (National Marine Fisheries Service 2010) addressing the ocean harvest impacts on this ESU from commercial and sport fisheries. The biological opinion concluded the fisheries jeopardized the species, and therefore, imposed further restrictions on the minimum retention size and fishing effort that are expected to reduce ocean harvest impacts. In summary, the available information indicates that the level of ocean fishery impacts on this ESU have not changed appreciably since the 2005 status review (Good et al. 2005), although they are expected to be much reduced in 2008 and 2009 because of ocean fishery closures (National Marine Fisheries Service 2011).

Because adult winter-run Chinook salmon hold in the mainstem Sacramento River until spawning during the summer months, they are particularly vulnerable to illegal (poaching) harvest. Various watershed groups have established public outreach and educational programs in an effort to reduce poaching. In addition, CDFW wardens have increased enforcement against illegal harvest of winter-run Chinook salmon. The level and effect of illegal harvest on adult winter-run Chinook salmon abundance and population reproduction is unknown.

11A.3.5.5 Reduced Genetic Diversity and Integrity

Artificial propagation programs conducted for winter-run Chinook salmon conservation purposes (i.e., Livingston Stone National Fish Hatchery) were developed to increase the abundance and diversity of winter-run Chinook salmon and to protect the species from extinction in the event of a catastrophic failure of the wild population. It is unclear what the effects of the hatchery propagation program are on the productivity and spatial structure of the winter-run Chinook salmon ESU (i.e., genetic fitness and productivity). One of the primary concerns with hatchery operations is the genetic introgression by hatchery origin fish that spawn naturally and interbreed with local natural populations (U.S. Fish and Wildlife Service 2001; Bureau of Reclamation 2004; Goodman 2005). It is now recognized that Central Valley hatcheries are a significant and persistent threat to wild Chinook salmon and steelhead populations and fisheries (National Marine Fisheries Service 2009a). Such introgression introduces maladaptive genetic changes to the wild winter-run stocks and may reduce overall fitness (Myers et al. 2004; Araki et al. 2007). Taking egg and sperm from a large number of individuals is one method to ameliorate genetic introgression, but artificial selection for traits that assure individual success in a hatchery setting (e.g., rapid growth and tolerance to crowding) are unavoidable (Bureau of Reclamation 2004).

Hatchery-origin winter-run Chinook salmon from Livingston Stone National Fish Hatchery represent more than 5% of the natural spawning run in recent years and as high as 18% in 2005 (National Marine Fisheries Service 2012). Lindley et al. (2007) recommended reclassifying the winter-run Chinook population extinction risk as moderate, rather than low, if hatchery introgression exceeds about 15% over multiple generations of spawners. Since 2005, however, the percentage of hatchery fish has been consistently below 15% of the spawning run (National Marine Fisheries Service 2012).

Investigations are continuing to evaluate the genetic characteristics of winter-run Chinook salmon, improve genetic management of the artificial propagation program, evaluate the minimum viable population size that would maintain genetic integrity in the population, and explore methods for establishing additional independent winter-run Chinook salmon populations as part of recovery planning and conservation of the species.

11A.3.5.6 Entrainment

The vulnerability of juvenile winter-run Chinook salmon to entrainment and salvage at SWP/CVP export facilities varies in response to multiple factors, including the seasonal and geographic distribution of juvenile salmon in the Delta, operation of Delta Cross Channel gates, hydrodynamic conditions occurring in the central and southern regions of the Delta (e.g., Old and Middle Rivers), and export rates. The loss of fish to entrainment mortality has been identified as an impact on Chinook salmon populations (Kjelson and Brandes 1989). Juvenile winter-run Chinook salmon tend to be distributed in the central and southern Delta where they have an increased risk of entrainment and salvage between February and April (Table 2A.3-1), with nearly 50% of the average annual salvage occurring in March (National Marine Fisheries Service 2012).

The effect of changing hydrodynamics in Delta channels, such as reversed flows in Old and Middle rivers resulting from SWP/CVP export operations, has the potential to increase attraction of emigrating juveniles into false migration pathways, delay emigration through the Delta, and directly or indirectly increase vulnerability to entrainment at unscreened diversions. In addition, there is an increase in the risk of predation and duration of exposure to seasonally elevated water temperatures and other water quality conditions. SWP/CVP exports have been shown to affect the tidal hydrodynamics (e.g., water current velocities and direction). The magnitude of these hydrodynamic effects vary in response to a variety of factors including tidal stage and magnitude of ebb and flood tides, the rate of SWP/CVP exports, operation of the Clifton Court Forebay radial gate opening, and inflow from the upstream tributaries.

Chinook salmon behaviorally respond to hydraulic cues (e.g., water currents) during both upstream adult and downstream juvenile migration through the Delta. Changes in these hydraulic cues as a result of SWP/CVP export operations during the period that salmon are migrating through Delta channels may contribute to the use of false migration pathways, delays in migration, or increased movement of migrating salmon toward the export facilities leading to an increase in entrainment risk. During the past several years, additional investigations have been designed using radio or acoustically tagged juvenile Chinook salmon to monitor migration behavior through the Delta channels and to assess the effects of changes in hydraulic cues and SWP/CVP export operations on migration (Holbrook et al. 2009; Perry et al. 2010, San Joaquin River Group Authority 2010). These studies are ongoing.

Incidental take of juvenile winter-run Chinook salmon at the SWP/CVP export fish salvage facilities is routinely monitored and reported as part of export operations. Salvage monitoring and the protocol for identifying juvenile winter-run Chinook salmon from other Central Valley Chinook salmon have been refined over the past decade. Run identification was originally determined based on the length of each fish and the date it was collected. Subsequent genetic testing has been used to refine species identification. Methods for estimating juvenile winter-run Chinook salmon production each year (year class strength) have been developed that take into account the number of adults spawning in the river from carcass surveys, hatching success based on a consideration of water temperatures and other factors, and estimated juvenile survival. Authorized incidental take can then be adjusted each year (1% to 2% of juvenile production) to reflect the relative effect of take at a population level rather than based on a predetermined level that does not reflect year-to-year variation in juvenile production in the Sacramento River.

In addition to SWP/CVP exports, there are more than 2,200 small water diversions throughout the Delta, including unscreened diversions located on the tributary rivers (Herren and Kawasaki 2001). The risk of entrainment is a function of the size of juvenile fish and the slot opening of the screen mesh (Tomljanovich et al. 1978; Schneeberger and Jude 1981; Zeitoun et al. 1981; Weisberg et al. 1987). Many juvenile winter-run Chinook salmon migrate downstream through the Delta during the late winter or early spring when many of the agricultural irrigation diversions are not operating or are only operating at low levels. Juvenile winter-run Chinook salmon also migrate primarily in the upper part of the water column, reducing their vulnerability to unscreened diversions located near the channel bottom. No quantitative estimates have been developed to assess the potential magnitude of entrainment losses for juveniles migrating through the rivers and Delta, or the effects of these losses on the overall population abundance of returning adult Chinook salmon. The effect of entrainment mortality on the population dynamics and overall adult abundance of winter-run Chinook salmon is not well understood.

Power plants in the Plan Area have the ability to impinge and entrain juvenile Chinook salmon on the existing cooling water system intake screens. However, use of cooling water is currently low with the retirement of older units. Furthermore, newer units are being equipped with a closed-cycle cooling system that virtually eliminates the risk of impingement of juvenile salmon.

Besides mortality, salmon fitness may be affected by delays in out-migration of smolts caused by reduced or reverse flows. Delays in migration resulting from water management related to SWP/CVP operations can make juvenile salmonids more susceptible to many of the threats and stressors discussed in this section, such as predation, entrainment, angling, exposure to poor water quality, and disease. The quantitative relationships among changes in Delta hydrodynamics, the behavioral and physiological response of juvenile salmon, and the increase or decrease in risk associated with other threats is unknown, but is currently the subject of a number of investigations and analyses.

11A.3.5.7 Exposure to Toxins

Inputs of toxins into the Delta watershed include agricultural drainage and return flows, municipal wastewater treatment facilities, and other point and nonpoint discharges (Moyle 2002). These toxic substances include mercury, selenium, copper, pyrethroids, and endocrine disruptors with the potential to affect fish health and condition, and adversely affect salmon distribution and abundance. Toxic chemicals have the potential to be widespread throughout the Sacramento River and Delta, or may occur on a more localized scale in response to episodic events (e.g., stormwater runoff and point source discharges). Agricultural return flows are widely distributed throughout the Sacramento River and the Delta, although dilution flows from the rivers may reduce chemical concentrations to sublethal levels. Toxic algae (e.g., Microcystis) have also been identified as a potential factor adversely affecting salmon and other fish. Exposure to these toxic materials has the potential to directly and indirectly adversely affect salmon distribution and abundance.

Concern regarding exposure to toxic substances for Chinook salmon includes both waterborne chronic and acute exposure, but also bioaccumulation and chronic dietary exposure. For example, selenium is a naturally occurring constituent in agricultural drainage water return flows from the San Joaquin River that is then dispersed downstream into the Delta (Nichols et al. 1986). Exposure to selenium in the diet of juvenile Chinook salmon has been shown to result in toxic effects (Hamilton et al. 1990; Hamilton and Buhl 1990). Selenium exposure has been associated with agricultural and natural drainage in the San Joaquin River basin and refining operations adjacent to San Pablo and San Francisco Bays.

Other contaminants of concern for Chinook salmon include, but are not limited to, mercury, copper, oil and grease, pesticides, herbicides, ammonia, and localized areas of depressed dissolved oxygen (e.g., Stockton Deep Water Ship Channel and return flows from managed freshwater wetlands). As a result of the extensive agricultural development in the Central Valley, exposure to pesticides and herbicides has been identified as a significant concern for salmon and other fish species in the Plan Area (Bennett et al. 2001). In recent years, changes have been made in the composition of herbicides and pesticides used on agricultural crops in an effort to reduce potential toxicity to aquatic and terrestrial species. Modifications have also been made to water system operations and discharges related to agricultural wastewater discharges (e.g., agricultural drainage water system lock-up and holding prior to discharge) and municipal wastewater treatment and discharges. Ammonia released from the City of Stockton Wastewater Treatment Plant contributes to the low dissolved oxygen conditions in the adjacent Stockton Deep Water Ship Channel. In addition to the adverse effects of the lowered dissolved oxygen on salmonid physiology, ammonia is toxic to salmonids at low concentrations. Actions have been implemented to remedy this source of ammonia, by modifying the treatment train at the wastewater facility (National Marine Fisheries Service 2012). Concerns remain, however, regarding the toxicity of contaminants such as pyrethroids that adsorb to sediments and other chemicals (e.g., including selenium and mercury, as well as other contaminants) on salmon.

Mercury and other metals such as copper have also been identified as contaminants of concern for salmon and other fish, as a result of direct toxicity and impacts such related to acid mine runoff from sites such as Iron Mountain Mine (U.S. Environmental Protection Agency 2006). The potential problems include tissue bioaccumulation that may adversely affect the fish, but also represent a human health concern (Gassel et al. 2008). These materials originate from a variety of sources including mining operations, municipal wastewater treatment, agricultural drainage in the tributary rivers and Delta, nonpoint runoff, natural runoff and drainage in the Central Valley, agricultural spraying, and a number of other sources.

The State Water Resources Control Board (State Water Board), Central Valley Regional Water Quality Control Board (CVRWQCB), U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), California Department of Water Resources (DWR), and others have ongoing monitoring programs designed to characterize water quality conditions and identify potential toxins and contaminant exposure to Chinook salmon and other aquatic resources in the Plan Area. Programs are in place to regulate point source discharges as part of the National Pollutant Discharge Elimination System (NPDES) program, as well as programs to establish and reduce total daily maximum loads of various constituents entering the Delta. Changes in regulations have also been made to help reduce chemical exposure and reduce the adverse impacts on aquatic resources and habitat conditions in the Plan Area. These monitoring and regulatory programs are ongoing. Regulations and changes in monitoring and management of agricultural pesticide and herbicide chemicals and their application, education on the effects of urban runoff and chemical discharges, and refined treatment processes have been adopted over the past several decades in an effort to reduce the adverse effects of chemical pollutants on salmon and other aquatic species.

In the final listing determination of the ESU, acid mine runoff from Iron Mountain Mine, located adjacent to the upper Sacramento River, was identified as one of the main threats to winter-run Chinook salmon (Upper Sacramento River Fisheries and Riparian Habitat Advisory Council 1989). Acid mine drainage, including elevated concentrations of metals, produced from the abandoned mine degraded spawning habitat of winter-run Chinook salmon and resulted in high mortality. Storage limitations and limited availability of dilution flows have caused downstream copper and zinc levels to exceed salmonid tolerances and resulted in documented fish kills in the 1960s and 1970s (Bureau of Reclamation 2004). EPA's Iron Mountain Mine remediation program and 2002 restoration plan has removed toxic metals in acidic mine drainage from the Spring Creek watershed with a state-of-the-art lime neutralization plant. Contaminant loading into the Sacramento River from Iron Mountain Mine has shown measurable reductions since the early 1990s. Pollution from Iron Mountain Mine is no longer considered to be a main factor threatening the winter-run Chinook salmon ESU.

Concern has been expressed regarding the potential to resuspend toxic materials into the water column where they may adversely affect salmon through seasonal floodplain inundation, habitat construction projects, channel and harbor maintenance dredging, and other means. For example, mercury deposits exist at a number of locations in the Central Valley and Delta, including the Yolo Bypass. Seasonal inundation of floodplain areas, such as in the Yolo Bypass, has the potential to create anaerobic conditions that contribute to the methylation of mercury, which increases toxicity. Additionally, there are problems with scour and erosion of these mercury deposits by increased seasonal flows. Similar concerns exist regarding creating aquatic habitat by flooding Delta islands or disturbance created by levee setback construction or other habitat enhancement measures. The potential to increase toxicity as a result of habitat modifications designed to benefit aquatic species is one of the factors that needs to be considered when evaluating the feasibility of habitat enhancement projects in the Central Valley.

Sublethal concentrations of toxics may interact with other stressors on salmonids, such as increasing their vulnerability to mortality as a result of exposure to seasonally elevated water temperatures, predation or disease (Werner 2007). For example, Clifford et al. (2005) found in a laboratory setting that juvenile fall-run Chinook salmon exposed to sublethal levels of a common pyrethroid, esfenvalerate, were more susceptible to the infectious hematopoietic necrosis virus than those not exposed to esfenvalerate. Although not tested on winter-run Chinook salmon, a similar response is likely.

11A.3.5.8 Increased Water Temperature

Water temperature is among the physical factors that affect the value of habitat for salmonid adult holding, spawning and egg incubation, juvenile rearing, and migration. Adverse sublethal and lethal effects can result from exposure to elevated water temperatures at sensitive lifestages, such as during incubation or rearing. The Central Valley is the southern limit of Chinook salmon geographic distribution and increased water temperatures are often recognized as an important stressor to California populations. Water temperature criteria for various life stages of salmonids in the Central Valley have been developed by NMFS (2009a).

The tolerance of winter-run Chinook salmon to water temperatures depends on life stage, acclimation history, food availability, duration of exposure, health of the individual, and other factors, such as predator avoidance (Myrick and Cech 2004; Bureau of Reclamation 2004). Higher water temperatures can lead to physiological stress, reduced growth rates, prespawning mortality, reduced spawning success, and increased mortality of salmon (Myrick and Cech 2001). Temperature can also indirectly influence disease incidence and predation (Waples et al. 2008). Exposure to seasonally elevated water temperatures may occur as a result of reductions in flow, as a result of upstream reservoir operations, reductions in riparian vegetation, channel shading, local climate and solar radiation.

The installation of the Shasta Temperature Control Device in 1998, in combination with reservoir management to maintain the cold water pool in Shasta Reservoir, has reduced many of the temperature issues on the Sacramento River. Water temperature management on the Sacramento River has been specified in the NMFS biological opinion and has been identified as one of the factors contributing to the observed increase in adult winter-run Chinook salmon abundance in some recent years. During dry years, however, the release of cold water from Shasta Dam is still limited. As the river flows further downstream, particularly during the warm spring, summer, and early fall months, water temperatures continue to increase until they reach thermal equilibrium with atmospheric conditions. As a result of the longitudinal gradient of seasonal water temperatures, the coldest temperatures and best areas for winter-run Chinook salmon spawning and rearing are typically located immediately downstream of Keswick Dam.

Increased temperature can also arise from a reduction in shade over rivers by tree removal (Watanabe et al. 2005). Because river water is typically in thermal equilibrium with atmospheric conditions by the time it enters the Delta, this issue is caused primarily from actions upstream of the Delta. As a result of the relatively wide channels that occur in the Delta, the effects of additional riparian vegetation on reducing water temperatures in the Delta are minimal.

The effects of climate change and global warming patterns, in combination with changes in precipitation and seasonal hydrology in the future, have been identified as important factors that may adversely affect the health and long-term viability of Sacramento River winter-run Chinook salmon (Crozier et al. 2008). The rate and magnitude of these potential future environmental changes, and their effect of habitat value and availability for winter-run Chinook salmon, however, are subject to a high degree of uncertainty.

11A.3.6 Relevant Conservation Efforts

Since the listing of Sacramento River winter-run Chinook salmon, several habitat and harvest-related problems that were identified as factors contributing to the decline of the species have been addressed and improved through restoration and conservation actions. The impetus for initiating restoration actions stems primarily from the following actions.

- ESA Section 7 consultation Reasonable and Prudent Alternatives on temperature, flow, and operations of the CVP and SWP (National Marine Fisheries Service 2009b).
- Regional Water Quality Control Board decisions requiring compliance with Sacramento River water temperature objectives which resulted in the installation of the Shasta Temperature Control Device in 1998.
- A 1992 amendment to the authority of the CVP through the Central Valley Improvement Act to give fish and wildlife equal priority with other CVP objectives.
- Fiscal support of habitat improvement projects from the CALFED Bay-Delta Program (CALFED) (e.g., installation of a fish screen on the Glenn-Colusa Irrigation District diversion).
- Establishment of the CALFED Environmental Water Account.
- EPA actions to control acid mine runoff from Iron Mountain Mine.
- Ocean harvest restrictions implemented in 1995.

Results of monitoring at the CVP and SWP fish salvage facilities and extensive experimentation over the past several decades have led to the identification of a number of management actions designed to reduce or avoid the potentially adverse effects of SWP/CVP export operations on salmon. Many of these actions have been implemented through State Water Board water quality permits (D-1485, D-1641), biological opinions issued on project export operations by NMFS, U.S. Fish and Wildlife Service (USFWS), and CDFW, as part of CALFED programs (e.g., Environmental Water Account), and as part of Central Valley Project Improvement Act actions. These requirements support multiple conservation efforts to enhance habitat and reduce entrainment of Chinook salmon by the SWP/CVP export facilities.

The artificial propagation program for winter-run Chinook salmon at Livingston Stone National Fish Hatchery, located on the mainstem of the Sacramento River, has operated for conservation purposes since the early 1990s. In 2010, about 12% of the spawning population consisted on hatchery fish, and only wild (not fin-clipped) fish are currently being spawned in the hatchery to reduce domestication effects on the population (National Marine Fisheries Service 2011).

Biological opinions for SWP/CVP operations (National Marine Fisheries Service 2009b) and other federal projects involving irrigation and water diversion and fish passage, for example, have improved or minimized adverse impacts on salmon in the Central Valley. In 1992, an amendment through the Central Valley Project Improvement Act gave protection of fish and wildlife equal priority with other CVP objectives. From this act arose several programs that have benefited listed salmonids. The Anadromous Fish Restoration Program is engaged in monitoring, education, and restoration projects designed to contribute toward doubling the natural populations of select anadromous fish species residing in the Central Valley. Restoration projects funded through the Anadromous Fish Restoration Program include fish passage, fish screening, riparian easement and land acquisition, development of watershed planning groups, instream and riparian habitat improvement, and gravel replenishment. The Anadromous Fish Screen Program combines federal funding with state and private funds to prioritize and construct fish screens on major water diversions mainly in the upper Sacramento River. Despite these and other conservation efforts, the program has fallen short of the goal of doubling the natural production of Sacramento River winter-run Chinook salmon (National Marine Fisheries Service 2011).

The goal of the Water Acquisition Program is to acquire water supplies to meet the habitat restoration and enhancement goals of the Central Valley Project Improvement Act, and to improve the ability of the U.S. Department of the Interior to meet regulatory water quality requirements. Water has been used to improve fish habitat for Central Valley salmon, with the primary focus on listed Chinook salmon and steelhead, including winter-run Chinook salmon, by maintaining or increasing instream flows (e.g., Environmental Water Account) on the Sacramento River at critical times, and to reduce salmonid entrainment at the SWP/CVP export facilities through reducing seasonal diversion rates during periods when protected fish species are vulnerable to export related losses. However, impacts from factors such as drought, climate change and poor survival conditions have increased in recent years and are likely to be substantial contributing factors to the declining abundance of the ESU (National Marine Fisheries Service 2011).

Two programs included under CALFED, the Ecosystem Restoration Program and the Environmental Water Account, were created to improve conditions for fish, including winter-run Chinook salmon, in the Central Valley. As part of developing the program, a series of conceptual models (DRERIP) have been constructed to provide a framework for identifying and assessing the benefits and/or consequences of potential restoration actions. The DRERIP models are being used to evaluate proposed conservation measures, as well as restoration actions as part of the program. Restoration actions implemented by the program include the installation of fish screens, modification of barriers to improve fish passage, habitat acquisition, and instream habitat restoration. The majority of these actions address key factors and stressors affecting listed salmonids. Additional ongoing actions include efforts to enhance fishery monitoring and improvements to hatchery management to support salmonid production through hatchery releases.

A major CALFED Ecosystem Restoration Program action currently under way is the Battle Creek Salmon and Steelhead Restoration Project. Although winter-run Chinook salmon do not currently inhabit Battle Creek, they occurred there historically. CALFED is funding the establishment of a second independent population of winter-run Chinook salmon in the upper Battle Creek watershed using the artificial propagation program as a source of fish. The project will restore 77 kilometers (48 miles) of habitat in Battle Creek to support steelhead and Chinook salmon spawning and juvenile rearing at a cost of over $90 million. The project includes removal of five small hydropower diversion dams, construction of new fish screens and ladders on another three dams, and construction of several hydropower facility modifications to ensure the continued hydropower operations. This restoration effort is thought to be the largest coldwater restoration project to date in North America. Other than the potential benefits of the Battle Creek restoration effort, there has been very limited habitat expansion, but no substantial changes in habitat condition or availability since the ESU was listed (National Marine Fisheries Service 2011).

As part of CALFED and Central Valley Project Improvement Act programs, many of the largest water diversions located on the Sacramento River and Delta (e.g., Glenn Colusa Irrigation District, Bureau of Reclamation [Reclamation] District 1001 Princeton diversion, RD 108 Wilkins Slough Pumping Plant, Sutter Mutual Water Company Tisdale Pumping Plant, Contra Costa Water District's Old River and Alternative Intake Project intake, and others) have been equipped with positive barrier fish screens, although the majority of smaller water diversions located on the Sacramento River and

Delta remain unscreened. Reclamation District 108 has also designed and constructed a new fish screen and pumping plant (Poundstone Pumping Plant) located on the Sacramento River that consolidates and eliminates three existing unscreened water diversions. These fish-screening projects are specifically intended to reduce and avoid entrainment losses of juvenile winter-run Chinook salmon and other fish inhabiting the river.

The DRERIP was formed to guide the implementation of CALFED Ecosystem Restoration Plan elements in the Delta (California Department of Fish and Game 2007). The DRERIP team has created a suite of ecosystem and species conceptual models, including winter-run Chinook salmon, that document existing scientific knowledge of Delta ecosystems. The DRERIP team has used these conceptual models to assess the suitability of actions proposed in the Ecosystem Restoration Plan for implementation. DRERIP conceptual models were used in the analysis of proposed conservation measures.

The Central Valley Salmonid Project Work Team, an interagency technical working group led by CDFW, drafted a proposal to develop a Chinook salmon escapement monitoring plan that was selected by the CALFED Ecosystem Restoration Program Implementing Agency Managers for directed action funding.

Recent habitat restoration initiatives sponsored primarily by the CALFED Ecosystem Restoration Program have funded 29 projects (approximately $24 million) designed to restore ecological function to 9,543 acres (8,091 acres in the Bay Area and the remaining acres located in the Delta and Eastside Tributaries Regions of the CALFED action area) of shallow-water tidal and marsh habitats in the Delta. Over the last 11 years, the CALFED Ecosystem Restoration Program has provided funding for about 580 projects, totaling over $700 million, and is currently managing 74 previously funded projects and 18 newly funded projects totaling about $24 million (California Department of Fish and Game et al. 2011). The majority of the funding has been spent on project focusing on riparian habitat restoration, fish screen installations, water and sediment quality improvements, and stream hydrodynamic enhancements.

EPA's Iron Mountain Mine remediation involves removing toxic metals in acidic mine drainage from the Spring Creek Watershed with a state-of-the-art lime neutralization plant. Contaminant loading into the Sacramento River from Iron Mountain Mine, and other mining operations, has shown measurable reductions since the early 1990s. Decreasing the heavy metal contaminants that enter the Sacramento River should increase the survival of salmonid eggs and juveniles. However, during periods of heavy rainfall upstream of the Iron Mountain Mine, Reclamation substantially increases Sacramento River flows to dilute heavy metal contaminants being spilled from the Spring Creek debris dam. This rapid change in flows can cause juvenile salmonids to become stranded or isolated in side channels below Keswick Dam.

In 2001, a new fish screen was constructed at the Anderson Cottonwood Irrigation District Diversion Dam and a state-of-the-art fish ladder was installed to address the threats caused by the dam. As described in the final listing determination for the ESU (70 FR 37160), the flashboard gates and inadequate fish ladders at the diversion dam blocked passage for upstream migrant winter-run Chinook salmon. Seasonal operation of the dam created unsuitable habitat upstream of the dam by reducing flow velocity over the incubating eggs, reducing egg survival. Evaluation of the fish ladder is ongoing.

To help reduce the effects of the Red Bluff Diversion Dam operation on migration of adult and juvenile salmonids and other species, management has changed in recent years to maintain the dam gates in the open position for a longer period of time, and thereby facilitate greater upstream and downstream migration. Changes in dam operations have benefited both upstream and downstream migration by salmon and have contributed to a reduction in juvenile predation mortality. In 2009, Reclamation received funding for the Fish Passage Improvement Project at the Red Bluff Diversion Dam to build a pumping facility to provide reliable water supply for high-valued crops in Tehama, Glenn, Colusa, and northern Yolo Counties, while providing year-round unimpeded fish passage. This project, which is expected to be completed in late 2012, will eliminate passage issues for winter-run Chinook salmon and other migratory species.

DWR's Delta Fish Agreement Program has approved approximately $49 million for projects that benefit salmon and steelhead production in the Sacramento and San Joaquin River basins and Delta since the agreement's inception in 1986. Delta Fish Agreement projects that benefit Sacramento River winter-run Chinook salmon include enhanced law enforcement efforts from San Francisco Estuary upstream into the Sacramento River, spawning gravel augmentations, and habitat enhancement projects. Through the Delta-Bay Enhanced Enforcement Program initiated in 1994, a team of 10 wardens focus their enforcement efforts on salmon, steelhead, and other species of concern from the San Francisco Estuary upstream into the Sacramento and San Joaquin River basins. Enhanced enforcement programs are believed to have had significant benefits on Chinook salmon attributed to CDFW, although results have not been quantified.

Harvest protective measures for Sacramento River winter-run Chinook salmon include seasonal constraints on sport and commercial fisheries south of Point Arena in an effort to reduce harvest of winter-run Chinook salmon. Ocean harvest restrictions since 1995 have led to reduced ocean harvest of winter-run Chinook salmon (i.e., Central Valley Chinook salmon ocean harvest index ranged from 0.55 to nearly 0.80 from 1970 to 1995, and was reduced to 0.27 in 2001). The average 2000 to 2007 harvest index was reduced to 0.17, and the closure of the primary ocean fishery on this stock in 2008 and 2009 is expected to reduce the harvest index to substantially below this level (National Marine Fisheries Service 2011). The state of California has also established specific in-river fishing regulations and no-retention prohibitions designed to protect Sacramento River winter-run Chinook salmon. CDFW has implemented enhanced enforcement efforts to reduce illegal harvests.

11A.3.7 Recovery Goals

The draft recovery plan for Central Valley salmonids, including Sacramento River winter-run Chinook salmon, was released on October 19, 2009 (National Marine Fisheries Service 2009a). Although not final, the overarching goal in the public draft is the removal of Sacramento River winter-run Chinook salmon, among other listed salmonids, from the federal list of Endangered and Threatened Wildlife (National Marine Fisheries Service 2009a). Several objectives and related criteria represent the components of the recovery goal, including the establishment of at least two viable populations in each historical diversity group, as well as other measurable biological criteria.

11A.3.8 References Cited

11A.3.8.1 Literature Cited

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11A.4 Central Valley Spring-Run Chinook Salmon (*Oncorhynchus tshawytscha*)

11A.4.1 Legal Status

The Central Valley spring-run Chinook salmon evolutionarily significant unit (ESU) is listed as a threatened species under the federal Endangered Species Act (ESA). The ESU includes all naturally spawned populations of spring-run Chinook salmon in the Sacramento River and its tributaries in California, including the Feather River (Figure 2A.4-1). The ESU was listed as threatened on September 16, 1999 (64 *Federal Register* [FR] 50394) for the following reasons:

- The species occurred in only a small portion of its historical range.
- From 70 to 90% of spawning and rearing habitats had been lost.
- Abundance declined to low levels (5-year average of 8,500 fish, compared with 40,000 fish in 1940s).
- There is a potential for hybridization between spring- and fall-run fish in hatcheries and the mainstem Sacramento River.

In June 2004, the National Marine Fisheries Service (NMFS) proposed that Central Valley spring-run Chinook salmon remain listed as threatened (69 FR 33102). This proposal was based on the recognition that, although Central Valley spring-run Chinook salmon productivity trends were positive, the ESU continued to face risks from having a limited number of remaining populations (i.e., three existing populations from an estimated 17 historical populations), a limited geographic distribution, and potential hybridization with Feather River Hatchery spring-run Chinook salmon. Until recently, Feather River Hatchery spring-run Chinook salmon were not included in the ESU, yet these fish are genetically distinct from other populations in Mill, Deer, and Butte Creeks.

On June 28, 2005, NMFS issued its final decision to retain the status of Central Valley spring-run Chinook salmon as threatened (70 FR 37160). This decision also included the Feather River Hatchery spring-run Chinook salmon population as part of the Central Valley spring-run Chinook salmon ESU.

On August 15, 2011, after a second 5-year review, NMFS determined that the ESU had an increased extinction risk (National Marine Fisheries Service 2011). With a few exceptions, escapements have declined over the past 10 years, particularly since 2006, placing the Mill and Deer Creek populations at high risk of extinction because of their rate of decline (National Marine Fisheries Service 2011). While the Butte Creek population continues to meet the low extinction risk criteria, the rate of decline is close to triggering the population decline criterion for high risk. Overall, the recent declines have been significant but not severe enough to qualify as a catastrophe under the criteria of Lindley et al. (2007). In addition, spring-run Chinook salmon appear to be repopulating Battle Creek, home to a historical independent population (National Marine Fisheries Service 2011).

Spring-run Chinook salmon was listed as a threatened species under the California Endangered Species Act (CESA) on February 5, 1999.

11A.4.2 Species Distribution and Status

11A.4.2.1 Range and Status

Historically, spring-run Chinook salmon were predominant throughout the Central Valley occupying the upper and middle reaches (1,000 to 6,000 feet) of the San Joaquin, American, Yuba, Feather, Sacramento, McCloud and Pit Rivers, with smaller populations in most tributaries with sufficient habitat for adult salmon holding over the summer months (Figure 2A.4-1) (Stone 1874; Rutter 1904; Clark 1929). Completion of Friant Dam extirpated the native spring-run Chinook salmon population from the San Joaquin River and its tributaries. Naturally spawning populations of Central Valley spring-run Chinook salmon with consistent spawning returns are currently restricted to Butte Creek, Deer Creek, and Mill Creek (Good et al. 2005).

A small spawning population has been documented in Clear Creek (Newton and Brown 2004). In addition, the upper Sacramento River and Yuba River support small populations, but their status is not well documented. The Feather River Hatchery produces spring-run Chinook salmon on the Feather River.

Central Valley spring-run Chinook salmon were once the most abundant run of salmon in the Central Valley (Campbell and Moyle 1992). The Central Valley drainage as a whole is estimated to have supported spring-run Chinook salmon runs as large as 600,000 fish between the late 1880s and 1940s (California Department of Fish and Game 1998). More than 500,000 Central Valley spring-run Chinook salmon were caught in the Sacramento-San Joaquin commercial fishery in 1883 (Yoshiyama et al. 1998). Population estimates of returning spring-run Chinook salmon for the years immediately preceding and after the closure of Friant Dam in February 1944 are as follows (Fry 1961; Yoshiyama et al. 1998):

- 35,000 in 1943
- 5,000 in 1944
- 56,000 in 1945
- 30,000 in 1946
- 6,000 in 1947
- 2,000 in 1948

There were occasional records of returning spring-run Chinook salmon during the 1950s and 1960s in wet years. The San Joaquin River population was essentially extirpated by the late 1940s. Populations in the upper Sacramento, Feather, and Yuba Rivers were eliminated with the construction of major dams from the 1940s through the 1960s.

The Central Valley spring-run Chinook salmon ESU has displayed broad fluctuations in adult abundance between 1960 and 2009 (Figure 2A.4-2). Adult spring-run salmon escapement to the Sacramento River system in 2009 was 3,802 fish. Sacramento River tributary populations in Mill, Deer, and Butte Creeks are probably the best trend indicators for the Central Valley spring-run Chinook ESU as a whole because these streams contain the primary independent populations in the ESU. Generally, there was a positive trend in escapement in these waterways between 1992 and 2005, after which there was a steep decline (Figure 2A.4-3). Adult spring-run salmon escapement to Mill, Deer, and Butte Creeks in 2009 was estimated to be between 2,492 and 2,561 fish. Escapement numbers are dominated by Butte Creek returns, which typically represent nearly 75% of fish returning to these three creeks, although the escapement to Butte Creek in 2009 was approximately 2,059 fish, or 80 to 83% of escapement to these three creeks.

Between 1992 and 2009 there were significant habitat improvements in these watersheds, including the removal of several small dams, increases in summer flows, reduced ocean salmon harvest, and a favorable terrestrial and marine climate. The significant recent declines in adult fall-run Chinook salmon escapement have resulted in significant curtailment of the commercial and recreational salmon fisheries, which is expected also to increase the level of protection and benefit the Central Valley spring-run Chinook salmon population.

On the Feather River, significant numbers of spring-run Chinook salmon, as identified by run timing, return to the Feather River Hatchery. However, coded-wire tag information from these hatchery returns and results of genetic testing indicate that substantial introgression has occurred between fall-run and spring-run Chinook salmon populations in the Feather River because of hatchery practices and the geographic and temporal overlap with spawning fall-run Chinook salmon in the river.

Although recent Central Valley spring-run Chinook salmon population trends are negative, annual abundance estimates display a high level of variation. The overall number of Central Valley spring-run Chinook salmon remains well below estimates of historical abundance. Central Valley spring-run Chinook salmon have some of the highest population growth rates in the Central Valley, but other than Butte Creek and the hatchery-influenced Feather River, population sizes are very small relative to fall-run Chinook salmon populations (Good et al. 2005).

An ESU that is essentially represented by three populations located in the same ecoregion is vulnerable to changes in the environment because it lacks spatial geographic diversity. The current geographic distribution of viable populations makes the Central Valley spring-run Chinook salmon ESU vulnerable to catastrophic disturbance (Lindley et al. 2007; National Marine Fisheries Service 2011). Such potential catastrophes include volcanic eruption of Mt. Lassen, prolonged drought conditions reducing coldwater pool adult holding habitat, and a large wildfire (approximately 30 kilometers maximum diameter) encompassing the Deer, Mill and Butte Creek watersheds. The Central Valley spring-run Chinook salmon ESU remains at a moderate to high risk of extinction for the following reasons:

- The ESU is spatially confined to relatively few remaining streams in its historical range.
- The population continues to display broad fluctuations in abundance.
- A large proportion of the population (in Butte Creek) faces the risk of high mortality rates resulting from high water temperatures during the adult holding period.

11A.4.2.2 Distribution and Status in the Plan Area

The entire population of the Central Valley spring-run Chinook salmon ESU must pass through the Plan Area as migrating adults and emigrating juveniles. Adult Central Valley spring-run Chinook salmon migrate primarily along the western edge of the Sacramento–San Joaquin River Delta (Delta) through the Sacramento River corridor, and juvenile spring-run Chinook salmon use the Delta, Suisun Marsh, and Yolo Bypass for migration and rearing. With the goal of returning spring-run Chinook salmon to the San Joaquin River, the San Joaquin corridor will presumably become an important migration route, with juveniles also using the south, central and west Delta areas as migration and rearing corridors.

11A.4.3 Habitat Requirements and Special Considerations

Critical habitat for spring run Chinook salmon ESU was updated on September 2, 2005, with an effective date of January 2, 2006 (70 FR 52488). Designated critical habitat includes 1,158 miles of stream habitat in the Sacramento River basin and 254 square miles of estuarine habitat in the San Francisco-San Pablo-Suisun Bay complex (70 FR 52488, Figure 2A.4-4). Critical habitat includes stream reaches such as those of the Feather and Yuba Rivers, Big Chico, Butte, Deer, Mill, Battle, Antelope, and Clear Creeks, and the Sacramento River and Delta.

This habitat is composed of physical and biological features considered essential to the conservation of the species, including space for individual and population growth and for normal behavior; cover; sites for breeding, reproduction, and rearing of offspring; and habitats protected from disturbance or are representative of the historical, geographical, and ecological distribution of the species.

Central Valley spring-run Chinook salmon habitats are also protected under the Magnuson-Stevens Fishery Conservation and Management Act as essential fish habitat (EFH). Those waters and substrate that are necessary to spring-run Chinook salmon for spawning, breeding, feeding, or growth to maturity are included as EFH (Figure 2A.4-5). Critical habitat and EFH are managed differently from a regulatory standpoint, but are biologically equal for the conservation of Central Valley spring-run Chinook salmon.

The critical habitat designation identified the following primary constituent elements considered essential for the conservation of the ESU.

- Freshwater spawning habitat
- Freshwater rearing habitat
- Freshwater migration corridors
- Estuarine habitat
- Nearshore and offshore marine habitats

11A.4.3.1 Freshwater Spawning Habitat

Freshwater spawning sites are those stream reaches with water quantity (instream flows) and quality conditions (e.g., water temperature and dissolved oxygen) and substrate suitable to support spawning, egg incubation, and larval development. Most spawning habitat in the Central Valley for spring-run Chinook salmon is located in areas directly downstream of dams containing suitable environmental conditions for spawning and incubation. Historically, spring-run Chinook salmon migrated upstream into high-elevation steep gradient reaches of the rivers and tributaries for spawning. Access to the majority of these historical spawning areas has been blocked by construction of major Central Valley dams and reservoirs. Currently, Central Valley spring-run Chinook salmon spawn on the mainstem Sacramento River between the Red Bluff Diversion Dam and Keswick Dam, and in tributaries such as the Feather River, Mill, Deer, Clear, Battle and Butte Creeks. There is currently an effort under way to reestablish a self-sustaining population of spring-run Chinook salmon on the San Joaquin River downstream of Friant Dam. Spawning habitat has a high conservation value as its function directly affects the spawning success and reproductive potential of listed salmonids.

11A.4.3.2 Freshwater Rearing Habitat

Freshwater rearing sites have sufficient water quantity and floodplain connectivity to form and maintain physical habitat conditions and support juvenile growth and mobility; suitable water quality; availability of suitable prey and forage to support juvenile growth and development; and natural cover such as shade, submerged and overhanging large wood, log jams, beaver dams, aquatic vegetation, large woody debris, rocks and boulders, side channels, and undercut banks. Both spawning areas and migratory corridors comprise rearing habitat for juveniles, which feed and grow before and during their outmigration.

Juveniles also rear in nonnatal, intermittent tributaries. Rearing habitat condition is strongly affected by habitat diversity and complexity, food supply, and presence of predators. Some of these more complex, productive habitats with floodplain connectivity are still present in limited amounts in the Central Valley (e.g., the lower Cosumnes River, Sacramento River reaches with setback levees [primarily located upstream of the City of Colusa]). However, the channeled, leveed, and riprapped river reaches and sloughs that are common along the Sacramento and San Joaquin Rivers and throughout the Delta typically have low habitat complexity, low abundance of food organisms, and offer little protection from predatory fish and birds. Freshwater rearing habitat also has a high conservation value, as the juvenile life stage of salmonids is dependent on the function of this habitat for successful survival and recruitment to the adult population.

11A.4.3.3 Freshwater Migration Corridors

Freshwater migration corridors for spring-run Chinook salmon, including river channels, channels through the Delta, and the Bay-Delta estuary support mobility, survival, and food supplies for juveniles and adults. Migration corridors should be free from obstructions (passage barriers and impediments to migration), have favorable water quantity (instream flows) and quality conditions (seasonal water temperatures), and contain natural cover such as submerged and overhanging large wood, native aquatic vegetation, large rocks and boulders, side channels, and undercut banks. Migratory corridors for spring-run Chinook salmon are located downstream of the spawning areas and include the lower Sacramento River, lower Feather River, tributaries providing suitable adult holding and spawning habitat, the Delta, and the San Francisco Bay complex extending to coastal marine waters. Efforts are currently under way to reestablish a spring-run salmon population on the San Joaquin River downstream of Friant Dam that would use the lower river and Delta as part of the migration corridor. These corridors allow the upstream passage of adults and the downstream emigration of juvenile salmon. Migratory corridor conditions are strongly affected by the presence of passage barriers, which can include dams, unscreened or poorly screened diversions, and degraded water quality. For freshwater migration corridors to function properly, they must provide adequate passage, provide suitable migration cues, reduce false attraction, avoid areas where vulnerability to predation is increased, and avoid impediments and delays in both upstream and downstream migration. For this reason, freshwater migration corridors are considered to have a high conservation value.

Results of mark-recapture studies conducted using juvenile Chinook salmon (typically fall-run or late fall-run Chinook salmon, which are considered to be representative of juvenile spring-run salmon) released into both the Sacramento and San Joaquin Rivers have shown high mortality during passage downstream through the rivers and Delta (Brandes and McLain 2001; Newman and Rice 2002; Manly 2004; San Joaquin River Group Authority 2007; Hanson 2008; Low and White n.d.). Mortality for juvenile salmon is typically greater in the San Joaquin River than in the Sacramento River (Brandes and McLain 2001). In both rivers, mortality is typically greater in years when spring flows are reduced and water temperatures are increased. Results of survival studies have shown that closing the Delta Cross Channel gates and installing the Head of Old River Barrier to reduce the movement of juvenile salmon into the Delta contribute to improved survival of emigrating juvenile Chinook salmon (Brandes and McLain 2001; Manly 2004; San Joaquin River Group Authority 2007; Low and White n.d.). Observations at the State Water Project (SWP) and Central Valley Project (CVP) fish salvage facilities have shown that very few of the marked salmon (typically fewer than 1%) are entrained and salvaged at the export facilities (San Joaquin River Group Authority 2007; Hanson 2008). Although the factors contributing to high juvenile mortality have not been quantified, results of acoustic tagging experiments and anecdotal observations suggest that exposure to adverse water quality (e.g., elevated water temperatures, toxic chemicals) and vulnerability to predation are two of the factors contributing to the high juvenile mortality observed in the rivers and Delta (San Joaquin River Group Authority 2007). Additional acoustic tagging experiments are currently under way to better assess factors affecting migration pathways, migration rates, effects of SWP/CVP exports on migration, and reach-specific survival rates for emigrating juvenile Chinook salmon (Lindley et al. 2008; MacFarlane et al. 2008a; Michel et al. 2009; Perry et al. 2010).

11A.4.3.4 Estuarine Habitat

Estuarine migration and juvenile rearing habitats should be free of obstructions (i.e., dams and other barriers) and provide suitable water quality, water quantity (river and tidal flows), and salinity conditions to support juvenile and adult physiological transitions between fresh and salt water. Natural cover, such as submerged and overhanging large wood, native aquatic vegetation, and side channels provide juvenile foraging habitat and cover from predators. Tidal wetlands and seasonally inundated floodplains are identified as high-value foraging and rearing habitats for juvenile salmon migrating downstream through the estuary. Estuarine areas have a high conservation value as they support juvenile Chinook salmon growth, smolting, avoidance of predators, and the transition to the ocean environment.

11A.4.3.5 Marine Habitats

Although ocean habitats are not part of the critical habitat listing for Central Valley spring-run Chinook salmon, biologically productive coastal waters are an important habitat component for the ESU. Juvenile Chinook salmon inhabit near-shore coastal marine waters for a period of typically 2 to 4 years before adults return to Central Valley rivers to spawn. During their marine residence, Chinook salmon forage on krill, squid, and other marine invertebrates as well as a variety of fish such as northern anchovy and Pacific herring. These features are essential for conservation because, without them, juveniles cannot forage and grow to adulthood.

Results of oceanographic studies have shown the variation in ocean productivity off the West Coast within and among years. Changes in ocean currents and upwelling are significant factors affecting nutrient availability, phytoplankton and zooplankton production, and the availability of other forage species in nearshore surface waters. Ocean conditions during the salmon's ocean residency period can be important, as indicated by the effect of the 1983 El Niño on the size and fecundity of Central Valley fall-run Chinook salmon (Wells et al. 2006). Although the effects of ocean conditions on

Chinook salmon growth and survival have not been investigated extensively, recent observations since 2007 have shown a significant decline in the abundance of adult Chinook salmon and coho salmon returning to California rivers and streams (Pacific Fishery Management Council 2008). These declines are believed to be the result of decreases in ocean productivity and associated high mortality rates during the period when these fish were rearing in nearshore coastal waters (MacFarlane et al. 2008b; Pacific Fishery Management Council 2008). The importance of changes in ocean conditions on growth, survival, and population abundance of Central Valley Chinook salmon is currently undergoing further investigation.

11A.4.4 Life History

Chinook salmon typically mature between 2and 6 years of age (Myers et al. 1998). Freshwater entry and spawning timing generally are thought to be related to local water temperature and flow regimes. Runs are designated based on adult migration timing; however, distinct runs also differ in the degree of maturation at the time of river entry, thermal regime, and flow characteristics of their spawning site, and the actual time of spawning (Myers et al. 1998). Spring-run Chinook salmon tend to enter fresh water as immature fish, migrate far upriver, hold in cool-water pools for a period of months during the spring and summer, and delay spawning until the early fall.

Adult Central Valley spring-run Chinook salmon begin their upstream migration in late January and early February (California Department of Fish and Game 1998) and enter the Sacramento River between February and September, primarily in May and June (Table 2A.4-1) (Yoshiyama et al. 1998; Moyle 2002). Lindley et al. (2006) reported that adult Central Valley spring-run Chinook salmon enter native tributaries from the Sacramento River primarily between mid-April and mid-June. Typically, spring-run Chinook salmon use mid- to high-elevation streams that provide appropriate seasonal water temperatures and sufficient flow, cover, and pool depth to allow over-summering while conserving energy and allowing their gonadal tissue to mature (Yoshiyama et al. 1998).

Chinook salmon spawn in clean, loose gravel in swift, relatively shallow riffles or along the margins of deeper reaches where suitable water temperature, depth, and velocity favor redd construction and adequate oxygenation of incubating eggs. Chinook salmon spawning typically occurs in gravel beds located at the tails of holding pools (U.S. Fish and Wildlife Service 1995). Fry emergence generally occurs at night. Upon emergence, fry swim or are displaced downstream (Healey 1991). The daily migration of juvenile spring-run Chinook salmon passing Red Bluff Diversion Dam is highest in the 4-hour period prior to sunrise (Martin et al. 2001).

Fry may continue downstream to the estuary and rear, or may take up residence in the stream for a period from weeks to a year (Healey 1991). Fry seek streamside habitats containing beneficial characteristics such as riparian vegetation and associated substrates that provide aquatic and terrestrial invertebrates, predator avoidance cover, and slower water velocities for resting (National Marine Fisheries Service 1996).

Table 2A.4-1. Temporal Occurrence of Adult and Juvenile Central Valley Spring-Run Chinook Salmon in the Sacramento River

Location	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Adult																								
Sacramento River basin[1,2]					▒	▒	▒	▒	▓	▓	▓	▓	▒	▒	▒	▒	▒	▒						
Sacramento River[3]					▒	▒	▒	▒	▒	▒	▒	▒	▒	▒										
Mill Creek[4]					░	░	▒	▓	▓	▓	▓	▒	▒	░	░	░								
Deer Creek[4]					░	░	▒	▓	▓	▓	▓	▒	▒	░	░	░								
Butte Creek[4,9]			▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	░	░	░								
Juvenile																								
Sacramento River Tributaries[5]	▒	▒	▒	▒	▒	▒													▒	▒	▓	▓	▓	▓
Upper Butte Creek[6]	▓	▓	▓	▓	▒	▒	▒	▒	▒	▒	░	░							░	░	░	░	▓	▓
Mill, Deer, Butte Creeks[4]	▓	▓	▓	▓	▒	▒	▒	▒	▒	▒	░	░							░	░	░	░	░	░
Sacramento River at Red Bluff Diversion Dam[3]	▓	▓	░	░	░	░	░	░													▓	▓	▓	▓
Sac. River at Knights Landing[7]	▓	▓	░	░	░	░	░	░													▓	▓	▓	▓
Chipps Island (trawl) [8*]	▓	▓	░	░	░	░	░	░													▓	▓	▓	▓
Lower Sacramento River/Delta[10]	▓	▓	░	░	░	░	░	░	░	░	░	░	░	░	░	░					▓	▓	▓	▓

Relative Abundance:	▓	= High	▒	= Medium	░	= Low

Note: Darker shades indicate months of greatest relative abundance.

* By the time spring-run Chinook salmon yearlings reach Chipps Island they cannot be distinguished with confidence from fall-run Chinook salmon yearlings.

Sources:

[1] Yoshiyama et al. 1998.

[2] Moyle 2002.

[3] Myers et al. 1998.

[4] Lindley et al. 2006.

[5] California Department of Fish and Game 1998.

[6] McReynolds et al. 2005; Ward et al. 2002, 2003.

[7] Snider and Titus 2000.

[8] U.S. Fish and Wildlife Service 2001.

[9] National Marine Fisheries Service 2009a.

[10] U.S. Fish and Wildlife Service 2012.

Spring-run Chinook salmon fry emerge from the gravel from September to April (Moyle 2002; Harvey 1995; Bilski and Kindopp 2009) and the emigration timing is highly variable, as they may migrate downstream as young-of-the-year or as juveniles or yearlings. The modal size of fry migrants at approximately 40 millimeters between December and April in Mill, Butte, and Deer Creeks reflects a prolonged emergence of fry from the gravel (Lindley et al. 2006). Studies in Butte Creek found that the majority of Central Valley spring-run Chinook salmon migrants are fry occurring primarily during December, January, and February, and that fry movements appeared to be influenced by flow (Ward et al. 2002, 2003; McReynolds et al. 2005). Small numbers of Central Valley spring-run Chinook salmon remained in Butte Creek to rear and migrated as yearlings later in the spring. Juvenile emigration patterns in Mill and Deer Creeks are very similar to patterns observed in Butte Creek, with the exception that juveniles from Mill and Deer creeks typically exhibit a later young-of-the-year migration and an earlier yearling migration (Lindley et al. 2006).

Once juveniles emerge from the gravel they initially seek areas of shallow water and low velocities while they finish absorbing the yolk sac (Moyle 2002). Many also disperse downstream during high-flow events. As is the case with other salmonids, there is a shift in microhabitat use by juveniles to deeper, faster water as they grow. Microhabitat use can be influenced by the presence of predators, which can force juvenile salmon to select areas of heavy cover and suppress foraging in open areas (Moyle 2002). Peak movement of yearling Central Valley spring-run Chinook salmon in the Sacramento River at Knights Landing occurs in December, and young-of-the-year juveniles occur in March and April; however, juveniles were also observed between November and the end of May (Snider and Titus 2000).

As juvenile Chinook salmon grow, they move into deeper water with higher current velocities, but still seek shelter and velocity refugia to minimize energy expenditures (Healey 1991). Catches of juvenile salmon in the Sacramento River near West Sacramento by the U.S. Fish and Wildlife Service (USFWS) (1997) showed that larger juvenile salmon were captured in the main channel and smaller fry were typically captured along the channel margins. When the channel of the river is greater than 9 to 10 feet in depth, juvenile salmon tend to inhabit surface waters (Healey 1980). Stream flow changes and/or turbidity increases in the upper Sacramento River watershed are thought to stimulate juvenile emigration (Kjelson et al. 1982; Brandes and McLain 2001).

Within the Delta, juvenile Chinook salmon forage in shallow areas with protective cover, such as tidally influenced sandy beaches and shallow water areas with emergent aquatic vegetation (Meyer 1979; Healey 1980). Cladocerans, copepods, amphipods, and larval dipterans, as well as small arachnids and ants are common prey items (Kjelson et al. 1982; Sommer et al. 2001a; MacFarlane and Norton 2002). Although the bulk of production in Butte and Big Chico Creeks emigrate as fry, yearlings can enter the Delta as early as February and as late as June (California Department of Fish and Game 1998). Yearling-sized spring-run Chinook salmon migrants appear at Chipps Island (entrance to Suisun Bay) between October and December (Brandes and McLain 2001; U.S. Fish and Wildlife Service 2001).

While there have been few studies of estuarine habitat use by juvenile spring-run Chinook, the low numbers of juveniles encountered throughout the bays and lower tidal marshes, and the lack of growth observed in those reaches reflect the immense changes and habitat alteration that have taken place in those areas over the last century (MacFarlane and Norton 2002). Over this period, the bulk of the tidal marsh and creek habitats had been leveed, channelized, and dredged, for navigation and other anthropogenic purposes. In addition, water transfers at the Delta pump facilities have drastically altered hydrology, salinity, and turbidity in the lower Delta. These changes in habitat conditions in the Delta over the past century may have resulted in a reduction in extended juvenile salmon rearing when compared to periods when habitat for juvenile salmon rearing was more suitable.

Central Valley spring-run Chinook salmon begin their ocean life in the coastal marine waters of the Gulf of the Farallones. Upon reaching the ocean, juveniles feed on larval and juvenile fishes, plankton, and terrestrial insects (Healey 1991; MacFarlane and Norton 2002). Juveniles grow rapidly in the ocean environment with growth rates dependent on water temperatures and food availability (Healey 1991). The first year of ocean life is considered a critical period of high mortality for Chinook salmon that largely determines survival to harvest or spawning (Beamish and Mahnken 2001; Quinn 2005).

11A.4.5 Threats and Stressors

In the last status review, Good et al. (2005) described the threats to the Central Valley spring-run Chinook salmon ESU as falling into three broad categories: loss of historical spawning habitat, degradation of remaining habitat, and genetic threats from the Feather River Hatchery spring-run Chinook salmon program. Other likely important threats and stressors include nonnative predators, commercial and recreational harvest, entrainment at water withdrawal facilities, toxin exposure, and increased water temperatures.

11A.4.5.1 Reduced Staging and Spawning Habitat

Access to most of the historical upstream spawning habitat for spring-run Chinook salmon (Figure 2A.4-1) has been eliminated or degraded by artificial structures (e.g., dams and weirs) associated with water storage and conveyance, flood control, and diversions and exports for municipal, industrial, agricultural, and hydropower purposes (Yoshiyama et al. 1998). Current spawning and juvenile rearing habitat is restricted to the mainstem and a few tributaries to the Sacramento River. Suitable summer water temperatures for adult and juvenile spring-run Chinook salmon holding and rearing are thought to occur at elevations from 492 to 1,640 feet (150 to 500 meters), most of which are now blocked by impassible dams. Habitat loss has resulted in a reduction in the number of natural spawning populations from an estimated 17 to 3 (Good et al. 2005).

Upstream diversions and dams have decreased downstream flows and altered the seasonal hydrologic patterns. These factors have been identified as resulting in delayed upstream migration by adults, increased mortality of outmigrating juveniles, and are responsible for making some streams uninhabitable by spring-run salmon (Yoshiyama et al. 1998; California Department of Water Resources 2005). Dams and reservoir impoundments and associated reductions in peak flows have blocked gravel recruitment and reduced flushing of sediments from existing gravel beds, thereby reducing and degrading natal spawning grounds. Further, reduced flows may decrease attraction cues for adult spawners, causing migration delays and increases in straying (California Department of Water Resources 2005). Adult salmon migration delays can reduce fecundity and increase susceptibility to disease and harvest (McCullough 1999).

Dams and other passage barriers also limit the geographic locations where spring-run Chinook salmon can spawn. In the Sacramento and Feather Rivers, restrictions to upstream movement and spawning site selection for spring-run salmon may increase the risk of hybridization with fall-run salmon, as co-occurrence contributes to an increased risk of redd superimposition. In creeks that are not affected by large dams, such as Deer and Mill Creeks, adult spring-run Chinook salmon have a greater opportunity to migrate upstream into areas where geographic separation from fall-run salmon reduces the risk of hybridization.

The Red Bluff Diversion Dam, located on the Sacramento River, is a barrier and impediment to adult spring-run Chinook salmon upstream migration. Although the dam is equipped with fish ladders, migration delays were reported when the dam gates are closed. Mortality from increased predation by Sacramento pikeminnow on juvenile salmon passing downstream through the fish ladder also affects abundance of salmon produced on the Sacramento River (Hallock 1991). To help reduce the effects of dam operation on migration of adult and juvenile salmonids and other species, dam gates have been opened for a longer period, thereby facilitating greater upstream and downstream migration. Changes in dam operations have benefited both upstream and downstream migration of salmon and have contributed to a reduction in juvenile predation mortality.

Since the ESU was listed as threatened in 1999, very little expansion of spawning habitat has occurred, particularly compared to the hundreds of miles of habitat blocked by dams. The removal of Seltzer Dam on Clear Creek in 2000 opened up 10 miles of habitat, and the removal of a partial low-flow barrier on Cottonwood Creek in 2010 improved access to 30 miles of habitat (National Marine Fisheries Service 2011). Additionally, the removal of Wildcat Dam in 2010 along with the completion of fish ladders at Eagle Canyon Dam and North Battle Feeder Dam opened up about 10 miles of habitat on Battle Creek. The Battle Creek Salmon and Steelhead Restoration Project will eventually remove five dams on Battle Creek, install fish screens and ladders on three dams, and end the diversion of water from the North Fork to the South Fork. When the program is completed, a total of 42 miles of mainstem habitat and 6 miles of tributary habitat will be accessible to anadromous salmonids, including Central Valley spring run Chinook salmon (National Marine Fisheries Service 2011).

The 2009 SWP/CVP biological opinion (BiOp) includes a phased fish passage program, intended to expand spring-run Chinook salmon habitat to areas upstream Shasta Dam. Phases of the fish passage program include habitat evaluations through January 2012, pilot reintroductions through January 2015, and implementation of the long-term program by January 2020 (National Marine Fisheries Service 2011).

11A.4.5.2 Reduced Rearing and Out-Migration Habitat

Juvenile spring-run Chinook salmon prefer natural stream banks, floodplains, marshes, and shallow water habitats as rearing habitat during out-migration. Channel margins throughout the Delta have been leveed, channelized, and fortified with riprap for flood protection and island reclamation, reducing and degrading the quality of natural habitat available for juvenile Chinook salmon rearing (Brandes and McLain 2001). Artificial barriers further reduce and degrade rearing and migration habitat and delay juvenile out-migration. Juvenile out-migration delays can reduce fitness and increase susceptibility to diversion screen impingement, entrainment, disease, and predation. Modification of natural flow regimes from upstream reservoir operations has resulted in dampening and altering the seasonal timing of the hydrograph, reducing the extent and duration of seasonal floodplain inundation and other flow-dependent habitat used by migrating juvenile Chinook salmon (70 FR 52488) (Sommer et al. 2001a; California Department of Water Resources 2005). Recovery of floodplain habitat in the Central Valley has been found to contribute to increases in production in Chinook salmon (Sommer et al. 2001b), but little is known about the potential benefit available to migrating spring-run salmon.

The potential adverse effects of dam operations include reductions in seasonal river flows, delays in juvenile emigration, and increased seasonal water temperature. In addition, exposure to a higher proportion of agricultural return flows, and exposure to reduced dissolved oxygen concentrations (e.g., Stockton Deep Water Ship Channel) likely affect the survival and success of reestablishing spring-run Chinook salmon on the San Joaquin River in the future (Regional Water Resources Control Board 2003).

11A.4.5.3 Predation by Nonnative Species

Predation on juvenile salmon by nonnative fish has been identified as an important threat to spring-run Chinook salmon in areas with high densities of nonnative fish (e.g., small and largemouth bass, striped bass, and catfish) that prey on out-migrating juveniles (Lindley and Mohr 2003). Nonnative aquatic vegetation, such as Brazilian waterweed (*Egeria dense*) and water hyacinth (*Eichhornia crassipes*), provide suitable habitat for nonnative predators (Nobriga et al. 2005; Brown and Michniuk 2007). Predation risk may covary with increased temperatures. Metabolic rates of nonnative, predatory fish increase with increasing water temperatures based on bioenergetic studies (Loboschefsky et al. 2009; Miranda et al. 2010). The low spatial complexity and reduced habitat diversity (e.g., lack of cover) of channelized waterways in the rivers and Delta reduces refuge space of salmon from predators (70 FR 52488) (Raleigh et al. 1984; Missildine et al. 2001; California Department of Water Resources 2005).

Increased predation mortality by native fish species, such as Sacramento pikeminnow at the Red Bluff Diversion Dam, is a factor affecting the survival of juvenile salmon in the rivers and Delta. Predation at the dam should decrease as the dam gates are in for shorter periods of time, and particularly in 2012 when the dam gates will be out year-round (National Marine Fisheries Service 2011). Although reducing predation at the Red Bluff Diversion Dam will benefit spring-run Chinook salmon at that location, it is unclear whether the reduction will substantially decrease the overall level of predation throughout the Sacramento River and Delta.

11A.4.5.4 Harvest

Commercial and recreational harvest of spring-run Chinook salmon in the ocean and inland fisheries has been a subject of management actions by the California Fish and Game Commission and Pacific Fishery Management Council. The primary concerns focus on the effects of harvest on wild Chinook salmon produced in the Central Valley as well as the incidental harvest of listed salmon as part of the fall-run and late fall-run salmon fisheries. Naturally reproducing spring-run Chinook salmon are less able to withstand high harvest rates when compared to hatchery-based stocks. Because survivorship has been reduced in incubating eggs and rearing and emigrating wild salmon relative to hatchery-reared individuals, naturally reproducing populations are less able to withstand high harvest rates compared to hatchery-based stocks (Knudsen et al. 1999). National Marine Fisheries Service (2011) reports that ocean harvest had not changed appreciably since the 2005 status review (Good et al. 2005), except for extreme reductions in 2008 through 2010. The ocean salmon fisheries were closed in 2008 and 2009 and substantially restricted in 2010. Because of recent changes in fishing regulations and restrictions on harvest, commercial and recreational fishing does not appear to have a significant effect on spring-run Chinook salmon populations, but continued assessment is warranted.

Commercial fishing for salmon in west coast ocean waters is managed by the Pacific Fishery Management Council, and is constrained by time and area closures to meet the Sacramento River winter-run ESA consultation standard and restrictions requiring minimum size limits and use of circle hooks for anglers. Ocean harvest restrictions since 1995 have led to reduced ocean harvest of spring-run Chinook salmon (i.e., Central Valley Chinook salmon ocean harvest index, ranged from 0.55 to nearly 0.80 from 1970 to 1995, and was reduced to 0.27 in 2001). The California Department of Fish and Wildlife (CDFW), NMFS, and Pacific Fishery Management Council continue to monitor and assess the effects of harvest of spring-run Chinook salmon, such that regulations can be refined and modified as new information becomes available.

Because adult spring-run Chinook salmon hold in a pool habitat in a stream during the summer months, they are vulnerable to illegal harvest (poaching). Various watershed groups have established public outreach and educational programs in an effort to reduce poaching. In addition, CDFW wardens have increase enforcement against illegal harvest of spring-run Chinook salmon. The level and effect of illegal harvest on adult spring-run Chinook salmon abundance and population reproduction is unknown.

11A.4.5.5 Reduced Genetic Diversity and Integrity

Interbreeding of wild spring-run Chinook salmon with both wild and hatchery fall-run Chinook salmon has the potential to dilute and eventually eliminate the adaptive genetic distinctiveness and diversity of the few remaining naturally reproducing spring-run Chinook salmon populations (California Department of Fish and Game 1995; Sommer et al. 2001b; Araki et al. 2007). Central Valley spring- and fall-run Chinook salmon spawning areas were historically isolated in time and space (Yoshiyama et al. 1998). However, the construction of dams has eliminated access to historical upstream spawning areas of spring-run salmon in the upper tributaries and streams of many river systems. Restrictions to upstream access, particularly on the Sacramento and Feather Rivers has forced spring-run individuals to spawn in lower elevation areas also used by fall-run individuals, potentially resulting in hybridization of the two races. Hybridization between spring- and fall-run salmon is a particular concern on the Feather River, where both runs co-occur and as a potential concern for restoration of salmon on the San Joaquin River downstream of Friant Dam.

Management of the Feather River hatchery and brood stock selection practices have been modified in recent years (e.g., tagging early returning adult salmon showing phenotypic and run timing characteristics of spring-run Chinook salmon for subsequent use as selected brood stock and genetic testing of potential brood stock) in an effort to reduce potential hybridization as a result of hatchery operations. Consideration has also been given to using a physical weir to help segregate and isolate adults showing spring-run characteristics and later-arriving fish showing characteristics of fall-run fish to reduce the risk of hybridization and redd superimposition in spawning areas of the river.

Habitat quality and availability for spring-run Chinook salmon spawning and juvenile rearing in the reaches of the Feather River upstream of Oroville Dam could be used to expand the geographic range of spring-run salmon using trap and haul techniques. On many of the other Central Valley tributaries, such as Deer and Mill Creeks, the risk of hybridization is reduced by the ability of the runs to segregate geographically in the watersheds.

Further, in an effort to improve juvenile survival and the contribution of the Feather River Hatchery to the adult spring-run Chinook salmon population, the spring-run salmon program at the hatchery has released juvenile spring-run salmon downstream of the hatchery (San Pablo Bay) in the past. This increased the rate of straying adults migrating back upstream (California Department of Fish and Game 2001). Recent changes in hatchery management by CDFW, however, have modified juvenile planting with a greater number of juvenile fish released into the Feather River in an effort to improve imprinting and reduce straying, which may reduce potential for hybridization with spring-run salmon in other watersheds (McReynolds et al. 2006). Half of the juvenile spring-run

Chinook salmon produced at the hatchery are now released in the Feather River at Live Oak as part of an experimental program designed to improve hatchery management.

11A.4.5.6 Entrainment

The vulnerability of juvenile spring-run Chinook salmon to entrainment and salvage at the SWP/CVP export facilities varies in response to multiple factors, including the seasonal and geographic distribution of juvenile salmon in the Delta, operation of Delta Cross Channel gates, hydrodynamic conditions occurring in the central and southern regions of the Delta (Old and Middle Rivers), and export rates. The loss of fish to entrainment mortality affects Chinook salmon populations (Kjelson and Brandes 1989). Juvenile spring-run Chinook salmon tend to be distributed in the central and southern Delta where they have an increased risk of entrainment/salvage between February and May. The effect of changing hydrodynamics in Delta channels, such as reversed flows in Old and Middle Rivers resulting from SWP/CVP export operations, may result in the following effects:

- Increase attraction of emigrating juveniles into false migration pathways.
- Delay emigration through the Delta.
- Directly or indirectly increase vulnerability to entrainment at unscreened diversions.
- Increase the risk of predation.
- Increase movement of migrating salmon toward the export facilities.
- Increase the risk that these fish will be entrained into the fish salvage facilities.
- Increase the duration of exposure to seasonally elevated water temperatures and other adverse water quality conditions.

SWP/CVP exports affect the tidal hydrodynamics (e.g., water current velocities and direction), and the magnitude of these effects varies in response to a variety of factors, including tidal stage and magnitude of ebb and flood tides, the rate of SWP/CVP exports, operation of the Clifton Court Forebay radial gate opening, and inflow from the upstream tributaries. Chinook salmon behaviorally respond to hydraulic cues (e.g., water currents) during both upstream adult and downstream juvenile migration through the Delta. Over the past several years, additional investigations have been designed using radio or acoustically tagged juvenile Chinook salmon to monitor their migration behavior through the Delta channels and to assess the effects of changes in hydraulic cues and SWP/CVP export operations on migration. These studies are continuing (San Joaquin River Group Authority 2007; Brandes et al. 2008; Lindley et al. 2008; MacFarlane et al. 2008a; Michel et al. 2009; North Delta Hydrodynamic and Juvenile Salmon Migration Study 2008; Perry et al. 2010).

In addition to SWP/CVP exports, over 2,200 small water diversions exist throughout the Delta, along with unscreened diversions located on the tributary rivers (Herren and Kawasaki 2001). The risk of entrainment is a function of the size of juvenile fish and the slot opening of the screen mesh (Tomljanovich et al. 1978; Schneeberger and Jude 1981; Zeitoun et al. 1981; Weisberg et al. 1987). Many of the juvenile salmon migrate downstream through the Delta during the late winter or early spring when many of the agricultural irrigation diversions are not operating or are only operating at low levels. Juvenile salmon also migrate primarily in the upper part of the water column and are less vulnerable to an unscreened diversion located near the channel bottom. While unscreened diversions used to flood agricultural fields (e.g., rice fields) during the winter have the potential to divert and strand juvenile salmonids, there are no quantitative estimates of the potential magnitude of entrainment losses for juvenile Chinook salmon migrating through the rivers and Delta. Draining these fields can also provide flow attractions to upstream migrating adult salmon, resulting in migration delays or stranding losses, although the loss of adult fish and the effects of these losses on the overall population abundance of returning adult Chinook salmon are also unknown. Despite these potential detrimental effects, flooding agricultural fields can increase nutrient loading to downstream habitats and increase productivity, and increase base flows during low stream flow periods. Many of the larger water diversions located in the Central Valley and Delta (e.g., Glenn Colusa Irrigation District, Reclamation District 108 Wilkins Slough, Poundstone, and Sutter Mutual Water Company Tisdale Pumping Plants, Contra Costa Water District Old River and Alternative Intake Project, and others) have been equipped with positive barrier fish screens to reduce and avoid the loss of juvenile Chinook salmon and other fish species.

Power plants in the Plan Area may impinge juvenile Chinook salmon on the existing cooling water system intake screens. However, use of cooling water is currently low with the retirement of older units. Newer units are equipped with a closed-cycle cooling system that virtually eliminates the risk of impingement of juvenile salmon.

Besides mortality, salmon fitness may be affected by entrainment at these diversions and delays in out-migration of smolts caused by reduced or reverse flows. Delays in migration due to management of the SWP/CVP operations can make juvenile salmonids more susceptible to many of the threats and stressors, such as predation, entrainment, angling, exposure to poor water quality and toxics, and disease. The quantitative relationships among changes in Delta hydrodynamics, the behavioral and physiological response of juvenile salmon, and the increase or decrease in risk associated with other threats are unknown, but are the subject of a number of investigations and analyses.

11A.4.5.7 Exposure to Toxins

Toxic chemicals have the potential to be widespread throughout the Delta, or may occur on a more localized scale in response to episodic events (stormwater runoff, point source discharges). These toxic substances include mercury, selenium, copper, pyrethroids, and endocrine disruptors with the potential to affect fish health and condition, and adversely affect salmon distribution and abundance. Chinook salmon may experience both waterborne chronic and acute exposure, but also bioaccumulation and chronic dietary exposure. For example, selenium is a naturally occurring constituent in the return flow of agricultural drainage water from the San Joaquin River that is then dispersed downstream into the Delta (Nichols et al. 1986). Exposure to selenium in the diet of juvenile Chinook salmon results in toxic effects (Hamilton et al. 1990; Hamilton and Buhl 1990). Selenium exposure has been associated with agricultural and natural drainage in the San Joaquin River basin and refining operations adjacent to San Pablo and San Francisco Bays. Other contaminants of concern for Chinook salmon include, but are not limited to, mercury, copper, oil and grease, pesticides, herbicides, ammonia[2], and localized areas of depressed dissolved oxygen (e.g., Stockton Deep Water Ship Channel, return flows from managed freshwater wetlands). As a result of the extensive agricultural development in the Central Valley, exposure to pesticides and herbicides is a significant concern for salmon and other fish species in the Plan Area (Bennett et al. 2001). In recent years, changes have been made in the composition of herbicides and pesticides used on agricultural crops in an effort to reduce potential toxicity to aquatic and terrestrial species. Modifications have also been made to water system operations and agricultural wastewater discharges (e.g., agricultural drainage water system lock-up and holding prior to discharge) and

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[2] Ammonia in water generally forms some amount of ammonium. Therefore, the use of the term *ammonia* implies that both ammonia and ammonium may be present.

municipal wastewater treatment and discharges. Concerns remain, however, regarding the toxicity of contaminants such as pyrethroids that adsorbed to sediments and other chemicals (selenium and mercury, as well as other contaminants) on salmon.

Mercury and other metals such as copper have also been identified as contaminants of concern for salmon and other fish as a result of direct toxicity and impacts such as those related to acid mine runoff from sites such as Iron Mountain Mine (U.S. Environmental Protection Agency 2006). Tissue bioaccumulation may adversely affect the fish, but also represents a human health concern (Gassel et al. 2008). These materials originate from a variety of sources, including mining operations, municipal wastewater treatment, agricultural drainage in the tributary rivers and Delta, nonpoint runoff, natural runoff and drainage in the Central Valley, agricultural spraying, and a number of other sources. The State Water Resources Control Board (State Water Board), Central Valley Regional Water Quality Control Board, U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), California Department of Water Resources (DWR), and others have ongoing monitoring programs designed to characterize water quality conditions and identify potential toxicants and contaminant exposure to Chinook salmon and other aquatic resources in the Plan Area. Programs are in place to regulate point source discharges as part of the National Pollutant Discharge Elimination System (NPDES) program as well as efforts to establish and reduce total daily maximum loads (TMDL) of various constituents entering the Delta. Regulations have been updated to help reduce chemical exposure and adverse effects on aquatic resources and habitat conditions in the Plan Area. These monitoring and regulatory programs are ongoing.

Sublethal concentrations of toxics may interact with other stressors on salmonids, possibly increasing their vulnerability to mortality because of exposure to seasonally elevated water temperatures, predation, or disease (Werner 2007). For example, Clifford et al. (2005) found in a laboratory setting that juvenile fall-run Chinook salmon exposed to sublethal levels of a common pyrethroid, esfenvalerate, were more susceptible to infectious hematopoietic necrosis virus than those not exposed to esfenvalerate. Although not tested on spring-run Chinook salmon, a similar response is likely due to the physiological similarity.

Iron Mountain Mine, located adjacent to the upper Sacramento River, has been a source of trace elements and metals that are known to adversely affect aquatic organisms (Upper Sacramento River Fisheries and Riparian Habitat Advisory Council 1989). Storage limitations and limited availability of dilution flows have caused downstream copper and zinc levels to exceed salmonid tolerances and resulted in documented fish kills in the 1960s and 1970s (Bureau of Reclamation 2004). The EPA's Iron Mountain Mine remediation program has removed toxic metals in acidic mine drainage from the Spring Creek watershed with a state-of-the-art lime neutralization plant. Contaminant loading into the Sacramento River from Iron Mountain Mine has shown measurable reductions since the early 1990s.

11A.4.5.8 Increased Water Temperature

Water temperature is among the physical factors that affect the value of habitat for salmonid adult holding, spawning and egg incubation, juvenile rearing, and migration. Adverse sublethal and lethal effects can result from exposure to elevated water temperatures at sensitive life stages, such as during incubation or rearing. The Central Valley is the southern limit of spring-run Chinook salmon geographic distribution, so increased water temperatures are often recognized as an important stressor to California populations. Water temperature criteria for various life stages of salmonids in the Central Valley have been developed (National Marine Fisheries Service 2009a). The tolerance of spring-run Chinook salmon to water temperatures depends on life stage, acclimation history, food availability, duration of exposure, health of the individual, and other factors such as predator avoidance (Myrick and Cech 2004; Bureau of Reclamation 2004). Higher water temperatures can lead to physiological stress, reduced growth rate, prespawning mortality, reduced spawning success, and increased mortality of salmon (Myrick and Cech 2001). Temperature can also indirectly influence disease incidence and predation (Waples et al. 2008). Exposure to seasonally elevated water temperatures may occur because of reductions in flow, upstream reservoir operations, reductions in riparian vegetation, channel shading, local climate and solar radiation. The installation of the Shasta Temperature Control Device in 1998, in combination with reservoir management to maintain the cold water pool, has reduced many of the temperature issues on the Sacramento River. During dry years, however, the release of cold water from Shasta Dam is still limited. As the river flows further downstream, particularly during the warm spring, summer, and early fall months, water temperatures continue to increase until they reach thermal equilibrium with atmospheric conditions. As a result of the longitudinal gradient of seasonal water temperatures, the coldest temperatures and best areas for salmon spawning and rearing are typically located immediately downstream of the dam. Climate change modeling predicts that the Butte Creek run of spring-run Chinook (the largest population of spring-run Chinook) will be extirpated as a result of warming temperature, even with the cessation of water and power operations (Thompson et al. 2011).

Increased temperature can also arise from a reduction in shade over rivers by tree removal (Watanabe et al. 2005). Because river water is typically in thermal equilibrium with atmospheric conditions by the time it enters the Delta, this issue results from actions upstream of the Delta. The relatively wide channels of the Delta minimize the effects of additional riparian vegetation on reducing water temperatures.

Adult and juvenile spring-run Chinook salmon hold and rear in pools at higher elevations in the watershed. On several tributaries, prespawning adult mortality has been reported for adults that accumulate in high densities in a pool and are then exposed to elevated summer water temperatures. Flow reductions, resulting from natural hydrologic conditions during the summer, evapotranspiration, or surface and groundwater extractions may all contribute to exposure to elevated temperatures and increased levels of stress or mortality. In some areas, groundwater wells have been used to pump cooler water into the stream to reduce summer temperatures. Dense riparian vegetation, streams incised into canyons that provide shading, cool water springs, and availability of deep holding pools are factors that affect summer holding and rearing conditions for spring-run Chinook salmon.

The effects of climate change and global warming patterns, in combination with changes in precipitation and seasonal hydrology in the future are important factors that may adversely affect the health and long-term viability of Central Valley spring-run Chinook salmon (Crozier et al. 2008). The rate and magnitude of these potential future environmental changes, and their effect on habitat value and availability for spring-run Chinook salmon, however, are subject to a high degree of uncertainty.

11A.4.6 Relevant Conservation Efforts

Results of salvage monitoring and extensive experimentation over the past several decades have led to the identification of a large number of management actions designed to reduce or avoid the potentially adverse effects of SWP/CVP export operations on salmon. Many of these actions have been implemented through State Water Board water quality permits (D-1485, D-1641), BiOps issued on project export operations by NMFS, USFWS, and CDFW, as part of CALFED programs (e.g., Environmental Water Account), and as part of actions associated with Central Valley Project Improvement Act. These requirements support multiple conservation efforts to enhance habitat and reduce entrainment of Chinook salmon by the SWP/CVP export facilities.

Several habitat problems that contributed to the decline of Central Valley salmonid species are being addressed and improved through restoration and conservation actions. Such actions include reasonable and prudent alternatives from ESA Section 7 consultations; addressing temperature, flow, and operations of the SWP/CVP facilities; EPA actions to control acid mine runoff from Iron Mountain Mine; and the Central Valley Regional Water Board decisions requiring compliance with Sacramento River water temperature objectives. These decisions resulted in the installation of the Shasta Temperature Control Device in 1998.

BiOps for SWP/ CVP operations (e.g., National Marine Fisheries Service 2009a) and other federal projects involving irrigation and water diversion and fish passage, for example, have improved or minimized adverse effects on salmon in the Central Valley. In 1992, an amendment to the authority of the CVP through the Central Valley Project Improvement Act was enacted to give protection of fish and wildlife equal priority with other CVP objectives. From this act arose several programs that have benefited listed salmonids.

- The Anadromous Fish Restoration Program is engaged in monitoring, education, and restoration projects designed to contribute toward doubling the natural populations of select anadromous fish species residing in the Central Valley. Restoration projects funded through the program include fish passage, fish screening, riparian easement and land acquisition, development of watershed planning groups, instream and riparian habitat improvement, and gravel replenishment.
- The Anadromous Fish Screen Program combines federal funding with state and private funds to prioritize and construct fish screens on major water diversions mainly in the upper Sacramento River.
- The goal of the Water Acquisition Program is to acquire water supplies to meet the habitat restoration and enhancement goals of the Central Valley Project Improvement Act, and to improve the ability of the U.S. Department of the Interior to meet regulatory water quality requirements. Water has been used to improve fish habitat for Central Valley salmon, with the primary focus on listed Chinook salmon and steelhead, by maintaining or increasing instream flows on the Sacramento River at critical times, and to reducing salmonid entrainment at the SWP/CVP export facilities through reducing seasonal diversion rates during periods when protected fish species are vulnerable to export related losses.

Two programs included under CALFED, the Ecosystem Restoration Program and the Environmental Water Account, were created to improve conditions for fish, including spring-run Chinook salmon, in the Central Valley. The Ecosystem Restoration Program Implementing Agency Managers selected a proposal for directed action funding written by the Central Valley Salmonid Project Work Team, an interagency technical working group led by CDFW, to develop a spring-run Chinook salmon escapement-monitoring plan. Long-term funding for implementation of the monitoring plan must still be secured.

A major CALFED Ecosystem Restoration Program action currently under way is the Battle Creek Salmon and Steelhead Restoration Project. The project will restore 48 miles (77 kilometers) of habitat in Battle Creek to support steelhead and Chinook salmon spawning and juvenile rearing at a cost of over $90 million. The project includes removal of five small hydropower diversion dams, construction of new fish screens and ladders on another three dams, and construction of several hydropower facility modifications to ensure the continued hydropower operations. It is thought that this restoration effort is the largest coldwater restoration project to date in North America.

The Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) was formed to guide the implementation of CALFED Ecosystem Restoration Program elements in the Delta (California Department of Fish and Game 2007). The DRERIP team has created a suite of ecosystem and species conceptual models, including for spring-run Chinook salmon, that document existing scientific knowledge of Delta ecosystems. The DRERIP team has used these conceptual models to assess the suitability of actions proposed in the Ecosystem Restoration Program for implementation. DRERIP conceptual models were used in the analysis of proposed conservation measures.

Recent habitat restoration initiatives sponsored and funded primarily by the Ecosystem Restoration Program have resulted in plans to restore ecological function to 9,543 acres of shallow-water tidal and marsh habitats in the Delta. Restoration of these areas primarily involves flooding lands previously used for agriculture, thereby creating additional rearing habitat for juvenile salmonids. Similar habitat restoration is adjacent to Suisun Marsh (at the confluence of Montezuma Slough and the Sacramento River) as part of the Montezuma Wetlands project, which is intended to provide for commercial disposal of material dredged from San Francisco Estuary in conjunction with tidal wetland restoration.

The Vernalis Adaptive Management Program has implemented migration flow augmentation for the San Joaquin River basin to improve juvenile and adult migration for fall-run Chinook salmon (San Joaquin River Group Authority 2007). The program also includes seasonal reductions in SWP/CVP export rates that may benefit juvenile spring-run Chinook salmon during their emigration period. The program was designed in the framework of adaptive management to improve the survival of juvenile salmonids migrating from the river through the Delta while providing an experimental framework to quantitatively evaluate the contribution of each action to salmonid survival. The incremental contribution of the program conditions to overall spring-run salmon survival and adult abundance is uncertain. The program's experimental design and results of survival testing conducted to date are currently undergoing peer review and will be the subject of a review conducted by the State Water Board. Based on results and recommendations from these technical reviews, the experimental design and testing program are expected to be refined.

The EPA's Iron Mountain Mine remediation involves the removal of toxic metals in acidic mine drainage from the Spring Creek Watershed with a state-of-the-art lime neutralization plant. Contaminant loading into the Sacramento River from Iron Mountain Mine has shown measurable reductions since the early 1990s. Decreasing the heavy metal contaminants that enter the Sacramento River should increase the survival of salmonid eggs and juveniles. However, during periods of heavy rainfall upstream of the Iron Mountain Mine, Reclamation substantially increases Sacramento River flows to dilute heavy metal contaminants spilled from the Spring Creek debris dam. This rapid change in flows can cause juvenile salmonids to become stranded or isolated in side channels below Keswick Dam.

Since 1986, DWR's Delta Fish Agreement Program has approved approximately $49 million for projects that benefit salmon and steelhead production in the Sacramento-San Joaquin basins and Delta. The Delta Fish Agreement projects that benefit Central Valley spring-run Chinook salmon include water exchange programs on Mill and Deer Creeks; enhanced law enforcement from San

Francisco Estuary upstream to the Sacramento and San Joaquin Rivers and their tributaries; design and construction of fish screens and ladders on Butte Creek; and screening of diversions in Suisun Marsh and San Joaquin River tributaries. The Spring-Run Salmon Increased Protection Project provides overtime wages for CDFW wardens to focus on reducing illegal take and illegal water diversions on upper Sacramento River tributaries and adult holding areas, where the fish are vulnerable to poaching. This project covers Mill, Deer, Antelope, Butte, Big Chico, Cottonwood, and Battle Creeks, and has been in effect since 1996. Through the Delta-Bay Enhanced Enforcement Program, initiated in 1994, ten wardens focus their enforcement efforts on salmon, steelhead, and other species of concern from the San Francisco Estuary upstream into the Sacramento and San Joaquin River basins. These two enhanced enforcement programs have likely had significant benefits to spring-run Chinook salmon attributed to CDFW, although results have not been quantified.

The Mill and Deer Creek Water Exchange projects will provide new wells that enable diverters to bank groundwater in place of stream flow, thus leaving water in the stream during critical migration and oversummering periods. On Mill Creek, several agreements between Los Molinos Mutual Water Company, Orange Cove Irrigation District, CDFW, and DWR allows DWR to pump groundwater from two wells into the Los Molinos Mutual Water Company canals to pay back Los Molinos Mutual Water Company water rights for surface water released downstream for fish. Although the Mill Creek Water Exchange project was initiated in 1990 and the agreement allows for a well capacity of 25 cubic feet per second (cfs), only 12 cfs has been developed to date. In addition, it has been determined that a base flow of greater than 25 cfs is needed from April through June for upstream passage of adult spring-run Chinook salmon in Mill Creek. In some years, water diversions from the creek are curtailed by amounts sufficient to provide for passage of upstream migrating adult spring-run Chinook salmon and downstream migrating juvenile steelhead and spring-run Chinook salmon.

The Feather River Hatchery is making efforts to segregate spring-run from fall-run Chinook salmon to enhance and restore the genotype of spring-run Chinook salmon in the Feather River (California Department of Fish and Game 2001; McReynolds et al. 2006).

To help reduce the effects of the Red Bluff Diversion Dam operation on migration of adult and juvenile salmonids and other species, the dam gates are now maintained in the open position for a longer period, thereby facilitating greater upstream and downstream migration. Changes in dam operations have benefited both upstream and downstream migration by salmon and have contributed to a reduction in juvenile predation mortality. In 2009, the Bureau of Reclamation (Reclamation) received funding for the Fish Passage Improvement Project at the Red Bluff Diversion Dam to build a pumping facility to provide reliable water supply for high-valued crops in Tehama, Glenn, Colusa, and northern Yolo Counties while providing year-round unimpeded fish passage. This project, which is expected to be completed in late 2012, will eliminate passage issues for spring-run Chinook salmon and other migratory species.

Seasonal constraints on sport and commercial fisheries south of Point Arena benefit spring-run Chinook salmon. CDFW has implemented enhanced enforcement efforts to reduce illegal harvests. Central Valley spring-run Chinook salmon is a state-listed fish that is protected by specific in-river fishing regulations.

11A.4.7 Recovery Goals

The draft recovery plan for Central Valley salmonids, including spring-run Chinook salmon, was released by NMFS on October 19, 2009. Although not final, the overarching goal is the removal of, among other listed salmonids, spring-run Chinook salmon from the federal list of endangered and threatened wildlife (National Marine Fisheries Service 2009b). Several objectives and related criteria represent the components of the recovery goal, including the establishment of at least two viable populations in each historical diversity group, as well as other measurable biological criteria.

11A.4.8 References Cited

11A.4.8.1 Literature Cited

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11A.5 Central Valley Fall- and Late Fall–Run Chinook Salmon (*Oncorhynchus tshawytscha*)

11A.5.1 Legal Status

The Central Valley fall- and late fall-run Chinook salmon evolutionary significant unit (ESU) includes all naturally spawned populations of fall- and late fall-run Chinook salmon in the Sacramento and San Joaquin River basins and their tributaries east of Carquinez Strait, California (64 Federal Register [FR] 50394) (Figure 2A.5-1 and Figure 2A.5-2, respectively). On September 16, 1999, after reviewing the best available scientific and commercial information, the National Marine Fisheries Service (NMFS) determined that listing Central Valley fall- and late fall-run Chinook salmon was not warranted. On April 15, 2004, the Central Valley fall- and late fall-run Chinook salmon ESU was identified by NMFS as a Species of Concern (69 FR 19975). The rationale for this determination included the following items.

- The average 5-year escapement was above 190,000 fish from natural production, although 20–40% of these natural spawners were of hatchery origin.
- Long-term trends were generally stable or increasing, but it was unclear if natural populations were self-sustaining because of the influence of hatchery production.
- Short-term trends for San Joaquin River tributaries were stable or increasing.
- Concerns remained over impacts from high hatchery production and harvest levels, although ocean and freshwater harvest rates have been recently reduced.
- Approximately 40 to 50% of spawning and rearing habitats have been lost or degraded.

In a subsequent 5-year status review of California ESUs (76 FR 50447), NMFS concluded that several Chinook salmon populations identified through genetic sampling, should be included in the Central Valley fall- and late fall-run Chinook salmon ESU (Williams et al. 2011). This includes populations in the Napa and Guadalupe Rivers, along with future populations found in basins inclusive of the San Francisco/San Pablo Bay complex, which express a fall-run timing,

The Central Valley fall- and late fall-run Chinook salmon ESU are not listed under the California Endangered Species Act (CESA). Fall- and late fall-run Chinook salmon are identified as a California Species of Special Concern (Moyle et al. 1995).

11A.5.2 Species Distribution and Status

11A.5.2.1 Range and Status

Central Valley fall-run Chinook salmon historically spawned in all major tributaries, as well as the mainstem of the Sacramento and San Joaquin Rivers (Figure 2A.5-1). The historical geographic distribution of Central Valley late fall-run Chinook salmon is not well understood, but is thought to be less extensive than that of fall-run (Figure 2A.5-2). The late fall-run fish most likely spawned in the upper Sacramento and McCloud Rivers in reaches now blocked by Shasta Dam, as well as in sections of major tributaries where there was adequate cold water in summer. There is also some evidence they once spawned in the San Joaquin River in the Friant region and in other large San Joaquin tributaries (Yoshiyama et al. 1998). A large percentage of fall-run Chinook spawning areas in the Sacramento and San Joaquin Rivers historically inhabited the lower gradient reaches of the rivers downstream of sites now occupied by major dams, such as Shasta and Friant Dams. As a result of the geographic distribution of spawning and juvenile rearing areas, fall-run Chinook salmon populations in the Central Valley were not as severely affected by early water projects that blocked access to upstream areas, as were spring and winter runs of Chinook salmon and steelhead that used higher elevation habitat for spawning and rearing (Reynolds et al. 1993; McEwan 2001). Changes in seasonal hydrologic patterns resulting from operation of upstream reservoirs for water supplies, flood control, and hydroelectric power generation have altered instream flows and habitat conditions for fall-run Chinook salmon and other species downstream of the dams (Williams 2006).

The abundance of Central Valley fall- and late fall-run Chinook salmon escapement before 1952 is poorly documented. Reynolds et al. (1993) estimated that production of fall- and late fall-run Chinook salmon on the San Joaquin River historically approached 300,000 adults and probably averaged approximately 150,000 adults. Calkins et al. (1940) estimated fall- and late fall-run Chinook salmon abundance at 55,595 adults in the Sacramento River basin from 1931 to 1939. In the early 1960s, adult fall- and late fall-run Chinook salmon escapement was estimated to be 327,000 fish in the Sacramento River basin (California Department of Fish and Game 1965). In the mid-1960s, fall- and late fall-run Chinook salmon escapement to the San Joaquin River basin was estimated to be about 2,400 fish, which spawned in the San Joaquin River tributaries—the Stanislaus, Tuolumne, and Merced Rivers.

Long-term trends in adult fall-run Chinook salmon escapement indicate that abundance in the Sacramento River has been consistently higher than abundance in the San Joaquin River (Figure 2A.5-3). Escapement on the Sacramento River has been characterized by relatively high interannual variability ranging from approximately 100,000 to over 800,000 fish. Sacramento River escapement showed a marked increase in abundance between 1990 and 2003 followed by a decline in abundance from 2004 to present. In 2009, adult fall-run Chinook salmon returns to the Central Valley rivers showed a substantial decline in both the Sacramento and San Joaquin River systems. Similar declines in adult escapement were also observed for coho salmon and Chinook salmon returning to other river systems in California (MacFarlane et al. 2008).

A variety of factors are thought to have influenced adult escapement on both rivers, including hydrological conditions for migration, spawning, and juvenile rearing; ocean conditions; and management actions. Measures have been implemented since the early 1990s to improve seasonal water temperatures, streamflows, modifications to Red Bluff Diversion Dam) gate operations, fish passage, construction of positive barrier fish screens on larger diversions, and improved habitat conditions.

Trends in adult fall-run Chinook salmon escapement on the San Joaquin River and tributaries has been relatively low since the 1950s, ranging from several hundred adults to approximately 100,000 adults (Figure 2A.5-3). Results of escapement estimates have shown a relationship between adult escapement in 1 year and spring flows on the San Joaquin River 2.5 years earlier when the juvenile in the cohort were rearing and migrating downstream through the Sacramento–San Joaquin River Delta (Delta). Adult escapement appears to be cyclical and may be related to hydrology during the juvenile rearing and migration period, among other factors (San Joaquin River Group Authority 2010; California Department of Fish and Game 2008).

Population estimates for late fall-run Chinook salmon on the San Joaquin River system are not available, but it is thought that late fall-run Chinook salmon do not regularly spawn in the tributaries of the San Joaquin River (Moyle et al. 1995). Adult escapement estimates for late fall-run Chinook salmon returning to the Sacramento River from 1971 through 2009 have ranged from several hundred adults to over 40,000 adults. Adult escapement showed a general trend of declining abundance between 1971 and 1997 (Figure 2A.5-4). During the late 1990s and continuing through 2006, escapement has increased substantially but is characterized by high interannual variability. The 2008 and 2009 escapement estimates were lower than the previous 4 years, but were not characterized by the massive decline observed for fall-run Chinook salmon (Figure 2A.5-3). Many factors have been identified that may be contributing to the observed trends and patterns in late fall-run Chinook salmon escapement to the upper Sacramento River and its tributaries.

11A.5.2.2 Distribution and Status in the Plan Area

The entire population of the Central Valley fall- and late fall-run Chinook salmon ESU must pass through the Plan Area as adults migrating upstream and juveniles emigrating downstream. Adult Central Valley fall- and late fall-run Chinook salmon migrating into the Sacramento River and its tributaries primarily use the western and northern portions of the Delta, whereas adults entering the San Joaquin River system to spawn use the western, central, and southern Delta as a migration pathway. Fall- and late fall-run Chinook salmon must migrate through the Delta toward the Pacific Ocean and use the Delta, Suisun Marsh, and the Yolo Bypass for rearing to varying degrees, depending on their life stage (fry versus juvenile), size, river flows, and time of year.

11A.5.3 Habitat Requirements and Special Considerations

Critical Habitat has not been designated for either fall- or late fall-run Chinook salmon because the ESU is not listed under the federal Endangered Species Act (ESA). However, Central Valley fall- and late fall-run Chinook salmon habitats are protected under the Magnuson-Stevens Fishery Conservation and Management Act as essential fish habitat (EFH). Those waters and substrate that support fall- and late fall-run Chinook salmon growth to maturity are included as EFH (Figure 2A.5-5 and Figure 2A.5-6).

Although no critical habitat has been designated, the primary constituent elements (PCEs) considered essential for the conservation of other ESA-listed Central Valley salmonids would likely also apply to fall- and late fall-run Chinook salmon. These PCEs include freshwater spawning sites, freshwater rearing sites, freshwater migration corridors, estuarine areas, nearshore marine areas, and offshore marine areas.

11A.5.3.1 Spawning Habitat

Chinook salmon spawning sites include those stream reaches with instream flows, water quality, and substrate conditions suitable to support spawning, egg incubation, and larval development. Central Valley fall-run Chinook salmon currently spawn downstream of dams on every major tributary in the Sacramento and San Joaquin River systems (with the exception of the San Joaquin River downstream of Friant Dam, which is currently the subject of a settlement agreement and salmonid restoration program) in areas containing suitable environmental conditions for spawning and egg incubation.

Late fall-run Chinook salmon spawning is limited to the mainstem and tributaries of the Sacramento River. No Chinook salmon spawning habitat is known to occur in the Plan Area.

11A.5.3.2 Freshwater Rearing Habitat

Fall- and late fall-run Chinook salmon rear in streams and rivers with sufficient water flow and floodplain connectivity. They rear in these areas to form and maintain physical habitat conditions that support growth and mobility and provide suitable water quality (e.g., seasonal water temperatures) and forage species that support juvenile salmon growth and cover such as shade, submerged and overhanging large wood, logjams, beaver dams, aquatic vegetation, large rocks and boulders, side channels, and undercut banks. Both spawning areas and migratory corridors might also function as rearing habitat for juveniles, which feed and grow before and during their out-migration. Nonnatal, intermittent tributaries and seasonally inundated flood-control bypasses such as the Yolo Bypass also support juvenile rearing (Sommer et al. 2001). Rearing habitat value is strongly affected by habitat complexity, food supply, and predators. Some of these more complex and productive habitats with floodplains are still present in limited amounts in the Central Valley, for example, the lower Cosumnes River, Sacramento River reaches with setback levees (i.e., primarily located upstream of the City of Colusa). The channeled, leveed, and riprapped river reaches and sloughs common in the Sacramento and San Joaquin Rivers and throughout the Delta typically have low habitat diversity and complexity, have low abundance of food organisms, and offer little protection from predation by fish and birds. Freshwater rearing habitat has a high conservation value because the juvenile life stage of salmonids is dependent on the function of this habitat for successful growth, survival, and recruitment to the adult population.

11A.5.3.3 Freshwater Migration Corridors

Freshwater migration corridors for fall- and late fall-run Chinook salmon, including river channels, channels through the Delta, and the Bay-Delta estuary, support mobility, survival, and food supply for juveniles and adults. Migration corridors should be free from obstructions (passage barriers and impediments to migration), have favorable water quantity (instream flows) and quality conditions (seasonal water temperatures), and contain natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, side channels, and undercut banks. Migratory corridors are typically downstream of the spawning area and include the lower Sacramento and San Joaquin Rivers, the Delta, and the San Francisco Bay complex extending to coastal marine waters. These corridors allow the upstream passage of adults and the downstream emigration of juvenile salmon. Migratory corridor conditions are strongly affected by the presence of passage barriers, which can include dams, unscreened or poorly screened diversions, and degraded water quality. For freshwater migration corridors to function properly, they must provide adequate passage, provide suitable migration cues, reduce false attraction, avoid areas where vulnerability to predation is increased, and avoid impediments and delays in both upstream and downstream migration. For this reason, freshwater migration corridors are considered to have a high conservation value.

Results of mark-recapture studies conducted using juvenile Chinook salmon released into both the Sacramento and San Joaquin Rivers have shown high mortality during passage downstream through the rivers and Delta (Brandes and McLain 2001; Newman and Rice 2002; Hanson 2008). Mortality for juvenile salmon is typically greater on the San Joaquin River than for those fish emigrating from the Sacramento River. On both rivers, mortality is typically greater in years when spring flows are reduced and water temperatures are increased. Results of survival studies have shown that closing the Delta Cross Channel gates and installation of the Head of Old River Barrier, to reduce the movement of juvenile salmon into the Delta, contribute to improved survival of emigrating juvenile Chinook salmon. Observations at the State Water Project (SWP) and the Central Valley Project (CVP) fish salvage facilities have shown that very few of the marked salmon are entrained and salvaged at the export facilities. Although factors contributing to high juvenile mortality have not been quantified, results of anecdotal observations and acoustic tagging experiments suggest the exposure to adverse water quality conditions leading to mortality and vulnerability to predation mortality are two of the factors contributing to the high juvenile mortality observed in the rivers and Delta.

11A.5.3.4 Estuarine Areas

Estuarine migration and juvenile rearing habitats should be free of obstructions (i.e., dams and other barriers) and provide suitable water quality, water quantity (river and tidal flows), and salinity conditions to support juvenile and adult physiological transitions between fresh- and saltwater. Natural cover, such as submerged and overhanging large wood, aquatic vegetation, and side channels, provides juvenile and adult foraging. Estuarine areas contain a high conservation value because they support juvenile Chinook salmon growth, smolting, and the avoidance of predators, as well as provide a transition to the ocean environment.

11A.5.3.5 Ocean Habitats

Biologically productive coastal waters are an important habitat component for Central Valley fall- and late fall-run Chinook salmon. Juvenile fall-run and late fall-run Chinook salmon inhabit near-shore coastal marine waters for typically 2 to 4 years before adults return to Central Valley rivers to spawn. During their marine residence Chinook salmon forage on krill, squid, and other marine invertebrates, as well as a variety of fish such as northern anchovy and Pacific herring. These features are essential for conservation because without them juveniles cannot forage and grow to adulthood.

Results of oceanographic studies have shown the variation in ocean productivity off the West Coast within and among years. Changes in ocean currents and upwelling have been identified as significant factors affecting nutrient availability, phytoplankton and zooplankton production, and the availability of other forage species in near-shore surface waters (Wells et al. 2012). Ocean conditions at the end of the salmon’s ocean residency period can be important, as indicated by the effect of the 1983 El Niño on the size and fecundity of Central Valley fall-run Chinook salmon (Wells et al. 2006). Although the effects of ocean conditions on Chinook salmon growth and survival have not been investigated extensively, recent observations since 2007 have shown a significant decline in the abundance of adult Chinook salmon and coho salmon returning to California rivers and streams (fall-run adult returns to the Sacramento and San Joaquin Rivers were the lowest on record [Pacific Fishery Management Council 2008]). This drop has been hypothesized to be the result of declines in ocean productivity and associated high mortality rates during the period when these fish were rearing in near-shore coastal waters (MacFarlane et al. 2008). The importance of changes in ocean conditions to growth, survival, and population abundance of Central Valley Chinook salmon is undergoing further investigation, although relatively rapid changes in ocean conditions would act on top of the long-term, steady degradation of the freshwater and estuarine environment (Lindley et al. 2009).

11A.5.4 Life History

The following life history information was summarized primarily from the *Final Restoration Plan for the Anadromous Fish Restoration Program* (U.S. Fish and Wildlife Service 2001a).

Chinook salmon exhibit two characteristic freshwater life history types (Healey 1991). Stream-type adult Chinook salmon enter fresh water months before spawning, and their offspring reside in fresh water 1 or more years following emergence. In contract, ocean-type Chinook salmon spend significantly less time in fresh water, spawning soon after entering fresh water as adults and migrating to the ocean as juvenile fry or parr in their first year. Adequate stream flows and cool water temperatures are more critical for the survival of Chinook salmon exhibiting the stream-type life history behaviors because of their residence in fresh water both as adults and juveniles over the warmer summer months.

Central Valley fall-run Chinook salmon exhibit an ocean-type life history. Adult fall-run Chinook salmon migrate through the Delta and into Central Valley rivers from June through December and spawn from September through December (Table 2A.5-1). Peak spawning activity usually occurs in October and November. The life history characteristics of late fall-run Chinook salmon are not well understood; however, they are thought to exhibit a stream-type life history. Adult late fall-run Chinook salmon migrate through the Delta and into the Sacramento River from October through April and may wait 1 to 3 months before spawning from December through April (Table 2A.5-2). Peak spawning activity occurs in February and March. Chinook salmon typically mature between 2 and 6 years of age (Myers et al. 1998). The majority of Central Valley fall-run Chinook salmon spawn at age 3.

Information on the migration rates of Chinook salmon in fresh water is scant, and is mostly taken from the Columbia River basin where migration behavior information is used to assess the effects of dams on salmon travel times and passage (Matter and Sandford 2003). Adult Chinook salmon upstream migration rates ranged from 29 to 32 kilometers per day in the Snake River, a Columbia River tributary (Matter and Sandford 2003). Keefer et al. (2004) found migration rates of adult Chinook salmon in the Columbia River to range between approximately 10 kilometers per day to greater than 35 kilometers per day. Adult Chinook salmon with sonic tags have been tracked throughout the Delta and the lower Sacramento and San Joaquin Rivers (CALFED Bay-Delta Program 2001).

Table 2A.5-1. Temporal Occurrence of Adult and Juvenile Central Valley Fall-Run Chinook Salmon in the Sacramento River and Delta

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult												
Delta[1]						▒▒	■■	■■	■■	■■	■■	▒▒
Sacramento River Basin[2]							░░	░░	░░	■■	■■	■■
San Joaquin River[2]								░░	░░	■■	■■	░░
Juvenile												
Sacramento River at Red Bluff[3]	■■	■■	■■	■■	▒▒	▒▒	▒▒	░░	░░	░░	░░	▒▒
Delta (beach seine)[4]	■■	■■	■■	■■	▒▒	▒▒	░░	░░	░░		░░	▒▒
Mossdale (trawl)[4]	▒▒	■■	■■	■■	■■	▒▒						
West Sacramento River (trawl)[4]	▒▒	■■	■■	■■	■■	░░	░░	░░	░░		░░	░░
Chipps Island (trawl)[4]	▒▒	▒▒	▒▒	■■	■■	■■	░░	░░	░░	░░	░░	░░
Knights Landing (trap)[5]	■■	■■	■■	■■	■■	░░	░░	░░	░░	░░	░░	▒▒

Relative Abundance: ■ = High ▒ = Medium ░ = Low

Note: Darker shades indicate months of greatest relative abundance.

Sources:

[1] State Water Project and Federal Water Project fish salvage data 1981–1988.

[2] Yoshiyama et al. 1998; Moyle 2002; Vogel and Marine 1991.

[3] Martin et al. 2001.

[4] U.S. Fish and Wildlife Service 2001b.

[5] Snider and Titus 2000.

Table 2A.5-2. Temporal Occurrence of Adult and Juvenile Central Valley Late Fall-Run Chinook Salmon in the Sacramento River and Delta

Location	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Adult																								
Delta[1]	▓	▓	▓	▓	▓	▓	▒	▒	▒	▒									▒	▒	▒	▒	▒	▒
Sacramento River Basin[2]	▓	▓	▓	▓	▓	▓	▒	▒											▒	▒	▒	▒	▒	▒
Juvenile																								
Sacramento River at Red Bluff[3]	▓	▓	▓	▓	▓	▓	▓	▓	▒	▒	░	░	░	░	▓	▓	▓	▓	▓	▓	▓	▓	▒	▒
West Sacramento River (trawl)[4]	▒	▒	░	░			░	░			░	░	░	░	░	░	░	░	░	░	▓	▓	▓	▓
Delta (beach seine)[4]	▓	▓	▒	▒			▓	▓	▓	▓	▒	▒	░	░							░	░	▓	▓
Chipps Island (trawl)[4]	▒	▒	░	░					░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▓	▓
Knights Landing (trap)[5]	▒	▒	░	░			▒	▒	▒	▒	░	░							░	░	▒	▒	▓	▓

Relative Abundance: ▓ = High ▒ = Medium ░ = Low

Note: Darker shades indicate months of greatest relative abundance.

Sources:

[1] Moyle 2002.

[2] Yoshiyama et al. 1998; Moyle 2002; Vogel and Marine 1991.

[3] Martin et al. 2001.

[4] U.S. Fish and Wildlife Service 2001b.

[5] Snider and Titus 2000.

These fish exhibited substantial upstream and downstream movement in a random fashion while migrating upstream several days at a time. Adult salmonids migrating upstream, particularly larger salmon such as Chinook (Hughes 2004), are assumed to make greater use of pool and mid-channel habitat than they do of channel margins (Stillwater Sciences 2004). Adult salmon are thought to exhibit crepuscular behavior during their upstream migrations, primarily migrating during twilight hours (Hallock et al. 1970).

Chinook salmon spawn in clean, loose gravel in swift, relatively shallow riffles, or along the margins of deeper river reaches where suitable water temperatures, depths, and velocities favor redd construction and oxygenation of incubating eggs. Chinook salmon spawning typically occurs in gravel beds located at the tails or downstream ends of holding pools (U.S. Fish and Wildlife Service 1995). Egg incubation for Central Valley – Chinook salmon begins with spawning in September and can extend into March (Vogel and Marine 1991). Egg incubation for late ––run salmon occurs from December through June (Vogel and Marine 1991; Earley et al. 2010).

Fry emergence generally occurs at night. Upon emergence from the gravel, fry swim or are displaced downstream (Healey 1991). Fry seek streamside habitats containing beneficial aspects such as riparian vegetation and associated substrates that provide aquatic and terrestrial invertebrates, predator avoidance cover, and slower water velocities for resting (National Marine Fisheries Service 1996). These shallow water habitats have been described as more productive juvenile salmon rearing habitat than the deeper main river channels. Higher juvenile salmon growth rates (partially due to greater prey consumption rates) and favorable environmental temperatures have been associated with floodplains that have extensive shallow water habitats (Sommer et al. 2001).

Central Valley fall-run Chinook salmon fry (i.e., juveniles shorter than 2 inches long) generally emerge from December through March, with peak emergence occurring by the end of January. In general, fall-run Chinook salmon fry abundance in the Delta increases following high winter flows. Most fall-run Chinook salmon fry rear in fresh water from December through June, with emigration as smolts occurring primarily from January through June (Table 2A.5-1). Smolts that arrive in the estuary after rearing upstream migrate quickly through the Delta and Suisun and San Pablo Bays. A very small number (generally less than 5%) of fall-run juveniles spend over a year in fresh water and emigrate as yearling smolts the following November through April.

Central Valley late fall-run Chinook salmon fry generally emerge from April through June. Late fall-run fry rear in fresh water from April through the following April and emigrating as smolts from October through February (Snider and Titus 2000). Juvenile fall-run Chinook salmon out-migration through the Delta is thought to be primarily a diurnal activity, whereas out-migration of juvenile late fall-run salmon through the Delta is thought to occur primarily at night (Wilder and Ingram 2006). There are a variety of possible explanations for the difference in diel activity between races, including fish size, water temperature, flow rate, and water clarity during downstream migration. Once downstream movement has commenced, individuals may continue this movement until reaching the estuary or they may reside in the stream for a few weeks to a few months (Healey 1991). Juvenile Chinook salmon migration rates vary considerably and likely depend on the physiological stage of the fish and hydrologic conditions. Kjelson et al. (1982) found Chinook salmon fry traveled downstream as fast as 30 kilometers per day in the Sacramento River. Sommer et al. (2001) found rates ranging from approximately 1 kilometer to greater than10 kilometers per day in the Yolo Bypass.

As juvenile Chinook salmon grow, they move into deeper water with higher current velocities, but still seek shelter and velocity refugia to minimize energy expenditures (Healey 1991). Catches of juvenile salmon in the Sacramento River near West Sacramento by the U.S. Fish and Wildlife Service (USFWS) (1997) indicate that larger juveniles were captured in the main channel and smaller-sized fry along the channel margins. Where the river channel is greater than 9 to 10 feet in depth, juvenile salmon tend to inhabit the surface waters (Healey 1980). Streamflow and/or turbidity increases in the upper Sacramento River basin are thought to stimulate juvenile emigration (Kjelson et al. 1982; Brandes and McLain 2001).

As Chinook salmon begin to smolt (i.e., make the physiological changes necessary for life in saltwater), they are found rearing further downstream where ambient salinity reaches 1.5 to 2.5 parts per thousand (Healey 1980; Levy and Northcote 1981). In the Delta, juvenile Chinook salmon forage in shallow areas with protective cover, such as tidally influenced sandy beaches and shallow vegetated zones (Meyer 1979; Healey 1980). Cladocerans, copepods, amphipods, and dipteran larvae dipteral, as well as small arachnids and ants, are common prey items (Kjelson et al. 1982; Sommer et al. 2001).

Juvenile Chinook salmon movement in the estuarine habitat is dictated by the interaction between tidally driven saltwater intrusions through the San Francisco Bay and freshwater outflow from the Sacramento and San Joaquin Rivers. Juvenile Chinook salmon follow rising tides into shallow water habitats from the deeper main channels, and return to the main channels when the tides recede (Levy and Northcote 1981; Healey 1991). Juvenile Chinook salmon were found to spend about

40 days migrating through the Delta to the mouth of San Francisco Bay and grew little in length or weight until they reached the Gulf of the Farallones (MacFarlane and Norton 2002). Based on the mainly ocean-type life history observed (i.e., fall-run Chinook salmon), MacFarlane and Norton (2002) concluded that unlike other salmonid populations in the Pacific Northwest, Central Valley Chinook salmon smolts currently show little estuarine dependence and may benefit from expedited ocean entry. However, this may not be the case for emigrating fry that rear for a longer period in the Delta and estuary before emigrating to coastal marine waters. In addition, changes in habitat conditions in the Delta over the past century may have resulted in a reduction in extended juvenile salmon rearing when compared to periods during which habitat for juvenile fall-run and late fall-run salmon rearing was more suitable.

Central Valley Chinook salmon begin their ocean life in the coastal marine waters of the Gulf of the Farallones from where they distribute north and south along the continental shelf, primarily between Point Conception and Washington State (Healey 1991). Upon reaching the ocean, juvenile Chinook salmon feed on larval and juvenile fishes, plankton, and terrestrial insects (Healey 1991; MacFarlane and Norton 2002). Chinook salmon grow rapidly in the ocean environment, with growth rates dependent on water temperatures and food availability (Healey 1991). The first year of ocean life is considered a critical period of high mortality for Chinook salmon that largely determines survival to harvest or spawning (Beamish and Mahnken 2001; Quinn 2005).

Recovery of coded-wire tagged Chinook salmon from the Feather River Hatchery in the ocean recreational and commercial fisheries (Pacific States Marine Fisheries Commission Regional Mark Information System database) indicates that Central Valley fall-run Chinook salmon adults are broadly distributed along the Pacific Coast from northern Oregon to Monterey. Recovery of tagged late fall-run Chinook salmon from the Coleman Hatchery in the ocean recreational and commercial fisheries (Pacific States Marine Fisheries Commission Regional Mark Information System database) indicates that Central Valley late fall-run Chinook salmon adults are the most broadly distributed along the Pacific Coast of the Central Valley salmon, ranging from British Columbia to Monterey.

Like other ocean-type Chinook salmon, Central Valley fall- and late fall-run Chinook salmon remain near the coast throughout their ocean life (Healey 1983, 1991; Myers et al. 1984). Central Valley fall- and late fall-run Chinook salmon remain in the ocean for 2 to 5 years. Fall-run Chinook salmon mature in the ocean before returning to fresh water to spawn. Late fall-run Chinook salmon may return to fresh water as immature adults as indicated by a 1- to 3-month delay in spawning once reaching the spawning grounds.

11A.5.5 Threats and Stressors

The following have been identified as important threats and stressors to fall- and late fall-run Chinook salmon (without priority). Additionally, recent record low numbers of fall-run Chinook salmon adult returns to the Central Valley (Pacific Fishery Management Council 2008) suggest that ocean conditions may be an important stressor to the ESU (MacFarlane et al. 2008), although the mechanisms driving this potential effect are not well understood. Lindley et al. (2009) found that unusual ocean conditions in the spring of 2005 and 2006 led to poor growth and survival of juvenile salmon entering the ocean in those years, including Sacramento River fall Chinook salmon. From 2007 to 2009, the Central Valley also experienced drought conditions and low river and stream discharges, which are generally associated with lower survival of Chinook salmon. There is a possibility that with the recent cessation of the drought and a return to more typical patterns of upwelling and sea-surface temperatures, declining trends in abundance may reverse in the near future (National Marine Fisheries Service 2011).

11A.5.5.1 Reduced Staging and Spawning Habitat

Access to the upper extent of the historical upstream spawning habitat for fall- and late fall-run Chinook salmon (Figure 2A.5-1 and Figure 2A.5-2) has been eliminated or degraded by artificial structures (e.g., dams and weirs) associated with water storage and conveyance, flood control, and diversions and exports for municipal, industrial, agricultural, and hydropower purposes (Yoshiyama et al. 1998). Because spawning locations of fall- and late fall-run Chinook salmon are typically in the lower reaches of rivers, fall- and late fall-run Chinook salmon have been less affected by dam construction relative to other Central Valley salmonids. Spawning habitat for fall- and late fall-run Chinook salmon is still widely distributed in the Sacramento River basin, but more limited in the San Joaquin River basin.

Upstream diversions and dams have decreased downstream flows and altered the seasonal hydrologic patterns. These factors have been identified as contributing to delays in upstream migration by adults, contributing to increased mortality of out-migrating juveniles, and responsible for making some streams uninhabitable for fall- and late fall-run salmon (Yoshiyama et al. 1998; California Department of Water Resources 2005). Dams and reservoir impoundments and associated reductions in peak flows have blocked gravel recruitment and reduced flushing of sediments from existing gravel beds, reducing and degrading natal spawning grounds. Further, reduced flows can lower attraction cues for adult spawners, causing straying and delays in spawning (California Department of Water Resources 2005). Adult salmon migration delays can reduce fecundity and increase susceptibility to disease and harvest (McCullough 1999) Because fall-run Chinook salmon spawn shortly after entering fresh water, a delay in migration can have substantial impacts on prespawning mortality and spawning success relative to other races of Chinook salmon.

The Red Bluff Diversion Dam located on the Sacramento River has been identified as a barrier and impediment to adult upstream migration. Although the Red Bluff Diversion Dam is equipped with fish ladders, migration delays have been reported when the dam gates are closed. Mortality as a result of increased predation by Sacramento pikeminnow on juvenile salmon passing downstream through the fish ladder has also been identified as a factor affecting abundance of salmon produced on the Sacramento River (Hallock 1991). To help reduce the effects of dam operation on migration of adult and juvenile salmonids and other species, management changes have occurred in recent years to maintain the dam gates in the open position for a longer period of time, facilitating greater upstream and downstream migration. Changes in dam operations have benefited both upstream and downstream migration and have contributed to a reduction in juvenile predation mortality.

11A.5.5.2 Reduced Rearing and Outmigration Habitat

Natural migration corridors for juvenile fall- and late fall-run Chinook salmon consist of complex habitat types, including stream banks, floodplains, marshes, and shallow water areas used as rearing habitat during out-migration. Much of the Sacramento and San Joaquin River corridor and Delta have been leveed, channelized, and modified with riprap for flood protection, thereby reducing and degrading the value and availability of natural habitat for rearing and emigrating juvenile Chinook salmon (Brandes and McLain 2001). Juvenile out-migration delays associated with artificial passage impediments can reduce fitness and increase susceptibility to diversion screen impingement, entrainment, disease, and predation. Modification of natural flow regimes from upstream reservoir operations has resulted in dampening of the hydrograph, reducing the extent and duration of seasonal floodplain inundation and other flow-dependent habitat used by migrating juvenile Chinook salmon (70 FR 52488; Sommer et al. 2001; California Department of Water Resources 2005). Recovery of floodplain habitat in the Central Valley has been found to contribute to increases in production in Chinook salmon (Sommer et al. 2001). Reductions in flow rates have resulted in increased water temperature and residence time, and reduced dissolved oxygen levels in localized areas of the Delta (e.g., Stockton Deep Water Ship Channel). Reduced dissolved oxygen levels in the San Joaquin River during summer and fall have been identified as a water quality barrier to salmon migration (Central Valley Regional Water Quality Control Board 2007).

Tidal and floodplain habitat areas provide important rearing habitat for foraging juvenile salmonids, including fall-run Chinook salmon. Studies have shown that these salmonids may spend 2 to 3 months rearing in these habitat areas, and losses resulting from land reclamation and levee construction are considered to be major stressors on juvenile salmonids (Williams 2009). Similarly, channel margins provide valuable rearing and connectivity habitat along migration corridors, particularly for smaller juvenile fry, such as fall-run Chinook salmon. However, these habitats are expected to provide less benefit to larger stream-type juvenile migrants, such as late fall-run Chinook salmon, which tend to spend less time rearing and foraging in the lower river reaches and the Delta.

11A.5.5.3 Predation by Nonnative Species

Predation on juvenile salmon by nonnative fish has been identified as an important threat to fall- and late fall-run Chinook salmon in areas with high densities of nonnative fish (e.g., small and large mouth bass, striped bass, and catfish) that prey on out-migrating juvenile salmon (Lindley and Mohr 2003). Nonnative aquatic vegetation, such as Brazilian waterweed (*Egeria densa*) and water hyacinth (*Eichhornia crassipes*), provide suitable habitat for nonnative predators (Nobriga et al. 2005; Brown and Michniuk 2007). Predation risk may also vary with increased temperatures. Metabolic rates of nonnative, predatory fish increase with increasing water temperatures based on bioenergetic studies (Loboschefsky et al. 2009; Miranda et al. 2010). Upstream gravel pits and flooded ponds attract nonnative predators because of their depth and lack of cover for juvenile salmon (California Department of Water Resources 2005). The low spatial complexity and reduced habitat diversity (e.g., lack of cover) of channelized waterways in the rivers and Delta reduce refuge space of salmon from predators (Raleigh et al. 1984; Missildine et al. 2001; 70 FR 52488).

Predation by native species, such as the Sacramento pikeminnow in the Sacramento River at the Red Bluff Diversion Dam has also been identified as a potentially significant source of mortality on juvenile salmonids.

11A.5.5.4 Harvest

Fall-run Chinook salmon have been the most abundant species in the Central Valley for many years and have supported much of the California commercial and sport fishery (Lindley et al. 2004). However, a sharp decline in returning fall-run Chinook salmon in recent years, and the influence of large-scale hatchery production on the genetics of the species (Barnett-Johnson et al. 2007) have prompted concern for the fall-run stock.

Commercial or recreational harvest of fall- and late fall-run Chinook salmon populations in the ocean and inland fisheries has been a subject of management actions by the California Fish and

Game Commission and the Pacific Fishery Management Council. Coastal marine waters offshore of San Francisco Bay are a mixed stock fishery comprised of both wild and hatchery produced salmon. As a result of differences in survival rates for eggs incubation, rearing, and emigration, juvenile salmon produced in streams and rivers have relatively low survival rates compared to Central Valley salmon hatcheries, which have relatively high survival rates. Therefore, naturally reproducing Chinook salmon populations are less able to withstand high harvest rates compared to hatchery-based stocks (Knudsen et al. 1999). The ocean fishery for fall- and late fall-run Chinook salmon is supplemented by hatchery enhancement programs (U.S. Fish and Wildlife Service 1999; Williams 2006). The Coleman National Fish Hatchery produces approximately 12 million fall-run and 1 million late fall-run Chinook salmon juveniles each year to mitigate for habitat loss from construction of Shasta and Keswick Dams (Williams 2006). Fall-run Chinook salmon are also produced at hatcheries on the Feather, American, Mokelumne, and Merced Rivers (Williams 2006). Harvest as a result of the commercial and recreational fisheries may ultimately be having detrimental effects on wild spawners in this mixed stock fishery, but few data are available. Commercial fishing for salmon is managed by the Pacific Fishery Management Council and is constrained by time and area to meet the Sacramento River winter-run ESA consultation standard and restrictions requiring minimum size limits and use of circle hooks for anglers.

Beginning in 2007, Central Valley hatcheries have implemented a proportional marking program (tagging a set percentage of salmon produced in each hatchery) that is designed to provide improved information on the effects of harvest on various stocks of Chinook salmon. The program also provides information on ocean migration patterns, growth and survival for fish released at various life stages and locations, the contribution of hatcheries to the adult population, straying among hatcheries and watersheds, the relative contribution of in-river versus hatchery production, and other data that will assist managers in refining harvest regulations. Results of coded wire tag mark-recapture studies and data from the proportional marking program are continually being reviewed and analyzed each year, and used to modify harvest regulations and Central Valley salmon management.

11A.5.5.5 Reduced Genetic Diversity and Integrity

Artificial propagation programs (hatchery production) for fall- and late fall-run Chinook salmon in the Central Valley present multiple threats to wild (in-river spawning) Chinook salmon populations, including genetic introgression by hatchery origin fish that spawn naturally and interbreed with local wild populations (U.S. Fish and Wildlife Service 2001a; Bureau of Reclamation 2004; Goodman 2005). Central Valley hatcheries are recognized as a significant and persistent threat to wild Chinook salmon and steelhead populations and fisheries (National Marine Fisheries Service 2009a). Interbreeding with hatchery fish contributes directly to reduced genetic diversity and introduces maladaptive genetic changes to the wild population (California Department of Fish and Game 1995; CALFED Bay-Delta Program 2004; Myers et al. 2004; Araki et al. 2007). In addition, releasing hatchery smolts downstream of hatcheries has resulted in an increase in straying rates, further reducing genetic diversity among populations (Williamson and May 2005). Central Valley hatcheries are currently undergoing a detailed review by NMFS and CDFW as part of a comprehensive hatchery master plan process. Various techniques and actions for reducing the effects of hatchery production on the genetic characteristics of Chinook salmon have been identified as part of the hatchery review. These include, but are not limited to, the following practices.

- Seasonally selecting brood stock for hatchery use in proportion to adult escapement to the river.

- Selecting brood stock from various age classes (including grilse) that represents the age structure of the wild population.
- Selecting brood stock by tagging and conducting genetic testing.
- Increasing the number of adults used as brood stock to increase genetic diversity.
- Reducing the interbasin transfer of eggs and fry.
- Imprinting juveniles to reduce straying among watersheds.

These and other hatchery management methods (e.g., reducing the use of antibiotics and implementing juvenile release strategies to reduce effects on wild rearing juveniles, and planning volitional releases) are expected to reduce the potential risk of hatchery production on the genetics and success of wild populations. However, artificial selection for traits that assure individual success in a hatchery setting (e.g., rapid growth and tolerance to crowding) are difficult to avoid (Bureau of Reclamation 2004).

The potential for inter-breeding between Central Valley spring- and fall-run salmon stocks is generally identified as a genetic concern (Yoshiyama et al. 1998). However, some studies indicate no evidence of natural hybridization among Chinook salmon runs despite the spatial and temporal overlap (Banks et al. 2000). Spring- and fall-run Chinook salmon were historically isolated in time and space during spawning; however, the construction of dams and reduction in flows have eliminated access to historical spawning areas of spring-run salmon in the upper tributaries and streams, forcing spring-run salmon to spawn in lower elevation areas also used by fall-run salmon (Yoshiyama et al. 1998). Hybridization between spring- and fall-run salmon is a particular concern on the Feather River, where both runs occur, and is a potential concern for future restoration of salmon on the San Joaquin River downstream of Friant Dam. However, the genotypic proportions in the Butte Creek spring run cluster farther from the fall run versus the spring run from Deer and Mill Creeks. This challenges the hybridization hypothesis (Banks et al. 2000), which proposes that the cluster would be closer to the fall run. Deer and Mill Creeks, like many of the other Central Valley tributaries, have a reduced risk of hybridization because the runs can segregate geographically in the watersheds.

11A.5.5.6 Entrainment

The vulnerability of fall- and late fall-run Chinook salmon to entrainment and salvage at the SWP and CVP export facilities varies in response to multiple factors, including the seasonal and geographic distribution of juvenile salmon in the Delta, operation of Delta Cross Channel gates and Head of Old River Barrier, hydrodynamic conditions occurring in the central and southern regions of the Delta (e.g., Old and Middle Rivers), and export rates. The losses of fish to entrainment mortality has been identified as an impact on Chinook salmon populations (Kjelson and Brandes 1989). Kimmerer (2008) estimated that losses of Chinook salmon may have been up to 10% at high rates of south Delta export pumping but noted considerable uncertainty in the estimates because prescreen losses due to predation and other factors are difficult to quantify.

Juvenile fall-run Chinook salmon tend to be distributed in the central and southern Delta where they have an increased risk of entrainment/salvage between January and April (Table 2A.5-1). Juvenile late fall-run Chinook salmon tend to be distributed in the Delta primarily between December and January and again between April and May (Table 2A.5-2). The effect of changing hydrodynamics in Delta channels, such as reversed flows in Old and Middle Rivers resulting from SWP and CVP export operations, has the potential to increase attraction of emigrating juveniles into false migration pathways, delay emigration through the Delta, and directly or indirectly increase vulnerability to entrainment at unscreened diversions, risk of predation, and the duration of exposure to seasonally elevated water temperatures and other water quality conditions.

SWP and CVP exports have been shown to affect the tidal hydrodynamics (e.g., water current velocities and direction). The magnitude of these hydrodynamic effects vary in response to a variety of factors that include the tidal stage and magnitude of ebb and flood tides, the rate of SWP and CVP exports, operation of the Clifton Court Forebay radial gate opening, and inflow from the upstream tributaries. Chinook salmon behaviorally respond to hydraulic cues (e.g., water currents) during both upstream adult and downstream juvenile migration through the Delta. During the past several years additional investigations have been designed using radio or acoustically tagged juvenile Chinook salmon to monitor their migration behavior through the Delta channels and assess the effects of changes in hydraulic cues and SWP and CVP export operations on migration (Holbrook et al. 2009; Perry et al. 2010; San Joaquin River Group Authority 2010). These studies are ongoing.

Besides mortality, salmon fitness may be affected by entrainment at diversions and delays in out-migration of smolts caused by reduced or reverse flows. Delays in migration resulting from water operations related to SWP and CVP export facilities can make juvenile salmonids more susceptible to many of the threats and stressors, such as predation, entrainment, harvest, exposure to toxins, etc. The quantitative relationships among changes in Delta hydrodynamics, the behavioral and physiological response of juvenile salmon, and the increase or decrease in risks associated with other threats is unknown, but the subject of a number of current investigations and analyses.

In addition to SWP and CVP exports, more than 2,200 small water diversions exist throughout the Delta, in addition to unscreened diversions located on the tributary rivers (Herren and Kawasaki 2001). The risk of entrainment is a function of the size of juvenile fish and the slot opening of the screen mesh (Tomljanovich et al. 1978; Schneeberger and Jude 1981; Zeitoun et al. 1981; Weisberg et al. 1987). Many of the juvenile salmon migrate downstream through the Delta during the late winter or early spring when many of the agricultural irrigation diversions are not operating or are only operating at low levels. Juvenile salmon also migrate primarily in the upper part of the water column and, as a result, their vulnerability to an unscreened diversion located near the channel bottom is reduced. No quantitative estimates have been developed to assess the potential magnitude of entrainment losses for juvenile Chinook salmon migration through the rivers and Delta, or the effects of these losses on the overall population abundance of returning adult fall- and late fall-run Chinook salmon. Many of the larger water diversions located in the Central Valley and Delta (e.g., Glenn Colusa Irrigation District, Reclamation District 108 Wilkins Slough and Poundstone Pumping Plants, Sutter Mutual Water Company Tisdale Pumping Plant, Contra Costa Water District Old River and Alternative Intake Project, and others) have been equipped with positive barrier fish screens to reduce and avoid the loss of juvenile Chinook salmon and other fish species.

Power plants in the Plan Area have the ability to impinge juvenile Chinook salmon on the existing cooling water system intake screens. However, as older units are retired, the use of cooling water has declined. Newer units are equipped with a closed-cycle cooling system that virtually eliminates the risk of impingement of juvenile salmon.

11A.5.5.7 Exposure to Toxins

Toxic chemicals have the potential to be widespread throughout the Delta, or may occur on a more localized scale in response to episodic events (stormwater runoff, point source discharges, etc.). These toxic substances include mercury, selenium, copper, pyrethroids, and endocrine disruptors with the potential to affect fish health and condition, and adversely affect salmon distribution and abundance. The concerns regarding exposure to toxic substances for Chinook salmon include waterborne chronic and acute exposure, as well as bioaccumulation and chronic dietary exposure. For example, selenium is a naturally occurring constituent in agricultural drainage water return flows from the San Joaquin River that is subsequently dispersed downstream into the Delta (Nichols et al. 1986). Exposure to selenium in the diet of juvenile Chinook salmon has been shown to result in toxic effects (Hamilton et al. 1990; Hamilton and Buhl 1990). Selenium exposure has been associated with agricultural and natural drainage in the San Joaquin River basin and refining operations adjacent to San Pablo and San Francisco Bays. Other contaminants of concern for Chinook salmon include, but are not limited to, mercury, copper, oil and grease, pesticides, herbicides, and ammonia[3].

Ammonia released from the City of Stockton Wastewater Treatment Plant contributes to low dissolved oxygen in the adjacent Stockton Deep Water Ship Channel. In addition to the adverse effects of the lowered dissolved oxygen on salmonid physiology, ammonia is toxic to salmonids at low concentrations. The treatment train at the wastewater facility has been modified to remedy this source of ammonia (National Marine Fisheries Service 2012).

As a result of the extensive agricultural development in the Central Valley, exposure to pesticides and herbicides has been identified as a significant concern for salmon and other fish species in the Plan Area (Bennett et al. 2001). Mercury and other metals such as copper have also been identified as contaminants of concern for salmon and other fish as a result of toxicity and tissue bioaccumulation adversely affecting fish (U.S. Environmental Protection Agency 2006), as well as representing a human health concern (Gassel et al. 2008). These materials originate from a variety of sources including mining operations, municipal wastewater treatment, agricultural drainage in the tributary rivers and Delta, nonpoint runoff, natural runoff and drainage in the Central Valley, agricultural spraying, and a number of other sources.

The State Water Resources Control Board (State Water Board), Central Valley Regional Water Quality Control Board, U.S. EPA, U.S. Geological Survey (USGS), California Department of Water Resources (DWR), and others have ongoing monitoring programs designed to characterize water quality and identify potential toxicants and contaminant exposure to Chinook salmon and other aquatic resources in the Plan Area. Programs are in place to regulate point source discharges as part of the National Pollutant Discharge Elimination System (NPDES) as well as programs to establish and reduce total maximum daily loads (TMDL) of various constituents entering the Delta. Changes in regulations have also been made to help reduce chemical exposure and reduce the adverse impacts on aquatic resources and habitat conditions in the Plan Area. These monitoring and regulatory programs are ongoing.

Sublethal concentrations of toxins may interact with other stressors to cause adverse effects on salmonids, such as increasing the salmonids' vulnerability to mortality as a result of exposure to seasonally elevated water temperatures, predation, or disease (Werner 2007). For example, Clifford

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[3] Ammonia in water generally forms some amount of ammonium. Therefore, the use of the term *ammonia* implies that both ammonia and ammonium may be present.

et al. (2005) found in a laboratory setting that juvenile fall-run Chinook salmon exposed to sublethal levels of a common parathyroid, esfenvalerate, were more susceptible to the infectious hematopoietic necrosis virus than those not exposed to esfenvalerate. Juvenile Chinook salmon have a relatively extended period of Delta and estuarine residence of several months (Quinn 2005), which increases exposure and susceptibility to toxic substances in these areas. Adult migrating Chinook salmon may be less affected by these toxins because they are not feeding, and thus not bioaccumulating toxic exposure, and they are moving rapidly through the system.

Iron Mountain Mine, located adjacent to the upper Sacramento River, has been a source of trace elements and metals that are known to adversely affect aquatic organisms (Upper Sacramento River Fisheries and Riparian Habitat Advisory Council 1989). Storage limitations and limited availability of dilution flows have caused downstream copper and zinc levels to exceed salmonid tolerances and resulted in documented fish kills in the 1960s and 1970s (Bureau of Reclamation 2004). EPA's Iron Mountain Mine remediation program has removed toxic metals in acidic mine drainage from the Spring Creek watershed with a state-of-the-art lime neutralization plant. Contaminant loading into the Sacramento River from Iron Mountain Mine has shown measurable reductions since the early 1990s.

11A.5.5.8 Increased Water Temperature

Water temperature is among the physical factors that affect the value of habitat for salmonid adult holding, spawning and egg incubation, juvenile rearing, and migration. Adverse sublethal and lethal effects can result from exposure to elevated water temperatures at sensitive life stages, such as during incubation or rearing. The Central Valley is the southern limit of Chinook salmon geographic distribution. As a result, increased water temperatures are often recognized as a particularly important stressor to California populations. Water temperature criteria for various life stages of salmonids in the Central Valley have been developed by NMFS (2009a). The tolerance of fall-run and late fall-run Chinook salmon to water temperatures depends on life stage, acclimation history, food availability, duration of exposure, health of the individual, and other factors such as predator avoidance (Myrick and Cech 2004; Bureau of Reclamation 2004). Higher water temperatures can lead to physiological stress, reduced growth rate, delayed passage, in vivo egg mortality of spawning adults, prespawning mortality, reduced spawning success, and increased mortality of salmon (Myrick and Cech 2001). Temperature can also indirectly influence disease incidence and predation (Waples et al. 2008). Exposure to seasonally elevated water temperatures may occur because of reductions in flow as a result of upstream reservoir operations, reductions in riparian vegetation, channel shading, local climate, and solar radiation. The installation of the Shasta Temperature Control Device in 1998, in combination with reservoir management to maintain the cold water pool, has reduced many of the temperature issues on the Sacramento River. During dry years, however, the release of cold water from Shasta Dam is still limited. As the river flows further downstream, particularly during the warm spring, summer, and early fall months, water temperatures continue to increase until they reach thermal equilibrium with atmospheric conditions. As a result of the longitudinal gradient of seasonal water temperatures, the coldest water—and, therefore, the best areas for salmon spawning and rearing—are typically located immediately downstream of the dam.

Increased temperature can also arise from a reduction in shade over rivers by tree removal (Watanabe et al. 2005). Because river water is typically in thermal equilibrium with atmospheric conditions by the time it enters the Delta, this issue is caused primarily from actions upstream of the Delta. As a result of the relatively wide channels that occur in the Delta, the effects of additional riparian vegetation on reducing water temperatures are minimal. The effects of climate change and global warming patterns, in combination with changes in precipitation and seasonal hydrology in the future have been identified as important factors that may adversely affect the health and long-term viability of Central Valley spring-run Chinook salmon (Crozier et al. 2008). The rate and magnitude of these potential environmental changes, and their effect on habitat value and availability for fall- and late fall-run Chinook salmon, however, are subject to a high degree of uncertainty.

11A.5.6 Relevant Conservation Efforts

Results of salvage monitoring and extensive experimentation over the past several decades have led to the identification of various management actions designed to reduce or avoid the potentially adverse effects of SWP and CVP export operations on salmon. Many of these actions have been implemented through State Water Board water quality permits (D-1485, D-1641), biological opinions issued on project export operations by NMFS, USFWS, and the California Department of Fish and Wildlife (CDFW), as part of CALFED Bay-Delta Program programs such as the Environmental Water Account, and as part of Central Valley Project Improvement Act actions. As a result of these requirements, multiple conservation efforts exist to reduce entrainment of Chinook salmon by the SWP and CVP export facilities.

Several habitat problems that contributed to the decline of Central Valley salmonid species are being addressed and improved through restoration and conservation actions related to ESA Section 7 consultation, Reasonable and Prudent Alternatives, addressing temperature, flow, and operations of the Central Valley and State Water Projects, the Central Valley Regional Water Board decisions requiring compliance with Sacramento River water temperature objectives that resulted in installation of the Shasta Temperature Control Device in 1998, and EPA actions to control acid mine runoff from Iron Mountain Mine.

Biological opinions for SWP and CVP operations (e.g., National Marine Fisheries Service 2009b) and other federal projects involving irrigation and water diversion and fish passage have improved or minimized adverse effects on salmon in the Central Valley. In 1992, an amendment to the authority of the CVP through the Central Valley Project Improvement Act was enacted to give the protection of fish and wildlife equal priority with other Central Valley Project objectives. From this act arose several programs that have benefited listed salmonids. The Anadromous Fish Restoration Program is engaged in monitoring, education, and restoration projects designed to contribute toward doubling the natural populations of select anadromous fish species residing in the Central Valley. Restoration projects funded through the program include fish passage, fish screening, riparian easement and land acquisition, development of watershed planning groups, instream and riparian habitat improvement, and gravel replenishment. The Anadromous Fish Screen Program combines federal funding with state and private funds to prioritize and construct fish screens on major water diversions mainly in the upper Sacramento River. The goal of the Water Acquisition Program is to acquire water supplies to meet the habitat restoration and enhancement goals of the Central Valley Project Improvement Act, and to improve the ability of the U.S. Department of the Interior to meet regulatory water quality requirements. Water has been used to improve fish habitat for Central Valley salmon. These improvements have focused primarily on listed Chinook salmon and steelhead but have provided incidental benefits to fall- and late fall-run Chinook salmon. The improvements involve maintaining or increasing instream flows (Environmental Water Account) on the Sacramento River and the San Joaquin River at critical times and lowering seasonal diversion rates during periods when protected fish species are vulnerable to export related losses to reduce salmonid entrainment at the SWP and CVP export facilities.

Two programs included under CALFED Bay-Delta Program, the Ecosystem Restoration Program and the Environmental Water Account, were created to improve conditions for fish, including fall- and late fall-run Chinook salmon, in the Central Valley. Restoration actions implemented by the program include the installation of fish screens, modification of barriers to improve fish passage, habitat acquisition, and instream habitat restoration. The majority of these actions address key factors and stressors affecting listed salmonids that incidentally benefit fall- and late fall-run Chinook salmon. Additional ongoing actions include efforts to enhance fishery monitoring and improvements to hatchery management to support salmonid production through hatchery releases.

A major Ecosystem Restoration Program action currently under way is the Battle Creek Salmon and Steelhead Restoration Project. The project will restore 48 miles (77 kilometers) of habitat in Battle Creek to support steelhead and Chinook salmon spawning and juvenile rearing at a cost of over $90 million. The project includes removal of five small hydropower diversion dams, construction of new fish screens and ladders on another three dams, and construction of several hydropower facility modifications to ensure continued hydropower operations. It is thought that this restoration effort is the largest cold water restoration project to date in North America.

The Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) was formed to guide the implementation of CALFED Bay-Delta Program Ecosystem Restoration Program elements in the Delta (California Department of Fish and Game 2007). The DRERIP team has created a suite of ecosystem and species conceptual models, including fall- and late fall-run Chinook salmon, that document existing scientific knowledge of Delta ecosystems. The DRERIP team has used these conceptual models to assess the suitability of actions proposed in the Ecosystem Restoration Program for implementation. DRERIP conceptual models were used in the analysis of proposed conservation measures.

The Vernalis Adaptive Management Program (VAMP) has implemented migration flow augmentation for the San Joaquin River basin to improve juvenile and adult migration for fall-run Chinook salmon (San Joaquin River Group Authority 2010). The VAMP program also includes seasonal reductions in SWP and CVP export rates and installation of the Head of Old River Barrier to further improve the survival of downstream migrating salmon. The program has been designed in the framework of adaptive management to improve the survival of juvenile salmon migrating from the river through the Delta, while also providing an experimental framework to quantitatively evaluate the contribution of each action to fall-run Chinook salmon survival. Preliminary results of the VAMP survival studies have shown evidence that juvenile Chinook salmon survival is positively correlated with San Joaquin River flows during the spring emigration period; however, no statistically significant relationship between juvenile salmon survival and SWP/CVP exports has been detected. The range of flows and SWP/CVP export rates that can be tested under the VAMP experimental design is relatively small (e.g., river flows from approximately 2,000 to 7,000 cubic feet per second [cfs] with SWP and CVP export rates ranging from 1,500 to 3,000 cfs). In addition, during the experimental period installation of the Head of Old River Barrier has been precluded by federal court order to protect delta smelt. As a result of these and other factors, the level of additional protection that the VAMP has provided to naturally produced Chinook salmon during emigration downstream from the San Joaquin River and Delta, and the incremental contribution of the VAMP conditions to overall salmon survival and adult abundance is uncertain. The VAMP experimental design and results of survival testing conducted to date is currently undergoing peer review and will also be the subject of a review conducted by the State Water Board. Based on results and recommendations from these technical reviews, the VAMP experimental design and testing program, as well as flow management for juvenile salmon migration on the San Joaquin River, is expected to be refined.

11A.5.7 Recovery Goals

Because fall- and late fall-run Chinook salmon are not listed for protection under either the federal or CESA, formal recovery goals will not be established. As part of other fishery management programs, such as the Central Valley Project Improvement Act and the State Water Board salmon doubling goal, goals and objectives have been established for Central Valley Chinook salmon.

11A.5.8 References Cited

11A.5.8.1 Literature Cited

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11A.6 Central Valley Steelhead (*Oncorhynchus mykiss*)

11A.6.1 Legal Status

The Central Valley steelhead evolutionarily significant unit (ESU) was listed as a threatened species under the federal Endangered Species Act (ESA) on March 19, 1998. This ESU includes all naturally spawned populations of steelhead in the Sacramento and San Joaquin Rivers and their tributaries, including the San Francisco Bay/Sacramento–San Joaquin River Delta (Bay-Delta) (63 *Federal Register* [FR] 13347). Steelhead from San Francisco and San Pablo Bays and their tributaries were excluded from this listing but were included in the Central California Coast distinct population segment (DPS), which is also listed as threatened under the ESA. On June 14, 2004, the National Marine Fisheries Service (NMFS) proposed that all west coast steelhead be reclassified from ESUs to DPSs and proposed to retain Central Valley steelhead as threatened (69 FR 33102). On January 5, 2006, after reviewing the best available scientific and commercial information, NMFS issued its final decision to retain the status of Central Valley steelhead as a threatened DPS (71 FR 834). This decision included the Coleman National Fish Hatchery and Feather River Hatchery steelhead populations. These populations were previously included in the ESU but were not deemed essential for conservation and thus not part of the listed steelhead population.

On August 15, 2011, after conducting a 5-year review, NMFS issued its findings concerning the status of the Central Valley steelhead DPS (76 FR 50447). Based on new information, NMFS determined that the status of the DPS was worse than the previous review (Good et al. 2005), and the DPS faces an even greater extinction risk. This review found that the decline in natural production of steelhead had continued unabated since the 2005 status review, and the level of hatchery influence on the DPS corresponds to a moderate risk of extinction.

Central Valley steelhead are not listed under the California Endangered Species Act (CESA) but are designated as a California Species of Special Concern.

11A.6.2 Species Distribution and Status

Information on the status and geographic distribution of Central Valley steelhead is extremely limited (The Nature Conservancy et al. 2008). Adult steelhead typically migrate upstream and spawn during the winter months when river flows are high and water clarity is low. Unlike Chinook salmon, adult steelhead do not necessarily die after spawning and can return to coastal waters. Juvenile steelhead cannot be differentiated from resident rainbow trout based on visual characteristics or genetics. In addition, steelhead frequently inhabit streams and rivers that are difficult to access and survey. Thus, information on the trends in steelhead abundance in the Central Valley has primarily been limited to observations at fish ladders and weirs (e.g., Red Bluff Diversion Dam when the gates were closed, Woodbridge Irrigation District dam, and fish ladders on the Mokelumne River, etc.) and returns to Central Valley fish hatcheries. Juvenile steelhead are collected incidentally in various fishery surveys (e.g., Mossdale and Chipps Island trawls). However, because of their relatively large size and good swimming performance, juvenile steelhead are able to avoid capture in most fishery surveys. Therefore, information on the distribution, abundance, habitat use, and behavior of steelhead in the Plan Area is very limited.

11A.6.2.1 Range and Status

Central Valley steelhead were widely distributed historically throughout the Sacramento and San Joaquin Rivers (Figure 2A.6-1) (Busby et al. 1996; McEwan 2001). Steelhead inhabited waterways from the upper Sacramento and Pit River systems (now inaccessible because of Shasta and Keswick Dams) south to the Kings River and possibly the Kern River systems, and in both east- and west-side Sacramento River tributaries (Yoshiyama et al. 1996). Lindley et al. (2006) estimated that there were historically at least 81 independent Central Valley steelhead populations distributed primarily throughout the eastern tributaries of the Sacramento and San Joaquin Rivers.

The geographic distribution of spawning and juvenile rearing habitat for Central Valley steelhead has been greatly reduced by the construction of dams (McEwan and Jackson 1996; McEwan 2001). Presently, impassable dams block access to 80% of historically available habitat and all spawning habitat for approximately 38% of historic populations (Lindley et al. 2006). Existing wild steelhead stocks in the Central Valley inhabit the upper Sacramento River and its tributaries, including Antelope, Deer, and Mill Creeks and the Yuba River. Populations may exist in Big Chico and Butte

Creeks, and a few wild steelhead are produced in the American and Feather Rivers (McEwan and Jackson 1996).

Historical Central Valley steelhead run sizes are difficult to estimate given the paucity of data but may have approached 1 to 2 million adults annually (McEwan 2001). By the early 1960s, steelhead run size had declined to approximately 40,000 adults (McEwan 2001). Over the past 30 years, naturally spawned steelhead populations in the upper Sacramento River have declined substantially (Figure 2A.6-2). Until recently, Central Valley steelhead were thought to be extirpated from the San Joaquin River system. However, recent monitoring has detected small self-sustaining populations in the Stanislaus, Mokelumne, and Calaveras Rivers, and other streams previously thought to be devoid of steelhead (McEwan 2001; Zimmerman et al. 2008; National Marine Fisheries Service 2011). Incidental catches and observations of steelhead juveniles also have occurred on the Tuolumne and Merced Rivers during fall-run Chinook salmon monitoring activities, indicating that steelhead are widespread throughout accessible streams and rivers in the Central Valley (Good et al. 2005). Some of these fish, however, may have been resident rainbow trout, which are the same species but have not found it advantageous to choose anadromy. Nonhatchery stocks of rainbow trout that have anadromous components within them are found in the Upper Sacramento River and its tributaries; Mill, Deer, and Butte Creeks; and the Feather, Yuba, American, Mokelumne, and Calaveras Rivers (McEwan 2001).

Along with the decline in accessible habitat, there has been a substantial decline in steelhead returning to the upper Sacramento River (Figure 2A.6-2). The reduction in numbers from an average of 6,574 fish from 1967 to 1991, to an average of 1,282 fish from 1992 to 2006, represents a significant drop in the upper Sacramento River populations. Although data are limited, similar population reductions are expected to have occurred throughout the Sacramento–San Joaquin system.

The most recent status review of the Central Valley steelhead DPS (National Marine Fisheries Service 2011) found that the status of the population appears to have worsened since the 2005 status review (Good et al. 2005), when it was considered to be in danger of extinction. Analysis of data from the Chipps Island monitoring program indicates that natural steelhead production has continued to decline and that hatchery origin fish represent an increasing fraction of the juvenile production in the Central Valley. In recent years, the proportion of hatchery produced juvenile steelhead in the catch has exceeded 90%, and in 2010 was 95% of the catch. This recent trend appears to be related to poor ocean conditions and dry hydrology in the Central Valley (National Marine Fisheries Service 2011).

11A.6.2.2 Distribution and Status in the Plan Area

The entire population of the Central Valley steelhead DPS must pass through the Plan Area as adults migrating upstream to spawning areas, with juveniles emigrating downstream to rearing areas and the ocean. Furthermore, juvenile steelhead likely use the Delta as well as Suisun Marsh and the Yolo Bypass for rearing. Adult Central Valley steelhead migrating into the San Joaquin River and its tributaries use the central, southern, and eastern edge of the Delta, whereas adults entering the Sacramento River system to spawn use the northern, western, and central Delta as a migration pathway.

11A.6.3 Habitat Requirements and Special Considerations

Critical habitat for the Central Valley steelhead DPS was designated by NMFS on September 2, 2005 (70 FR 52488) with an effective date of January 2, 2006, and includes 2,308 miles of stream habitat in the Central Valley and an additional 254 square miles of estuarine habitat in the San Francisco-San Pablo-Suisun Bay complex (Figure 2A.6-3). Critical habitat for Central Valley steelhead includes stream reaches such as those of the Sacramento, Feather, and Yuba Rivers; Deer, Mill, Battle, and Antelope Creeks in the Sacramento River basin; the San Joaquin River and its tributaries; and the Delta. Critical habitat includes stream channels in the designated stream reaches and the lateral extent as defined by the ordinary high-water line. In areas where the ordinary high-water line has not been defined, the lateral extent of critical habitat is defined by the bank-full elevation (defined as the level at which water begins to leave the channel and move into the floodplain. The bank-full elevation occurs at a discharge that generally has a recurrence interval of 1 to 2 years on the annual flood series) (70 FR 52488).

Critical habitat for Central Valley steelhead is defined as specific areas that contain the primary constituent elements (PCEs) and physical habitat elements or biological features essential to the conservation of the species (U.S. Fish and Wildlife Service 2004). The following are the habitat types considered PCEs for Central Valley steelhead.

- Freshwater spawning—includes areas with substrate and water quantity and quality that support steelhead spawning, incubation, and larval development.
- Freshwater rearing—includes reaches with water quantity and floodplain connectivity to form and maintain physical habitat conditions to support juvenile steelhead growth and mobility; suitable water quality; availability of suitable prey and forage to support juvenile growth and development; and natural cover habitat.
- Freshwater migration corridors—include areas free of migratory obstructions, with water quantity and quality conditions that enhance migratory movements. They contain natural cover habitat that augments juvenile and adult mobility, survival, and food supply.
- Estuarine rearing—includes areas free of migratory obstructions, with water quality and quantity, and salinity conditions to support juvenile and adult physiological transitions between fresh and salt water. These areas include natural cover and side channels, suitable for juvenile and adult foraging.

While ocean habitat is not designated as critical habitat for Central Valley steelhead, biologically productive coastal waters are an important habitat component for the survival and success of Central Valley steelhead.

11A.6.3.1 Spawning Habitat

Freshwater spawning sites are those with water quantity and quality conditions and substrate supporting spawning, egg incubation, and larval development. Spawning habitat for Central Valley steelhead primarily occurs in mid to upper elevation reaches or immediately downstream of dams located throughout the Central Valley that contain suitable environmental conditions (e.g., seasonal water temperatures, substrate, dissolved oxygen) for spawning and egg incubation. Spawning habitat has a high conservation value because its function directly affects the spawning success and reproductive potential of steelhead.

11A.6.3.2 Freshwater Rearing Habitat

Freshwater steelhead rearing sites contain suitable instream flows, water quantity (e.g., water temperatures), and floodplain connectivity to form and maintain physical habitat conditions that support juvenile growth and mobility, provide forage species, and include cover such as shade, submerged and overhanging large wood, log jams, beaver dams, aquatic vegetation, large rocks and boulders, side channels, and undercut banks. Spawning areas and migratory corridors may also function as rearing habitat for juveniles, which feed and grow before and during their out-migration. Rearing habitat value is strongly affected by habitat complexity, food supply, and the presence of predators. Some of these more complex and productive habitats with floodplain connectivity are still present in the Central Valley (e.g., the lower Cosumnes River, Sacramento River reaches with set-back levees [i.e., primarily located upstream of the City of Colusa]). The channeled, leveed, and riprapped river reaches and sloughs common in the lower Sacramento and San Joaquin Rivers and throughout the Delta, however, typically have low habitat complexity and low abundance of food organisms, and offer little protection from predation by fish and birds. Freshwater rearing habitat has a high conservation value because juvenile steelhead are dependent on the function of this habitat for successful survival and recruitment to the adult population.

11A.6.3.3 Freshwater Migration Corridors

Optimal freshwater steelhead migration corridors (including river channels, channels through the Delta, and the Bay-Delta estuary) support mobility, survival, and food supply for juveniles and adults. Migration corridors should be free from obstructions (passage barriers and impediments to migration), provide favorable water quantity (instream flows) and quality conditions (seasonal water temperatures), and contain natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, side channels, and undercut banks. Migratory corridors are typically downstream of the spawning area and include the lower Sacramento and San Joaquin Rivers, the Delta, and the San Francisco Bay complex extending to coastal marine waters. These corridors allow the upstream passage of adults and the downstream emigration of juvenile steelhead. Migratory corridor conditions are strongly affected by the presence of passage barriers, which can include dams, unscreened or poorly screened diversions, and degraded water quality. For freshwater migration corridors to function properly, they must provide adequate passage, provide suitable migration cues, reduce false attraction, avoid areas where vulnerability to predation is increased, and avoid impediments and delays in both upstream and downstream migration. For this reason, freshwater migration corridors are considered to have a high conservation value.

11A.6.3.4 Estuarine Rearing Areas

Estuarine migration and juvenile rearing habitats should be free of obstructions (i.e., dams and other barriers) and provide suitable water quality, water quantity, and salinity to support juvenile and adult physiological transitions between fresh and salt water. Natural cover, such as submerged and overhanging large wood, aquatic vegetation, and side channels, provide juvenile and adult foraging. Estuarine areas contain a high conservation value as they function to support juvenile steelhead growth, smolting, and avoidance of predators, and provide a transition to the ocean environment.

11A.6.3.5 Ocean Habitats

Juvenile steelhead rear in coastal marine waters for a period of approximately 1 to 4 years before returning to the Central Valley rivers as adults to spawn (McEwan and Jackson 1996). During their marine residence, steelhead forage on krill and other marine organisms. Offshore marine areas with water quality conditions and food, including squid, crustaceans, and fish (fish become a larger component in the steelhead diet later in life [Moyle 2002]) that support growth and maturation are important habitat elements. These features are essential for conservation because, without them, juveniles cannot forage and grow to adulthood.

Results of oceanographic studies have shown variation in ocean productivity off the West Coast within and among years. Changes in ocean currents and upwelling have been identified as significant factors affecting nutrient availability, and phytoplankton and zooplankton production in near-shore surface waters. Although the effects of ocean conditions on steelhead growth and survival have not been investigated, recent observations since 2007 have shown a significant decline in the abundance of adult Chinook and coho salmon returning to California rivers and streams. This decline has been hypothesized to be the result of declines in ocean productivity and associated high mortality rates during the period when these fish were rearing in near-shore coastal waters (MacFarlane et al. 2008). The importance of changes in ocean conditions on growth, survival, and population abundance of Central Valley steelhead, although potentially similar to that of Chinook salmon, is largely unknown.

11A.6.4 Life History

Steelhead can be divided into two life history types based on their state of sexual maturity at the time of river entry and the duration of their spawning migration: stream-maturing and ocean-maturing. Stream-maturing steelhead enter fresh water in a sexually immature condition and require several months to mature prior to spawning, whereas ocean-maturing steelhead enter fresh water with well-developed gonads and spawn shortly after river entry. These two life history types are more commonly referred to by their season of freshwater entry (i.e., summer [stream-maturing] and winter [ocean-maturing] steelhead). Only winter steelhead currently are present in Central Valley rivers and streams (McEwan and Jackson 1996). There are, however, indications that summer steelhead were present in the Sacramento River system prior to the commencement of large-scale dam construction in the 1940s (Interagency Ecological Program Steelhead Project Work Team 1999; McEwan 2001). At present, summer steelhead are found only in North Coast drainages, mostly in tributaries of the Eel, Klamath, and Trinity River systems (McEwan and Jackson 1996).

There is high polymorphism among steelhead/rainbow trout populations with respect to a continuum from anadromy to permanent freshwater residency (McEwan 2001). Furthermore, there is plasticity in an individual from a specific life history form to assume a different life history strategy if conditions necessitate it (McEwan 2001). For example, if environmental conditions, such as water temperature and flow, allow for year-round residence in fresh water, an individual may choose not to emigrate to the ocean. This polymorphic life history structure provides the flexibility for steelhead to remain persistent in highly variable conditions, particularly near the edges of their range (McEwan 2001).

Central Valley steelhead generally leave the ocean and migrate upstream from June through March (Busby et al. 1996; Hallock et al. 1957; National Marine Fisheries Service 2009a), and spawn from October through April (Newton and Stafford 2011; Bureau of Reclamation 2008). Peak immigration seems to have occurred historically in the fall from late September to late October, with some creeks such as Mill Creek showing a small run in mid-February (Hallock 1989). Peak spawning typically occurs from January through March in small streams and tributaries where cool, well-oxygenated water is available year-round (Table 2A.6-1) (Hallock et al. 1961; McEwan and Jackson 1996). Timing of upstream migration corresponds with higher flow events (e.g., freshets), associated lower water temperatures, and increased turbidity. Before the occurrence of large-scale changes to the hydrology of the Delta system, the peak period of adult immigration appears to have been during fall months with a smaller component of immigrants in the winter (as reviewed in McEwan 2001). Unlike Pacific salmon, steelhead are iteroparous, or capable of spawning more than once before death (Busby et al. 1996). It is, however, rare for steelhead to spawn more than twice before dying; most individuals that do spawn more than twice are females (Busby et al. 1996). Iteroparity is more common among southern steelhead populations than northern populations (Busby et al. 1996). Although one-time spawners are the great majority, Shapolov and Taft (1954) reported that repeat spawners are relatively numerous (17.2%) in California streams.

After reaching a suitable spawning area, the female steelhead selects a site with good intergravel flow, digs a redd, and deposits eggs while an attendant male fertilizes them. Eggs in the redd are covered with gravel dislodged just upstream by similar redd building actions. The length of time it takes for eggs to hatch varies in response to water temperature. Optimal spawning temperatures range between from 4°C and 11°C (39°F to 52°F), with egg mortality beginning at about 13°C (55°F) (McEwan and Jackson 1996). Hatching of steelhead eggs in hatcheries takes about 30 days at 10.6°C (51°F). Fry generally emerge from the gravel 4 to 6 weeks after hatching, but factors such as redd depth, gravel size, siltation, and water temperature can speed or retard the time to emergence (McEwan and Jackson 1996). Newly emerged fry move to shallow, protected areas with lower water velocities associated with the stream margin, and soon establish feeding locations in the juvenile rearing habitat (McEwan and Jackson 1996).

Steelhead rearing during the summer takes place primarily in higher velocity areas in pools, although young-of-the-year also are abundant in glides and riffles. Productive steelhead habitat is characterized by habitat complexity, primarily in the form of large and small woody debris. Cover is an important habitat component for juvenile steelhead both as velocity refugia and as a means of avoiding predation (McEwan and Jackson 1996).

About 70% of Central Valley steelhead spend 2 years within their natal streams before migrating out of the Sacramento-San Joaquin system as smolts, with small percentages (29%) and (1%) spending 1 or 3 years, respectively (Hallock et al. 1961). Juvenile steelhead emigrate episodically from natal streams during fall, winter, and spring high flows. Emigrating Central Valley steelhead use the lower reaches of the Sacramento and San Joaquin Rivers and the Delta for rearing and as a migration corridor to the ocean. Juvenile Central Valley steelhead feed mostly on drifting aquatic organisms and terrestrial insects, and will take active bottom invertebrates (Moyle 2002).

Table 2A.6-1. Temporal Occurrence of Adult and Juvenile Central Valley Steelhead in the Central Valley

Location	**Jan**		**Feb**		**Mar**		**Apr**		**May**		**Jun**		**Jul**		**Aug**		**Sep**		**Oct**		**Nov**		**Dec**	
Adult																								
Sacramento River [1,3]	░	░	░	░	░	░						░	░	░	░	▒	▒	▓	▓	▒	░	░	░	░
Sacramento River at Red Bluff Diversion Dam[2,3]	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▓	▒	░	░	░	░
Mill, Deer Creeks[4]			▓	▒	▒	░	░	░	░	░	░	░								▓	▓	▒	▒	▒
Sacramento River at Fremont Weir[5]	░	░	░	░											▒	▒	▓	▓	▒	▒	░	░	░	░
San Joaquin River[6]	▒	▒	▒	▒	▒	▒							░	░	░	░	▒	▒	▒	▒	▒	▒	▓	▓
Juvenile																								
Sacramento River[1,2]	░	░	░	░	▒	▒	▒	▒	▒	▒	▒	▒	░	░	░	░	░	░	▒	▒	▒	▒	░	░
Sacramento River at Knights Landing[2,6]	░	░	░	░	▓	▓	░	░	░															░
Sacramento River at Knights Landing[2,6]	▒	▒	▒	▒	▓	▓	▓	▓	▒	▒											░	░	░	░
Chipps Island (wild)[7]	░	░	░	░	▓	▓	▓	▓	▒	▒	▒	▒	░	░					░	░	░	░	░	░
Mossdale[6]	░	░	░	░	░	░	▓	▓	▓	▓	░	░	░	░					░	░	░	░	░	░
Woodbridge Dam[8]	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒										
Stanislaus River at Caswell[9,11]	░	░	▒	▒	▓	▓	▒	▒	▒	▒	░	░												
Sacramento River at Hood[10]	░	░	▓	▓	▓	▓	▓	▓	▓	▓											░	░	░	░

Relative Abundance: ▓ = High ▒ = Medium ░ = Low

Note: Darker shades indicate months of greatest relative abundance

Sources:

[1] Hallock et al. 1961.
[2] McEwan 2001.
[3] Hallock 1989.
[4] California Department of Fish and Game 1995.
[5] Hallock et al. 1957.
[6] Hallock 1989.
[7] Nobriga and Cadrett 2003.
[8] Jones & Stokes Associates Inc., 2002.
[9] S.P. Cramer and Associates, Inc. 2000, 2001.
[10] Schaffter 1980.
[11] Cramer Fish Sciences 2012.

Some juvenile steelhead may use brackish tidal marsh areas, nontidal marshes, and other shallow water areas in the Delta and estuary as rearing areas for short periods prior to their emigration to the ocean. Hallock et al. (1961) found that juvenile steelhead in the Sacramento River basin migrate downstream during most months of the year, but the peak emigration period occurred in the spring, with a much smaller peak in the fall. Nobriga and Cadrett (2003) verified these temporal findings based on analysis of captures in U.S. Fish and Wildlife Service (USFWS) salmon monitoring conducted near Chipps Island. Diversity and richness of habitat and food sources in the estuary allow juveniles to attain a larger size before entry into the ocean, thereby increasing their chances for survival in the marine environment.

Central Valley steelhead typically spend from several months to 3 years (with a maximum of 6 years) in the Pacific Ocean before returning to fresh water to spawn. The age composition of the steelhead population in the Pacific Ocean is dominated by 1-year-old (61.9%) and 2-year-old (31.4%) fish (Burgner et al. 1992). Ocean migration and distribution of Central Valley steelhead stocks is unknown.

Steelhead experience most of their marine phase mortality soon after they enter the Pacific Ocean (Pearcy 1992). Ocean mortality is poorly understood, however, because few studies have been conducted to evaluate the importance of various factors, including predation mortality, changes in ocean currents, water temperatures, and coastal upwelling, on steelhead survival. Possible causes of ocean mortality include predation, competition, starvation, osmotic stress, unauthorized driftnet fisheries on the high seas, disease, advective losses, and other poor environmental conditions (Wooster 1983; Cooper and Johnson 1992; Pearcy 1992). Competition between steelhead and other species for limited food resources in the Pacific Ocean may be a contributing factor to declines in steelhead populations, particularly during years of low productivity (Cooper and Johnson 1992).

Ocean and climate conditions such as sea surface temperatures, air temperatures, strength of upwelling, El Niño events, salinity, ocean currents, wind speed, and primary and secondary productivity affect all facets of the physical, biological, and chemical processes in the marine environment. Some of the conditions associated with El Niño events include warmer water temperatures, weak upwelling, low primary productivity (which leads to decreased zooplankton biomass), decreased southward transport of subarctic water, and increased sea levels (Pearcy 1992). For juvenile steelhead, warmer water and weak upwelling are possibly the most important of the ocean conditions associated with El Niño. Because of the weakened upwelling during an El Niño year, juvenile California steelhead must migrate more actively offshore through possibly stressful warm waters with numerous inshore predators. Strong upwelling is probably beneficial because of the greater transport of smolts offshore, beyond major concentrations of inshore predators (Pearcy 1992). Investigations are currently under way to examine decadal oscillations in coastal marine environmental conditions and the associated biological changes that may affect the survival, growth, and recruitment of steelhead to the adult population.

11A.6.5 Threats and Stressors

The following conditions are important threats and stressors to Central Valley steelhead.

11A.6.5.1 Reduced Staging and Spawning Habitat

Adult steelhead historically migrated upstream into higher gradient reaches of rivers and tributaries where water temperatures were cooler, turbidity was lower, and gravel substrate size was suitable for spawning and egg incubation (McEwan 2001). Steelhead are known to migrate upstream into higher gradient and elevation reaches of the rivers and streams than fall-run Chinook salmon, which predominantly spawn at lower elevations in the valley floor. Most historical adult staging/holding and spawning habitat for Central Valley steelhead is no longer accessible to upstream migrating steelhead. Habitat has been eliminated or degraded by artificial structures (e.g., dams and weirs) associated with water storage and conveyance; diversions; flood control; and municipal, industrial, agricultural, and hydropower purposes (Figure 2A.6-1) (McEwan and Jackson 1996; McEwan 2001; Bureau of Reclamation 2004; Lindley et al. 2006; National Marine Fisheries Service 2007). These impediments and barriers to upstream passage limit the geographic distribution of steelhead to lower elevation habitats in the Central Valley.

Steelhead in the Central Valley migrate upstream into the mainstem Sacramento River and major tributaries (e.g., American and Feather Rivers; Clear and Battle Creeks), and are also known to occur in tributaries to the San Joaquin River (e.g., Mokelumne, Cosumnes, Stanislaus, Merced, Tuolumne Rivers), where they spawn and rear. Steelhead do not currently spawn in the mainstem San Joaquin River. The majority of current steelhead spawning habitat exists upstream of the Red Bluff Diversion Dam on the Sacramento River and its tributaries. Although the overall effect of operations of the dam on the Central Valley steelhead populations is not well understood, concerns have been expressed regarding the effect of gate operations on upstream and downstream migration by steelhead. Additional concerns include the potential for increased vulnerability of juvenile steelhead to predation by Sacramento pikeminnow, striped bass, and other predators that pass through the Red Bluff Diversion Dam gates or fish ladder.

Reduced flows from dams and upstream water diversions can lower attraction cues for adult spawners, causing straying and delays in spawning or the inability to spawn (California Department of Water Resources 2005). Adult steelhead migration delays can reduce fecundity and egg viability and increase susceptibility to disease and harvest.

11A.6.5.2 Reduced Rearing and Out-Migration Habitat

Juvenile steelhead prefer to utilize natural stream banks, floodplains, marshes, and shallow water habitats for rearing during out-migration. Modification of natural flow regimes from upstream reservoir operations has resulted in dampening of the hydrograph in most Central Valley rivers, reducing the extent and duration of inundation of floodplains and other flow-dependent habitat used by migrating juvenile steelhead (California Department of Water Resources 2005; 70 FR 52488). Changes in river hydrology that have affected floodplain inundation may have affected areas thought to provide significant growth benefits to rearing fish (Sommer et al. 2001). Reductions in flow rates have also resulted in increased water temperature and residence time, and reductions in dissolved oxygen levels in localized areas of the Delta (e.g., Stockton Deep Water Ship Channel), which affect the value of rearing and migration habitat. Reduced dissolved oxygen levels in the lower San Joaquin River during late summer and early fall have been identified as a barrier and/or impediment to migration for some salmonids (Regional Water Resources Control Board 2003), including Central Valley steelhead (Jassby and Van Nieuwenhuyse 2005). The data derived from the California Data Exchange Center files indicate that dissolved oxygen depressions occur during all migratory months, with significant events occurring from November through March when Central Valley steelhead adults and smolts would be utilizing this portion of the San Joaquin River as a migratory corridor (National Marine Fisheries Service 2012).

Much of the Delta has been leveed, channelized, and fortified with riprap for flood protection, reducing and degrading the quality and availability of natural habitat for use by steelhead during migration (McEwan 2001). Furthermore, impacts on the value, quantity, and availability of suitable habitat are likely to reduce fitness and increase susceptibility to entrainment, disease, exposure to contaminants, and predation.

11A.6.5.3 Predation by Nonnative Species

Native species such as the Sacramento pikeminnow are a potentially significant source of mortality in the Sacramento River at locations such as the Red Bluff Diversion Dam. However, predation by nonnative species is of particular concern. In general, the effect of nonnative predation on the Central Valley steelhead DPS is unknown but predation is most likely a threat in areas with high densities of nonnative fish (e.g., small and large mouth bass, striped bass, and catfish), which are thought to prey on out-migrating juvenile steelhead. Predation risk may covary with increased temperatures. Metabolic rates of nonnative, predatory fish increase with increasing water temperatures based on bioenergetic studies (Loboschefsky et al. 2009; Miranda et al. 2010). Upstream gravel pits and flooded ponds, such as those that occur on the San Joaquin River and its tributaries, attract nonnative predators because of their depth and lack of cover for juvenile steelhead (California Department of Water Resources 2005). Nonnative aquatic vegetation, such as Brazilian waterweed (*Egeria densa*) and water hyacinth (*Eichhornia crassipes*), provide suitable habitat for nonnative predators (Brown and Michniuk 2007). The low spatial complexity of channelized waterways (e.g., riprap-lined levees that provide virtually no cover protection from predators) and general low habitat diversity elsewhere in the Delta reduces refuge cover and protection of steelhead from predators (Raleigh et al. 1984; Missildine et al. 2001; 70 FR 52488). A major concern is the potential invasion of the Delta by the highly predatory northern pike. The pike, recently present in Lake Davis on the Feather River, is currently the target of a major eradication effort (California Department of Fish and Game 2007a). If eradication fails and pike were to escape downstream to the Delta, they would likely be present in areas frequently inhabited by Central Valley steelhead.

11A.6.5.4 Harvest

Steelhead have been, and continue to be, an important recreational fishery in inland rivers throughout the Central Valley. Although there are no commercial fisheries for steelhead, inland steelhead fisheries include tribal and recreational fisheries. In the Central Valley, recreational fishing for steelhead of hatchery origin is popular, but harvest is restricted to only visibly marked fish of hatchery origin (adipose fin clipped). Unmarked steelhead (adipose fin intact) must be released, reducing the take of naturally spawned wild fish. While the level of illegal harvest of Chinook salmon and steelhead in the Delta and bays is unknown, it is generally believed to be relatively common. The effects of recreational fishing and this unknown level of illegal harvest on the abundance and population dynamics of wild Central Valley steelhead have not been quantified.

11A.6.5.5 Reduced Genetic Diversity and Integrity

Artificial propagation programs for steelhead in Central Valley hatcheries present multiple threats to the wild steelhead population, including mortality of natural steelhead in fisheries targeting hatchery origin steelhead, competition for prey and habitat, predation by hatchery origin fish on younger natural fish, disease transmission, and impediments to fish passage imposed by hatchery facilities. It is now recognized that Central Valley hatcheries are a significant and persistent threat to wild Chinook salmon and steelhead populations and fisheries (National Marine Fisheries Service 2009b). One major concern with hatchery operations is the genetic introgression by hatchery origin fish that spawn naturally and interbreed with local natural populations (U.S. Fish and Wildlife Service 2001; Bureau of Reclamation 2004; Goodman 2005). Such introgression introduces maladaptive genetic changes to the wild steelhead stocks (McEwan and Jackson 1996; Myers et al.

2004). Hatchery operations have been found to decrease Chinook salmon fitness (Araki et al. 2007). Taking eggs and sperm from a large pool of individuals is one method for ameliorating genetic introgression, but artificial selection for traits that assure individual success in a hatchery setting (e.g., rapid growth and tolerance to crowding) are unavoidable (Bureau of Reclamation 2004).

The increase in Central Valley hatchery production has reversed the composition of the steelhead population, from 88% naturally produced fish in the 1950s (McEwan 2001) to an estimated 23% to 37% naturally produced fish by 2000 (Nobriga and Cadrett 2003), and less than 10% currently (National Marine Fisheries Service 2011). The increase production of in hatchery steelhead has reduced the viability of the wild steelhead populations (National Marine Fisheries Service 2012).

11A.6.5.6 Entrainment

Juvenile steelhead migrating downstream through the Delta are vulnerable to entrainment and salvage at the State Water Project (SWP) and Central Valley Project (CVP) export facilities, primarily between March and May (Table 2A.6-1). Multiple factors can influence the vulnerability of juvenile steelhead to entrainment by SWP/CVP export facilities, including the geographic distribution of steelhead in the Delta and hydrodynamic factors such as reverse flows in the Old and Middle Rivers, which are a function of export operations relative to San Joaquin River inflows, and southward flows of Sacramento River water towards pumps through an open Delta Cross Channel and Georgiana Slough. SWC/CVP exports have been shown to affect the tidal hydrodynamics (e.g., water current velocities and direction). The magnitude of these hydrodynamic effects varies in response to a variety of factors including tidal stage and magnitude of ebb and flood tides, the rate of SWP/CVP exports, operation of the Clifton Court Forebay radial gate opening, and inflow from upstream tributaries. Steelhead respond behaviorally to hydraulic cues (e.g., water currents) during both upstream adult and downstream juvenile migration through the Delta. Changes in these hydraulic cues as a result of SWP/CVP export operations when steelhead are migrating through Delta channels may contribute to attraction to false migration pathways, delays in migration, or increased movement of migrating steelhead toward the export facilities where there is an increased risk of entrainment and/or predation at the salvage facilities. The California Department of Water Resources and Bureau of Reclamation (1999) found significant relationships between total monthly exports in January through May and monthly steelhead salvage at SWP/CVP facilities, suggesting the risk of steelhead entrainment is related, in part, to export rates. During the past several years, additional investigations have used radio- or acoustically tagged juvenile and adult (post spawning adults) steelhead to monitor their migration behavior through the Delta channels and to assess the effects of changes in hydraulic cues and SWP/CVP export operations on migration (Holbrook et al. 2009; Perry et al. 2010; San Joaquin River Group Authority 2010). These studies are ongoing. Studies have also been conducted to assess the potential losses of juvenile steelhead to predation by adult striped bass during passage through Clifton Court Forebay (Clark et al. 2008). Results of these studies have estimated that prescreen losses of juvenile steelhead in Clifton Court Forebay are greater than 80%.

In addition to SWP/CVP export facilities, there are more than 2,200 small water diversions in the Delta, of which the majority are unscreened (Herren and Kawasaki 2001). The risk of entrainment is a function of the size of juvenile fish and the slot opening of the screen mesh (Tomljanovich et al. 1978; Schneeberger and Jude 1981; Zeitoun et al. 1981; Weisberg et al. 1987). Although entrainment/salvage of steelhead at the SWP/CVP export facilities is well documented, it is unclear how many juvenile steelhead are entrained at other unscreened Delta diversions. Because steelhead are moderately large (greater than 200-millimeter fork length) and relatively strong swimmers when out-migrating, the effects on steelhead of small in-Delta agricultural water diversions are thought to be lower than those on other Central Valley salmonids. In addition, many of the juvenile steelhead migrate downstream through the Delta during the late winter or early spring before many of the agricultural irrigation diversions are operating. Power plants in the Plan Area have the ability to impinge juvenile steelhead on the existing intake screens. However, use of cooling water is currently low with the retirement of older units. Furthermore, newer units are equipped with a closed-cycle cooling system that virtually eliminates the risk of impingement of juvenile steelhead.

11A.6.5.7 Exposure to Toxins

Toxic chemicals are widespread throughout the Delta and may occur on a more localized scale in response to episodic events (e.g., stormwater runoff, point source discharges, etc.). These toxic substances include mercury, selenium, copper, pyrethroids, and endocrine disruptors with the potential to affect fish health and condition, and negatively affect steelhead distribution and abundance directly or indirectly. Some loads of toxics, such as selenium, are much higher in the San Joaquin River than the Sacramento River because they are naturally occurring in the alluvial soils and have been leached by irrigation water and concentrated by evapotranspiration (Nichols et al. 1986). This may indicate that the potential effects of chronic exposure could be greater for steelhead of San Joaquin River origin. Additionally, agricultural return flows that may contain toxic chemicals are widely distributed throughout the Sacramento and San Joaquin Rivers and the Delta, although dilution flows from the rivers may reduce chemical concentrations to sublethal levels. Sublethal concentrations of toxic substances may interact with other stressors on salmonids, such as increasing their vulnerability to predation or disease (Werner 2007). For example, Clifford et al. (2005) found in a laboratory setting that juvenile fall-run Chinook salmon exposed to sublethal levels of a common pyrethroid, esfenvalerate, were more susceptible to infectious hematopoietic necrosis virus than those not exposed to esfenvalerate. Although not tested on steelhead, a similar response is likely; however, juvenile steelhead generally migrate through the Delta in a comparatively shorter time than Chinook salmon. The short duration may decrease juvenile steelhead exposure and susceptibility to toxic substances in the Delta. Adult migrating steelhead may be less affected by toxins in the Delta because they are not feeding, and thus not bioaccumulating toxic exposure, and they are moving rapidly through the system.

Iron Mountain Mine, located adjacent to the upper Sacramento River, has been a source of trace elements that are known to adversely affect aquatic organisms (Upper Sacramento River Fisheries and Riparian Habitat Advisory Council 1989). Storage limitations and limited availability of dilution flows have caused downstream copper and zinc levels to exceed salmonid tolerances and resulted in documented fish kills in the 1960s and 1970s (Bureau of Reclamation 2004). The U.S. Environmental Protection Agency's Iron Mountain Mine remediation program has removed toxic metals in acidic mine drainage from the Spring Creek watershed with a state-of-the-art lime neutralization plant. Contaminant loading into the Sacramento River from Iron Mountain Mine has shown measurable reductions since the early 1990s.

Ammonia[4] released from the City of Stockton Wastewater Treatment Plant contributes to the low dissolved oxygen in the adjacent Deep Water Ship Channel. In addition to the adverse effects of the lowered dissolved oxygen on salmonid physiology, ammonia is toxic to salmonids at low

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[4] Ammonia in water generally forms some amount of ammonium. Therefore, the use of the term *ammonia* implies that both ammonia and ammonium may be present.

concentrations. Actions have been implemented to remedy this source of ammonia, by modifying the treatment train at the wastewater facility (National Marine Fisheries Service 2012).

11A.6.5.8 Increased Water Temperature

Water temperature is among the physical factors that affect the value of habitat for salmonid adult holding, spawning and egg incubation, juvenile rearing, and migration. Adverse sublethal and lethal effects can result from exposure to elevated water temperatures at sensitive life stages, such as during incubation or rearing. Water temperature criteria for various life stages of salmonids in the Central Valley have been developed by the NMFS (2009a). The tolerance of steelhead water temperatures depends on life stage, acclimation history, food availability, duration of exposure, health of the individual, and other factors such as predator avoidance (Myrick and Cech 2004; Bureau of Reclamation 2004). Higher water temperatures can lead to physiological stress, reduced growth rate, reduced spawning success, and increased mortality of steelhead (Myrick and Cech 2001). Temperature can also indirectly influence disease incidence and predation (Waples et al. 2008). Exposure to seasonally elevated water temperatures may occur from reductions in flow because of upstream reservoir operations, reductions in riparian vegetation, channel shading, local climate, and solar radiation. The installation of the Shasta Temperature Control Device in 1998, in combination with reservoir management to maintain the cold water pool, has reduced many of the temperature issues on the Sacramento River. During dry years, however, the release of cold water from Shasta Dam is still limited. As the river flows farther downstream, particularly during the warm spring, summer, and early fall months, water temperatures continue to increase until they reach thermal equilibrium with atmospheric conditions. Because of the longitudinal gradient of seasonal water temperatures, the coldest water and, therefore, the best areas for steelhead spawning and rearing are typically located immediately downstream of the dam.

Increased temperature can also arise from a reduction in shade over rivers by tree removal (Watanabe et al. 2005). Because river water is typically in thermal equilibrium with atmospheric conditions by the time it enters the Delta, this issue is caused primarily by actions upstream of the Delta. Because the Delta channels are relatively wide, additional riparian vegetation will not significantly reduce water temperatures.

11A.6.6 Relevant Conservation Efforts

Because steelhead biology is similar to that of Chinook salmon, few conservation actions are specific to steelhead. Efforts by the California Department of Fish and Wildlife (CDFW) to restore Central Valley steelhead are described in *Steelhead Restoration and Management Plan for California* (McEwan and Jackson 1996). Measures to protect steelhead throughout the state of California have been in place since 1998, and a wide range of measures have been implemented, including 100% marking of all hatchery steelhead, zero bag limits for unmarked steelhead, gear restrictions, closures, and size limits designed to protect rearing juveniles and smolts. The Central Valley Steelhead Project Work Team, an interagency technical working group led by CDFW, drafted a proposal to develop a comprehensive steelhead monitoring plan that was selected by the CALFED Bay-Delta Program (CALFED) Ecosystem Restoration Program Implementing Agency Managers for directed action funding. Long-term funding for implementation of the monitoring plan still needs to be secured.

Biological opinions for SWP/CVP operations (e.g., National Marine Fisheries Service 2009a) and other federal projects involving irrigation and water diversion and fish passage, for example, have improved or minimized adverse effects on steelhead in the Central Valley. In 1992, an amendment to the authority of the CVP through the Central Valley Project Improvement Act was enacted to give protection of fish and wildlife equal priority with other Central Valley Project objectives. Several programs under this act have benefited listed salmonids. The USFWS's Anadromous Fish Restoration Program is engaged in monitoring, education, and restoration projects designed to contribute toward doubling the natural populations of select anadromous fish species residing in the Central Valley. Restoration projects funded through the program include fish passage, fish screening, riparian easement and land acquisition, development of watershed planning groups, instream and riparian habitat improvement, and gravel replenishment. The program combines federal funding with state and private funds to prioritize and construct fish screens on major water diversions mainly in the upper Sacramento River. The goal of the Water Acquisition Program is to acquire water supplies to meet the habitat restoration and enhancement goals of the Central Valley Project Improvement Act, and to improve the ability of the U.S. Department of the Interior to meet regulatory water quality requirements. Water has been used to improve fish habitat for Central Valley steelhead by maintaining or increasing instream flows on Butte and Mill Creeks and the San Joaquin River at critical times. Additionally, salmonid entrainment at the SWP/CVP export facilities is decreased by reducing seasonal diversion rates during periods when protected fish species are vulnerable to export related losses.

Two programs included under CALFED, the Ecosystem Restoration Program and the Environmental Water Account, were created to improve conditions for fish, including steelhead, in the Central Valley. Restoration actions implemented by the Ecosystem Restoration Program include the installation of fish screens, modification of barriers to improve fish passage, habitat acquisition, and instream habitat restoration. The majority of these actions address key factors affecting listed salmonids, and emphasis has been placed on tributary drainages with high potential for Central Valley steelhead and spring-run Chinook salmon production. Additional ongoing actions include efforts to enhance fishery monitoring and directly support salmonid production through hatchery releases. The Environmental Water Account has been under scrutiny recently as to its success in meeting its original goal.

A major CALFED Ecosystem Restoration Program action currently under way is the Battle Creek Salmon and Steelhead Restoration Project. The project will restore 77 kilometers (48 miles) of habitat in Battle Creek to support steelhead and Chinook salmon spawning and juvenile rearing at a cost of over $90 million. The project includes removal of five small hydropower diversion dams, construction of new fish screens and ladders on another three dams, and construction of several hydropower facility modifications to ensure the continued hydropower operations. It is thought that this restoration effort is the largest cold-water restoration project to date in North America.

The Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) was formed to guide the implementation of CALFED Ecosystem Restoration Plan elements in the Delta (California Department of Fish and Game 2007b). The DRERIP team has created a suite of ecosystem and species conceptual models, including steelhead, that document existing scientific knowledge of Delta ecosystems. The team has used these conceptual models to assess the suitability of actions proposed in the Ecosystem Restoration Plan for implementation. DRERIP conceptual models were used in the analysis of proposed conservation measures.

Oroville Dam Federal Energy Regulatory Commission relicensing efforts on the Feather River have considered instream flows and temperature management for steelhead spawning and juvenile rearing downstream of the dam.

Multiple fish passage projects have been recently implemented for steelhead and other salmonids in the Sacramento and San Joaquin Watersheds. Multiple large diversions on the Sacramento River (e.g., Glenn-Colusa Irrigation District, Reclamation District 108, Reclamation District 1004, Sutter Mutual, and Wilkins Slough) have been equipped with positive barrier fish screens to reduce entrainment of steelhead and other salmonids. The Woodbridge Irrigation District Dam on the Mokelumne River was designed to improve upstream and downstream passage of steelhead and other salmonids by installing fish screens and fish ladders at the dam.

Mitigation under the Delta Fish Agreement has increased the number of wardens enforcing harvest regulations for steelhead and other fish in the Delta and upstream tributaries by creating the Delta Bay Enhanced Enforcement Program. Initiated in 1994, the program currently consists of nine wardens and a supervisor.

Many smaller tributaries to the Sacramento and San Joaquin Rivers have local watershed conservancies with master plans to contribute to conservation and recovery of steelhead and other salmonids.

11A.6.7 Recovery Goals

The draft recovery plan for Central Valley salmonids, including steelhead, was released on October 19, 2009 (National Marine Fisheries Service 2009b). Although not final, the overarching goal in the public draft is the removal of, among other listed salmonids, the Central Valley steelhead DPS from the federal List of Endangered and Threatened Wildlife (National Marine Fisheries Service 2009b). Several objectives and related criteria represent the components of the recovery goal, including the establishment of at least two viable populations in each historical diversity group, as well as other measurable biological criteria.

11A.6.8 References Cited

11A.6.8.1 Literature Cited

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11A.7 Sacramento Splittail (*Pogonichthys macrolepidotus*)

11A.7.1 General

The Sacramento splittail, a cyprinid fish, is endemic to the San Francisco Estuary and watershed (Moyle 2002). Splittail regularly inhabit the Sacramento River upstream to the Red Bluff Diversion Dam at River Mile 243 and the San Joaquin River into Salt Slough (River Mile 135) (Moyle 2002) and Mud Slough at River Mile 125 (plus an additional 10.5 miles into Mud Slough). Splittail also inhabit the Napa and Petaluma River drainages (upper documented range: River Miles 18 and 17, respectively) and marshes. Splittail inhabiting these drainages have been found to be genetically distinct from splittail inhabiting the Sacramento and San Joaquin Rivers (Baerwald et al. 2007). Splittail from the Petaluma River exhibited a higher degree of differentiation from the Sacramento–San Joaquin population than did Napa River splittail, suggesting high salinities in San Pablo Bay and Carquinez Strait isolated these populations to differing degrees from the larger Sacramento–San Joaquin population. Spawning occurs in the Petaluma and Napa Rivers, but spawning locations within these rivers remain unknown (Moyle et al. 2004; Feyrer et al. 2005). No populations of splittail exist outside of the Central Valley rivers and the San Francisco/Sacramento–San Joaquin River Delta (Bay-Delta) estuary.

11A.7.2 Legal Status

The Sacramento splittail was listed as threatened under the federal Endangered Species Act (ESA) on February 8, 1999 (64 *Federal Register* [FR] 5963). This ruling was challenged by two lawsuits

(*San Luis & Delta-Mendota Water Authority v. Anne Badgley et al.* and *State Water Contractors et al. v. Michael Spear et al.*). On June 23, 2000, the Federal Eastern District Court of California found the ruling to be unlawful and on September 22 of the same year remanded the determination back to the U.S Fish and Wildlife Service (USFWS) for re-evaluation of their original listing decision. Upon further evaluation, splittail was removed from the ESA on September 22, 2003 (68 FR 55139). On August 13, 2009, the Center for Biological Diversity (2009) challenged the 2003 decision to remove splittail from the ESA. However, on October 7, 2010, the USFWS found that listing of splittail was not warranted (75 FR 62070).

The splittail is designated as a species of special concern by the California Department of Fish and Wildlife (CDFW).

11A.7.3 Distribution and Abundance

The splittail range includes the Sacramento River up to the Red Bluff Diversion Dam and the San Joaquin River to River Mile 135 (Figure 2A.7-1). Selected observations in the lower portions of Sacramento River and tributaries include the American River to River Mile 12, in the Feather River to River Mile 58 and from just below the Thermalito Afterbay outlet (Seesholtz pers. comm.), and in Butte Creek/Sutter Bypass to vicinity of Colusa State Park.

Long-term beach seine sampling data for age 0 splittail (less than or equal to 50-millimeter fork length) in the Sacramento River spanning 32 years (1976 to 2008) indicates that the farthest location upstream where juvenile splittail have been collected was 144 to 184 miles upstream of the confluence of the Sacramento and San Joaquin Rivers. The consistency in the upstream range of juvenile splittail found in these long-term studies supports a finding that there was no decrease in distribution during this period (Feyrer et al. 2005).

The following rivers are within the splittail range:

- Cosumnes River—just above the confluence with the Mokelumne River (Crain et al. 2004).
- Mokelumne River—observed above Woodbridge Diversion Dam to River Mile 60.
- Stanislaus River—no confirmed sightings, but, based on observations from other tributaries, splittail probably inhabit low-gradient portions of the lower river.
- Tuolumne River—River Mile 17 (Legion Park, Modesto) (Moyle et al. 2004), and several annually at River Mile 5 from 1999 to 2002 (Moyle et al. 2004).
- Merced River—River Mile 13, several annually from 1999 to 2001 (1 mile upstream of Hagaman Park) (Moyle et al. 2004).

Near Mud and Salt Sloughs, splittail can access historical valley floodplains and apparently use them for spawning in wet years (e.g., 1995 and 1998) (Baxter 1999; Moyle et al. 2004). Splittail occasionally extend their range farther southward into central and southern San Francisco Bays using freshwater and low-salinity habitats created during high-outflow years (Moyle et al. 2004). After high-outflow years in the early 1980s and mid-1990s, splittail were captured in the estuary of Coyote Creek, South San Francisco Bay (Leidy 2007). In a study by researchers at the University of California, Davis, that started in August of 2010 and samples monthly, no splittail have been caught in Coyote Creek (Hobbs et al. 2012).

The abundance of juvenile splittail (young-of-the-year) is highly variable from one year to the next and positively correlated with hydrologic conditions within the rivers and Delta during the late-winter and spring spawning period and the magnitude and duration of floodplain inundation (Sommer et al. 1997). Because splittail are a long-lived species (5 to 7 years) (Moyle 2002), the abundance of juveniles in a given year may not be a good predictor of adult splittail abundance. Results of CDFW fall midwater trawl surveys indicate a marked decline in overall splittail abundance and consistently low population levels since 2002 (Figure 2A.7-2). In addition, Bay study indices were extremely low (Figures 2A.7-2[B] and [C]).

No population-level estimates currently exist for Sacramento splittail. However, because much of the overall distribution of splittail occurs in the Plan Area, population status and trends in the Plan Area are expected to be very similar to overall population status and trends.

11A.7.4 Life Stages

Kratville (2008) describes five life stages of Sacramento splittail. Moyle (2002) also described five life stages, although rather than two adult stages (spawning and postspawning), Moyle described two juvenile life stages (young-of-year and yearling). Table 2A.7-1 compares the Sacramento splittail life stages of Kratville and Moyle.

Table 2A.7-1. Sacramento Splittail Life Stages

Kratville 2008	Moyle 2002	BDCP
Eggs	Egg/embryo	Egg/embryo
Larvae	Larvae	Larvae
Juvenile	Juvenile (young-of-year)	Juvenile (young-of-year)
Adult/spawning	Juvenile (yearling)	Juvenile (yearling)
Adult/postspawning	Adult	Adult/nonspawning
		Adult/spawning

11A.7.5 Life History

11A.7.5.1 Phenology

Mature splittail begin a gradual upstream migration towards spawning areas sometime between late November and late January, with larger splittail migrating earlier (Caywood 1974; Moyle et al. 2004). The relationship between migrations and river flows is poorly understood, but it is likely that splittail have a positive behavioral response to increases in flows and turbidity. Feeding in flooded riparian areas in the weeks just prior to spawning may be important for later spawning success and for postspawning survival. Not all splittail make significant movements prior to spawning, as indicated by evidence of spawning in Suisun Marsh (Meng and Matern 2001) and the Petaluma River.

The upstream movement of splittail is closely linked with flow events from February to April that inundate floodplains and riparian areas (Garman and Baxter 1999; Harrell and Sommer 2003). Seasonal inundation of shallow floodplains provides both spawning and foraging habitat for splittail (Caywood 1974; Daniels and Moyle 1983; Baxter et al. 1996; Sommer et al. 1997). Evidence of splittail spawning on floodplains has been found on both the San Joaquin and Sacramento Rivers. In the San Joaquin River drainage, spawning has apparently taken place in wet years in the region where the San Joaquin River is joined by the Tuolumne and Merced Rivers (Moyle et al. 2004). In the Plan Area, splittail spawn on inundated floodplains in the Yolo and Sutter Bypasses, which are extensively flooded in wet years, and along the Cosumnes River area from February to July (Sommer et al. 1997, 2001, 2002; Crain et al. 2004; Moyle et al. 2004). When floodplain inundation does not occur in the Yolo or Sutter Bypasses, adult splittail migrate farther upstream to suitable habitat along channel margins or flood terraces; spawning in such locations occurs in all water year types (Feyrer et al. 2005). Although spawning is typically greatest in wet years, CDFW surveys demonstrate spawning takes place every year along the river edges and backwaters created by small increases in flow. In the eastern Delta, the floodplain along the lower Cosumnes River appears to be important as spawning habitat. Ripe splittail have been observed in areas flooded by levee breaches, turbid water, and flooded terrestrial vegetation.

Limited collections of ripe adults and early stage larvae indicate splittail spawn in shallow water (less than 2 meters [6.6 feet] deep) over flooded vegetated habitat with a detectable water flow in association with cool temperatures (less than 15°C [59°F]) (Moyle et al. 2004). Turbidity is typically high under these conditions, but decreases rapidly as flows diminish. On floodplains, complex topography slows water velocities, creating eddies and increasing hydraulic residence time. Increased hydraulic residence time promotes phytoplankton and zooplankton production on seasonally inundated floodplains.

With rising water temperatures during the spring, young juveniles (about 25 to 40 millimeters) begin their migration downstream through the Delta. Such migrations often occur in late April, May, or even June of high-flow years (Moyle et al. 2004; Crain et al. 2004). In low-flow years, juvenile splittail are most abundant in the northern and western regions of the Delta; in high-flow years, their distribution is more even throughout the Delta (Sommer et al. 1997).

When juveniles reach a length of approximately 29 millimeters fork length, they move into deeper habitats (Sommer et al. 2002). On the Cosumnes River, juveniles have been observed leaving the floodplain at a size of 25 to 40 millimeters total length, when they disperse rapidly downstream. Although some larval and juvenile splittail are swept off floodplains and downstream by flood currents (Baxter et al. 1996), many larvae and juveniles remain in riparian or annual vegetation along shallow edges on floodplains as long as water temperatures remain cool (Sommer et al. 2002; Moyle et al. 2004). Most late-stage juveniles and nonreproductive adults inhabit moderately shallow (less than 4 meters [13 feet]) brackish and freshwater tidal sloughs and shoals, such as those found in Suisun Bay and Suisun Marsh and the margins of the lower Sacramento River (Moyle et al. 2004; Feyrer et al. 2005). Figure 2A.7-3 indicates the geographic distribution of splittail over the past 34 years throughout the Delta region and Figure 2A.7-4 indicates seasonal variation in the abundance of postlarval and juvenile splittail throughout their range.

Splittail spend little time in habitats (sloughs, ditches, creeks etc.) surrounding floodplains after leaving (Moyle et al. 2007), and are only present for about two weeks in adjacent sloughs after leaving the Cosumnes floodplain. Migration through river corridors is also fairly quick, with splittail from the Cosumnes floodplain reaching the mouth of Mokelumne River in about two weeks after leaving the area (Moyle et al. 2007). There is some evidence that a small fraction of splittail young-of-year that are spawned in the Sacramento River and Butte Creek remain upstream their first year (Baxter 1999).

Channel margins and backwater habitats can be critical to the survival of young-of-year splittail, as well as the population as a whole (Moyle et al. 2004; Feyrer et al. 2005). Such habitats provide refugia from predatory fishes and feeding sites as fish grow in upstream regions before and during downstream migration. Many backwater habitats are associated with the complex topography of remnant riparian habitats and are created ephemerally in response to increases in river stage (water surface elevation); others are synthetic creations such as cut channels, boat ramps, or agricultural pump intakes. This contrasts with major floodplain inundation typically associated with large splittail year classes (Meng and Moyle 1995; Baxter et al. 1996; Sommer et al. 1997), which may require an 8- to 10-meter [26- to 33-foot] increase in river stage (typically associated with flood flow events).

Two early life history strategies occur in juvenile splittail produced in the Sacramento River system. The dominant strategy is characterized by juveniles migrating downstream in late spring and early summer to the Delta, Suisun Bay, and Suisun Marsh; a less well-studied strategy is to remain upstream through the summer into the next fall or spring and migrate downstream as a subadult (Baxter 1999; Moyle et al. 2004). This latter strategy occurs in Butte Creek and the mainstem Sacramento River. As water recedes further, juveniles remaining in upstream riverine habitats and congregate in large eddies for feeding.

11A.7.6 Life Cycle

Splittail spawning occurs between late February and early July (Wang 1986). Females lay between 5,000 and 150,000 eggs, but fecundity is size-dependent and highly variable, probably related to food availability and selenium content in bivalve prey (Feyrer and Baxter 1998; Moyle et al. 2004). Egg incubation lasts for 3 to 7 days depending on water temperature (Moyle 2002). Newly hatched larvae are typically 6.5 to 8 millimeters [0.26 to 0.32 inches] long (Wang 1986). Larvae remain in shallow weedy areas near spawning areas for 10 to 14 days (Meng and Moyle 1995). In the case of floodplains, larvae are found in shallow water associated with flooded terrestrial vegetation (Crain et al. 2004).

Splittail grow to a typical length of 110 to 120 millimeters [4.3 to 4.7 inches] during their first year, 140 to 160 millimeters [5.5 to 6.3 inches] during their second year, 200 to 215 millimeters [7.9 to 8.5 inches] during their third year, and grow 25 to 35 millimeters/year during remaining years, reaching up to 400 millimeters [15.75 inches]. Growth has decreased since the introduction of the overbite clam (*Potamocorbula amurensis*) (Moyle et al. 2004). Maturity is typically reached at the end of their second year (Daniels and Moyle 1983).

11A.7.6.1 Diet

The diet of splittail larvae up to 15 millimeters in length is dominated by zooplankton, primarily cladocerans with some copepods, rotifers, and chironomids present in small amounts; chironomids become important after splittail reach 15 millimeters long (Kurth and Nobriga 2001; Moyle 2002; Feyrer et al. 2007). In the 1980s, the diet for splittail age 1 and above included the native mysid shrimp, *Neomysis*, amphipods, and harpacticoid copepods, with detritus accounting for more than half the diet (Feyrer et al. 2003). After the invasion of *Potamocorbula* in the 1980s and the crash of *Neomysis*, clams, especially *Potamocorbula*, became an important component of the diet (Feyrer et al. 2003).

11A.7.6.2 Temperature and Salinity Requirements

Juvenile and subadult splittail commonly inhabit regions of the estuary characterized by salinities of 10 to 18 parts per thousand (ppt) (Meng and Moyle 1995; Sommer et al. 1997). Relatively warm temperatures and an abundance of food allow young splittail to grow and develop rapidly on floodplains so that they are physically prepared to leave floodplains when water levels recede. Increased water temperatures and reduced water levels may cue floodplain emigration of juvenile splittail. Many of these ecosystem benefits are dependent upon the frequency, duration, and timing of the floodplain inundation.

Salinity tolerance increases with size (and age) such that adult splittail can survive salinities up to 29 ppt for brief periods of time (Young and Cech 1996). Splittail inhabit a broad range of temperatures, 5 to 24°C (41 to 75.2°F) depending upon season, and acclimated fish can tolerate 29 to 33°C (84.2 to 91.4°F) for short periods (Young and Cech 1996).

Complementing their temperature and salinity tolerances, splittail of all sizes can tolerate low dissolved oxygen levels (less than 1 milligram of oxygen per liter^{-1}) (Moyle et al. 2004), making them well suited to slow-moving sections of sloughs and rivers. In Suisun Marsh during summer, splittail commonly inhabit areas with salinities of 6 to 10 ppt and temperatures of 15 to 23°C (59 to 73.4°F) (Meng and Moyle 1995). Juveniles are most abundant in shallow (less than 2 meters), turbid water with a current. Napa and Petaluma River stocks may possess a higher salinity tolerance than the Central Valley stock (Baerwald et al. 2007; Feyrer et al. 2010).

11A.7.7 Threats and Stressors

A number of threats and stressors exist for splittail. Stressor rankings and the certainty associated with these rankings for splittail are provided in Chapter 5 of the BDCP. The discussion below outlines some of the main threats and stressors to splittail.

11A.7.7.1 Water Diversions

Splittail are salvaged year-round in the State Water Project (SWP) and Central Valley Project (CVP) fish salvage facilities, with the greatest occurrence during May to July. The majority of splittail observed in fish salvage monitoring are early juveniles. Splittail mortality during the SWP/CVP fish salvage process has not been quantified, but it is thought to be high. Mortality to young splittail may occur because of overcrowding within transport tanks and predation at release locations within the Delta. Furthermore, adults that are salvaged are returned to an area downstream of the export facilities, which is expected to increase the energy expenditure needed to reach their upstream spawning sites and could reduce their ability to spawn successfully (Moyle et al. 2004). Young-of-year splittail have critical swimming velocities that are similar to water velocities occurring at the SWP/CVP diversions (Young and Cech 1996).

The highest levels of splittail salvage occur during years with high outflows that persist into the March and April spawning period (Sommer et al. 1997). For example, splittail salvage increased substantially in both 2005 and 2006, but was even higher in 2011, corresponding to high levels of juvenile production, reaching a record high of over 7.5 million fish at the CVP Tracy Fish Collection Facility (Aasen 2012). However, because salvage rates are high when splittail abundance is high, the net effect of entrainment at the export facilities on the overall population of splittail may not be great, and there is no evidence that juvenile entrainment mortality has a significant population-level effect (Sommer et al. 1997). Nevertheless, prolonged drought and subsequent reduction in adult splittail abundance could eventually cause a proportionally large effect of entrainment on the population, particularly if the geographic distribution of the splittail population were to occur near the export facilities (Sommer et al. 1997).

In addition to SWP/CVP export facilities, there are over 2,200 small water diversions within the Plan Area, the majority of which are unscreened (Herren and Kawasaki 2001). Results of surveys at unscreened diversions (Nobriga et al. 2004) have shown that a variety of fish species (e.g., threadfin shad, silversides, striped bass), primarily larval and juvenile life stages, are vulnerable to entrainment. Based on results of this and similar studies conducted on unscreened diversions, it has been hypothesized that early juvenile splittail would be vulnerable to entrainment from these smaller diversions. However, water velocities at these relatively small agricultural pumps and siphons are low enough that larger fish are able to avoid entrainment. The potential magnitude of the entrainment risk, risk variations across seasons and areas, and the cumulative effect of entrainment losses on the population dynamics of splittail cannot be determined. No comprehensive, quantitative estimates have been developed for the level of potential entrainment mortality that may occur because of diversions from the rivers and Delta.

Power plants within the Plan Area have the ability to entrain large numbers of fish. However, with the retirement of older units, use of cooling water is currently low. Furthermore, recent State Water Resources Control Board regulations require that units at these plants be equipped with a closed cycle cooling system by 2017.

11A.7.7.2 Habitat-Changing Structures

In the Sacramento River, levees constrain river meander from River Mile 194 at Chico Landing downstream to Collinsville (River Mile 0) and restrict the riparian zone accessible via the river channel. Levee configuration differs through three reaches downstream of Chico Landing and has important implications in terms of splittail spawning and rearing habitat (Feyrer et al. 2005).

- The river reach from Chico Landing to Colusa (River Mile 144) is characterized by setback levees enclosing remnant floodplain (flood terraces) and a narrowly meandering river channel.
- The reach from Colusa to Verona (River Mile 80) is tightly leveed and contains fewer and much narrower flood terraces, many of which are actively eroding and targeted for riprap.
- The reach from Verona to Collinsville (River Mile 0) is also tightly leveed and contains extensive, narrow flood terraces between Verona and Sacramento, but is almost completely riprapped from Sacramento to Collinsville.

11A.7.7.3 Habitat Loss

Maintaining and increasing seasonally inundated floodplain habitat suitable for splittail spawning and juvenile rearing throughout the species range has been identified as a factor that will help maintain successful reproduction and increase juvenile abundance and genetic diversity during prolonged drought events and avoid a genetic "bottleneck."

11A.7.7.3.1 Reduced Juvenile/Adult Rearing Habitat

Reclamation of Delta islands and wetlands during the 19th and early 20th centuries removed or degraded large areas of high-value juvenile/adult rearing habitat. This habitat consisted of shallow,

low-velocity areas throughout the Delta, and particularly in the western Delta and Suisun Marsh (Moyle et al. 2004). In the 1960s and 1970s, the U.S. Army Corps of Engineers increased downstream water conveyance and reinforced levees by clearing and riprapping levees along the lower Sacramento River. These actions further reduced or eliminated suitable rearing habitat for splittail from the City of Sacramento downstream by removing large areas of shallow channel margins. Current efforts are underway to improve flood protection for communities along much of the lower Sacramento River and several other valley rivers. Actions being proposed and conducted include removal of trees and riparian vegetation and armoring with riprap. The current policy is for removal of all large trees and brush from levees to improve detection of weak points and potential levee failures.

11A.7.7.3.2 Reduced Spawning/Larval Rearing Habitat

Reclamation and levee construction along the majority of Delta waterways and upstream riverine habitats has degraded or eliminated large areas of seasonally inundated floodplains that once served as spawning and larval rearing habitat for splittail. Although some spawning occurs on shallow margins of the main channels every year, floodplains are highly productive and, when inundated, are used by splittail for spawning and larval rearing more heavily than narrow channel margins.

Changes in river stage resulting from upstream diversions and reservoir storage have not been well studied, but during low- and moderate-runoff years, water management may affect splittails' access to floodplains and their ability to emigrate successfully after spawning and early rearing (Moyle et al. 2004). Reservoir operations are designed to reduce peak flows during winter and spring months that historically would have resulted in seasonal inundation of floodplains.

11A.7.7.4 Food Resources

There are multiple mechanisms that may cause reductions in food supplies for juvenile and adult splittail, including competition with nonnative species and reductions in productivity as a result of heavy grazing by introduced clams. The introduced *Potamocorbula* is a highly efficient filter feeder that has reduced phytoplankton in the Delta and Suisun Bay, with subsequent effects on zooplankton consumers (Kimmerer and Orsi 1996). The invasion of the estuary by *Potamocorbula* reduced the availability of the native mysid, *Neomysis*, to splittail (Feyrer et al. 2003). However, the effect of *Potamocorbula* on food availability to splittail is mixed because splittail now consume the clams as well as the nonnative mysid shrimp, *Acanthomysis* (Feyrer et al. 2003).

In addition to the effect of introduced clams, reductions in productivity within the estuary have been attributed to changes in hydrology associated with in-Delta water diversions, upstream reservoir operations, reduced hydraulic residence time in the Delta, and ammonia[5] from wastewater treatment plants.

- The SWP/CVP export facilities and the over 2,200 in-Delta agricultural diversions (Herren and Kawasaki 2001) export nutrients, organic material, phytoplankton, and zooplankton from the Delta that would otherwise support the base of the food web (Jassby et al. 2002; Resources Agency 2007).

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[5] Ammonia in water generally forms some amount of ammonium. Therefore, the use of the term *ammonia* implies that both ammonia and ammonium may be present.

- Upstream reservoir operations have reduced seasonal variability in Delta and river hydrology, resulting in fewer and shorter high-flow events and, therefore, reduced frequency and duration of floodplain inundation (Sommer et al. 1997, 2002; Meng and Matern 2001; Feyrer et al. 2005, 2006). Floodplains are an important source of food for splittail (Sommer et al. 2001; Schemel et al. 2004; Lehman et al. 2008).
- Reductions in hydraulic residence time in the central Delta have resulted, in part, from the need to maintain good water quality in the Delta for agricultural uses and SWP/CVP exports (Resources Agency 2007). Water of a higher quality is conveyed from the Sacramento River southward through the Delta via the Delta Cross Channel, creating a hydraulic barrier against salt water that may otherwise enter the Delta from the west. As a result, water movement has increased and hydraulic residence time has declined in the central Delta. Reduced hydrologic residence time is thought to reduce productivity in the Delta because nutrients and organics are transported downstream and out of the Delta before stimulating phytoplankton or zooplankton production (Jassby et al. 2002; Kimmerer 2002a, 2002b; Resources Agency 2007). Increased hydraulic residence time allows more opportunity for phytoplankton and zooplankton production.
- High concentrations of ammonium from municipal wastewater treatment plants inhibits diatom production, reducing the food available for the prey of splittail prey and other fish species (Wilkerson et al. 2006; Dugdale et al. 2007; Glibert 2010; Cloern et al. 2011; Glibert et al. 2011).

11A.7.7.5 Exposure to Toxins

Although there is strong support from laboratory studies that toxics can be lethal to splittail (Teh et al. 2002, 2004a, 2004b, 2005), there is little information about the chronic or acute toxicity of contaminants within the Delta (Greenfield et al. 2008). The longevity of splittail relative to most other covered fish species (5 to 7 years) (Moyle 2002) enables their tissue to bioaccumulate toxicants to higher concentrations than those other species. This makes splittail potentially vulnerable to heavy metals such as mercury, and other fat-soluble chemicals. Perhaps the greatest concern among the impacts of contaminants on splittail relates to selenium. Tissues of splittail collected in Suisun Bay had sufficiently high selenium concentrations to cause physiological impacts, in particular, reproductive abnormalities (Stewart et al. 2004). Adult splittail feed on the *Potamocorbula,* which bioaccumulates and transfers selenium in high concentrations (Luoma and Presser 2000). With the decline of the mysid shrimp, *Neomysis*, in the estuary, juvenile and adult splittail have increased foraging on benthic macroinvertebrates such as clams (Feyrer et al. 2003). Teh et al. (2004b) found that young splittail that were fed a diet high in selenium grew significantly slower and had higher liver and muscle selenium concentrations after nine months of testing.

Kuivila and Moon (2004) documented dissolved pesticides in the Sacramento–San Joaquin Delta during April to June (1998 to 2000) when young, growing splittail were migrating into the Delta and estuary. The use of pyrethroid pesticides has increased substantially in the Central Valley since the early 1990s (Oros and Werner 2005). Though relatively nontoxic to mammals, these chemicals are highly toxic to aquatic organisms, including fishes. Also, pesticide use on row crops (including rice) commonly grown in the Yolo and Sutter Bypasses and their proclivity to adhere to sediment particles suspended in water and deposited on the bottom provide a dietary pathway to splittail ingestion along with detritus during feeding (Werner 2007). Exposure to pesticides and other chemical contaminants may occur while splittail forage on inundated floodplains or in the estuary after the pesticides have entered Delta channels through agricultural drainage and have been transported to and settled in the Delta.

11A.7.7.6 Predation

Major nonnative predatory fish introduced into the Bay-Delta estuary, such as striped bass and largemouth bass, have resided in the Delta for over a century (Dill and Cordone 1997), and splittail have persisted. However, reduced turbidity in the Delta and increased habitat for nonnative predatory species provided by Brazilian waterweed (*Egeria densa*) and water hyacinth (*Eichhornia crassipes*) have enhanced both largemouth bass abundance and their ability to visually forage, thus increasing predation risk to splittail (Brown and Michniuk 2007).

11A.7.7.7 Harvest

The legal fishery for splittail is thought to be substantial, despite poor documentation (Moyle et al. 2004). Subadult and adult splittail are harvested by recreational anglers for consumption, as well as for use as bait by striped bass anglers. There is no evidence that splittail are affected at a population level by the fishery, but there is insufficient evidence to conclude this with confidence. The California Department of Fish and Game now regulates the take of splittail to two fish per day, which may only be taken by angling (California Code of Regulations 14(2):4,5.70).

11A.7.8 Relevant Conservation Efforts

The Ecosystem Restoration Program (CALFED Bay-Delta Program 2000) includes specific objectives for splittail as follows.

> Species recovery objectives will be achieved when 2 of the following 3 criteria are met in at least 4 of every 5 years for a 15 year period: 1) the fall midwater trawl survey numbers must be 19 or greater for 7 of 15 years. 2) Suisun Marsh catch per trawl must be 3.8 or greater and the catch of young-of-year must exceed 3.1 per trawl for 3 of 15 years, and 3) Bay Study otter trawls must be 18 or greater AND catch of young-of-year must exceed 14 for 3 out of 15 years.

The CALFED Bay-Delta Program (CALFED) Ecosystem Restoration Program has funded the Yolo Bypass Watershed Restoration Strategy. The purpose is to develop a local implementation strategy for a broad landscape level of restoration and rehabilitation for the Yolo Bypass, which should have direct benefits to splittail. The program has also funded a feasibility study for flood protection and ecosystem restoration at Hamilton City.

A new integrated monitoring and outreach program to evaluate fish contamination issues has recently been funded by the Ecosystem Restoration Program. This project will monitor mercury levels in sport fish and biosentinel indicators for three years throughout the watershed. The monitoring will evaluate spatio-temporal variability and gather information needed for management decisions.

Several conservation activities are planned to improve shallow subtidal habitat in the Delta that should provide benefit to splittail. The CALFED Ecosystem Restoration Program Suisun Marsh Land Acquisition and Tidal Marsh Restoration project will restore 500 acres within the Suisun Marsh to tidal wetland. The Suisun Marsh/North San Francisco Bay Ecological Zone Biological Restoration and Monitoring project will restore, maintain, and monitor the biology of at least three major eastern San Pablo Bay and southern Suisun Bay areas within a single CALFED-defined ecological zone (Suisun Bay/North San Francisco Bay), and compare and improve these restoration efforts through an integrated monitoring program. Restoration of three commercial salt ponds along the Napa River will provide habitat benefits for splittail and other aquatic species.

Connectivity to and restoration of floodplain habitat were achieved along the Cosumnes River through breaching of levees on the Cosumnes River Preserve during the 1990s (Booth et al. 2006). The Cosumnes River Preserve is managed by a coalition of state, federal, and nonprofit organizations, such as The Nature Conservancy California. The Cosumnes River floodplain is now thought to be used for spawning by splittail (Crain et al. 2004; Moyle et al. 2004).

Construction is ongoing for the Reclamation District 108 Poundstone Intake Consolidation and Positive Barrier Fish Screen Project in Colusa County, which will construct an 81-foot-long, positive barrier fish screen at the entrance to a new water diversion site on the Sacramento River (River Mile 110.5) in Colusa County. The new diversion will consolidate and allow removal of three existing unscreened diversions. Other projects (e.g., Reclamation District 1004 intake screens, Reclamation District 108 Wilkins Slough Positive Barrier Fish Screen) have been constructed on the Sacramento River to reduce entrainment of splittail and other fish.

The Sacramento River Conservation Area Forum, DWR, USFWS, CDFW, the California Department of Parks and Recreation, the Wildlife Conservation Board, nonprofit organizations such as the Nature Conservancy and the Sacramento River Partners, and many other stakeholders conduct conservation and restoration activities in the middle and upper reaches of the Sacramento River.

On December 10, 2009, the California Fish and Game Commission adopted CDFW's proposal to establish fishing regulations on splittail in an effort to reduce the potential effects of harvest on the splittail population. Effective March 1, 2010, there is a year-round two-fish daily bag and possession limit.

11A.7.9 Recovery Goals

Although splittail is not listed, it is included in the *Sacramento–San Joaquin Delta Native Fishes Recovery Plan* (U.S. Fish and Wildlife Service 1996), which also includes the delta smelt, longfin smelt, green sturgeon, Sacramento perch, and three races of Chinook salmon. USFWS has the responsibility to review and update the recovery plan for these species. To accomplish this task, USFWS has formed a new Delta Native Fishes Recovery Team to assist in the preparation of this updated plan.

11A.7.10 References Cited

11A.7.10.1 Literature Cited

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11A.8 Green Sturgeon (*Acipenser meditrostris*)

11A.8.1 Legal Status

The North American green sturgeon is composed of two distinct population segments (DPSs): the Northern DPS, which includes all populations in the Eel River and northward; and the Southern DPS, which includes all populations south of the Eel River. The Northern DPS green sturgeon currently spawns in the Klamath River in California and the Rogue River in Oregon, and is listed as a Species of Concern (69 *Federal Register* [FR] 19975). Only the Southern DPS is found in the Plan Area.

The primary threat to the southern DPS is the reduction in habitat and spawning area due to dams (such as Keswick, Shasta, and Oroville). Spawning is limited to one population in the Sacramento River, making green sturgeon highly vulnerable to catastrophic events. Continuing threats include migration barriers, insufficient flow, increased water temperatures, juvenile entrainment in water export facilities, nonnative forage species, competitors, predators, poaching, pesticides and heavy metals, and harvest (Biological Review Team 2005).

After a status review was completed in 2002 (Adams et al. 2002), the National Marine Fisheries Service (NMFS) determined that the Southern DPS did not warrant listing as threatened or endangered but should be identified as a Species of Concern. This determination was challenged on April 7, 2003. NMFS updated its status review on February 22, 2005, and determined that the Southern DPS should be listed as threatened under the federal Endangered Species Act (ESA) (Biological Review Team 2005). NMFS published a final rule on April 7, 2006 that listed the Southern DPS as threatened (71 FR 17757); the rule took effect on June 6, 2006. Included in the listing are the spawning population in the Sacramento River and fish living in the Sacramento River, the Sacramento–San Joaquin River Delta (Delta), and the San Francisco Estuary.

In September 2008, NMFS proposed critical habitat for the Southern DPS (73 FR 52084). NMFS made a final critical habitat designation for the Southern DPS on October 9, 2009 (74 FR 52300). Designated areas in California include the Sacramento River, lower Feather River, and lower Yuba River; the Delta; and Suisun, San Pablo, and San Francisco Bays (National Marine Fisheries Service 2012).

On May 21, 2009, NMFS proposed an ESA Section 4(d) rule to apply ESA take prohibitions to the Southern DPS. NMFS published the final 4(d) rule and protective regulations July 2, 2010 (75 FR 30714). In California, green sturgeon is a Class 1 Species of Special Concern (qualifying as threatened under the California Endangered Species Act [CESA]) (Moyle et al. 1995).

11A.8.2 Species Distribution and Abundance

11A.8.2.1 Range

Green sturgeon ranges from Ensenada, Mexico to the Bering Sea, Alaska (Colway and Stevenson 2007; Moyle 2002). Green sturgeon spawns in two California basins: the Sacramento and Klamath Rivers (Figure 2A.8-1). These reproducing populations are genetically distinct and occupy the Southern and Northern DPS, respectively (Adams et al. 2002; Israel et al. 2004). Adult populations in the less-altered Klamath and Rogue Rivers are fairly constant, with a few hundred spawning adults typically harvested annually by tribal fisheries. In the Sacramento River, the green sturgeon population is believed to have declined over the last two decades, with less than 50 spawning green sturgeon sighted annually in the best spawning habitat (Israel and Klimley 2008). In the Umpqua, Feather, Yuba, and Eel Rivers, green sturgeon sightings are extremely limited and spawning has not been recently recorded. In the San Joaquin and South Fork Trinity Rivers, the green sturgeon population appears extirpated (Figure 2A.8-1).

Green sturgeon have been recorded in the Feather River as larvae caught in screw traps (Beamesderfer et al. 2004). Spawning has recently been recorded with eggs from three different sturgeon females (Van Eenenaam 2011). In spring 2011 (a wet year), many sturgeon adults were spotted while DIDSON surveys were being conducted (Seesholtz 2011). No juvenile green sturgeon have been documented in the San Joaquin River. Moyle (2002) suggested that reproduction may have taken place in the San Joaquin River because adults have been captured at Santa Clara Shoal and Brannan Island. However, given the low flow conditions and resulting water quality that exist in the San Joaquin River today, they are probably extirpated (Israel and Klimley 2008).

Green sturgeon are anadromous and pass through the San Francisco Bay to the ocean at about 1 to 3 years of age. In the ocean they primarily move northward and commingle with other sturgeon populations, spending much of their lives in the ocean or in Oregon and Washington estuaries (California Department of Fish and Game 2002; Kelly et al. 2007). Subadult and adult green sturgeon are thought to potentially migrate thousands of miles along the coasts of northern California and the Pacific Northwest. Relatively large concentrations of sturgeon occur in the Columbia River estuary, Willapa Bay, and Grays Harbor, with smaller aggregations in the San Francisco estuary (Emmett et al. 1991; Moyle et al. 1992; Israel 2006).

Musick et al. (2000) noted that the abundance of North American green sturgeon has declined by 88% throughout much of its range. The California Department of Fish and Game (2002) estimated that green sturgeon abundance in the Bay-Delta estuary (generally defined as the San Francisco Bay and the Sacramento River-San Joaquin River Delta) ranged from 175 to more than 8,000 adults between 1954 and 2001 with an annual average of 1,509 adults. Fish monitoring efforts at Red Bluff Diversion Dam and the Glenn-Colusa Irrigation District pumping facility on the upper Sacramento River have recorded between zero and 2,068 juvenile North American green sturgeon per year (Adams et al. 2002). Using CDFW angler report card reports, the number of green sturgeon caught from 2006 to 2011 ranged from 311 to 389 (Gleason et al. 2008; DuBois et al. 2009, 2010, 2011, 2012). Because these fish were primarily captured in San Pablo Bay, where both northern and Southern DPSs exist, the proportion of fish captured in sampling from the Southern DPS is unknown.

Green sturgeon are long-lived (up to 60 to 70 years) and late maturing (sexual maturity is reached at approximately 15 years of age) (Van Eenennaam et al. 2006). They have a low fecundity rate (59,000 to 242,000 eggs per female) due to a larger egg size and smaller adult size relative to white sturgeon (180,000 to 590,000 eggs per female). They may spawn every 3 to 5 years (California Fish Tracking Consortium 2009; National Marine Fisheries Service 2010). These characteristics make green sturgeon particularly susceptible to habitat degradation and overharvest (Musick 1999). With only one population in the Central Valley, a lack of spatial and geographic diversity make the viability of the Southern DPS vulnerable to changes in the environment and catastrophic events. As a result of low abundance, the population has limited genetic diversity, which decreases the ability of individuals in the green sturgeon population to withstand environmental variation.

11A.8.2.2 Distribution in the Plan Area

The Delta serves as a migratory corridor, feeding area, and juvenile rearing habitat for North American green sturgeon in the Southern DPS. Adults migrate upstream primarily through the western edge of the Delta into the lower Sacramento River between March and June (Adams et al. 2002). The only confirmed spawning site for Southern DPS green sturgeon is a short stretch of the upper mainstem Sacramento River below Keswick Dam (National Marine Fisheries Service 2010). Larvae and post-larvae are present in the lower Sacramento and North Delta between May and October, primarily in June and July (California Department of Fish and Game 2002). Juvenile green sturgeon have been captured in the Delta during all months of the year (Borthwick et al. 1999; California Department of Fish and Game 2002). Adult green sturgeon have been documented in the Yolo Bypass, but these individuals usually end up stranded against the Freemont Weir (Marshall pers. comm.).

11A.8.3 Habitat Requirements and Special Considerations

As anadromous fish, North American green sturgeon rely on riverine, estuarine, and marine habitats during their long life. On October 9, 2009, NMFS (74 FR 52300) designated critical habitat for the green sturgeon Southern DPS. Critical habitat in marine waters includes areas within the 60-fathom isobath from Monterey Bay to the U.S.-Canada border. Coastal bays and estuaries designated as critical habitat include San Francisco Estuary and Humboldt Bay in California; Coos, Winchester, Yaquina, and Nehalem Bays in Oregon; Willapa Bay and Grays Harbor in Washington; and the lower Columbia River Estuary from the mouth to River Kilometer 74. In fresh water, critical habitat includes the mainstem Sacramento River downstream of Keswick Dam (including the Yolo and Sutter Bypasses), the Feather River below Fish Barrier Dam, the Yuba River below Daguerre Point Dam, and the Delta (Figure 2A.8-2). The essential physical and biological habitat features identified for the Southern DPS include prey resources (benthic invertebrates and small fish), water quality, water flow (particularly in freshwater rivers), water depth, substrate type/size (i.e., appropriate spawning substrates in freshwater rivers), sediment quality, and migratory corridors.

Freshwater habitat of green sturgeon of the Southern DPS varies in function, depending on location in the Sacramento River watershed. Spawning areas currently are limited to accessible reaches of the Sacramento River upstream of Hamilton City and downstream of Keswick Dam (Figure 2A.8-1) (California Department of Fish and Game 2002). Preferred spawning habitats are thought to contain large cobble in deep and cool pools with turbulent water (California Department of Fish and Game 2002; Moyle 2002; Adams et al. 2002). Sufficient flows are needed to oxygenate and limit disease and fungal infection of recently laid eggs (Deng et al. 2002; Parsley et al. 2002). In the Sacramento River, spawning appears to be triggered by large increases in water flow during spawning (Brown and Michniuk 2007).In the Rogue River, Erickson et al. (2002) found that green sturgeon were most often found at depths greater than 5 meters (16 feet) with low or no currents during summer and fall months.

In addition, acoustic tagging studies by Erickson et al. (2002) indicate that adult green sturgeon hold for as long as six months in deep (greater than 5 meters [16 feet]), low-gradient reaches or off-channel sloughs or coves of the river during summer months when water temperatures were between 15 and 23°C (59 and 73.5°F). When ambient temperatures in the river dropped in fall and early winter (less than 10°C [50°F]) and flows increased, fish moved downstream and into the ocean. Water temperatures in spawning and egg incubation areas are critical; temperatures greater than 19°C (66.2°F) are lethal to green sturgeon embryos (Cech et al. 2000; Mayfield and Cech 2004; Van Eenennaam et al. 2005; Allen et al. 2006).

Habitats for migration are downstream of spawning areas and include the mainstem Sacramento River, Delta, and San Francisco Bay Estuary. These corridors allow the upstream passage of adults and the downstream emigration of juveniles (71 FR 17757). Migratory habitat conditions are strongly affected by the presence of barriers and impediments to migration (e.g., dams), unscreened or poorly screened diversions, and degraded water quality. Heublein et al. (2009) found two different patterns of "spawning migration" and out-migration for green sturgeon in the Sacramento River. Results of this study found six individuals potentially spawned, over-summered, and moved out of the river with the first fall flow event, this is the pattern that is thought to be the common behavior of green sturgeon. Alternatively, nine individuals promptly moved out of the Sacramento River before September 1 without any known flow or temperature cue. While some green sturgeon appeared to be impeded on their upstream movement by closure of the Red Bluff Diversion Dam in mid-May, at least five individuals passed under the dam gates during their downstream migration. Both spawning areas and migratory corridors comprise rearing habitat for juvenile green sturgeon, which feed and grow up to 3 years in fresh water. Stomach contents from adult and juvenile green sturgeon captured in the Delta point to the importance of habitat that supports shrimp, mollusks, amphipods, and small fish (Radtke 1966; Houston 1988; Moyle et al. 1992). Rearing habitat condition and function may be affected by variation in annual and seasonal flow and water temperatures (71 FR 17757).

Nearshore marine habitats must provide adequate food resources, suitable water quality, and natural cover for juvenile green sturgeon to successfully forage and grow to adulthood. Offshore marine habitats are also important for supporting growth and maturation of sub-adult green sturgeon.

11A.8.4 Life History

There is relatively little known about the North American green sturgeon, particularly for those that spawn in the Sacramento River (The Nature Conservancy et al. 2008). Adult North American green sturgeon are believed to spawn every 3 to 5 years, but can spawn as frequently as every 2 years (National Marine Fisheries Service 2005) and reach sexual maturity at an age of 15 to 20 years, with males maturing earlier than females. Adult green sturgeon begin their upstream spawning migrations into the San Francisco Bay in March, reach Knights Landing during April, and spawn between March and July (Heublein et al. 2009). Based on the distribution of sturgeon eggs, larvae, and juveniles in the Sacramento River, CDFW (California Department of Fish and Game 2002) concluded that green sturgeon spawn in late spring and early summer upstream of Hamilton City, and possibly to Keswick Dam. Peak spawning is believed to occur between April and June. Adult female green sturgeon produce between 59,000 and 242,000 eggs, depending on body size, with a mean egg diameter of 4.3 millimeters (0.17 inch) (Moyle et al. 1992; Van Eenennaam et al. 2006). Life stages are summarized in Table 2A.8-1.

Table 2A.8-1. Green Sturgeon Life Stages in Delta

River	Life Stage	Start Month	End Month	Reference
Upper Sacramento	Migrant	January	December	National Marine Fisheries Service 2009
	Adult Migration	February	June	Bureau of Reclamation 2008
	Adult river holding	March	December	Israel and Klimley 2008
	Adult summer emigration	March	August	
	Eggs	March	July	National Marine Fisheries Service 2009
		March	June	Bureau of Reclamation 2008
		April	Jul July	Israel and Klimley 2008
	Larvae, post-larvae	May	October	National Marine Fisheries Service 2009
		May	October	Bureau of Reclamation 2008
		May	October	Israel and Klimley 2008
Bay-Delta	Adult Bay-Delta holding	July	December	
South Delta	Older juvenile >10 months	January	December	National Marine Fisheries Service 2009
Delta	Older juvenile >10 months	January	December	National Marine Fisheries Service 2009
		April	October	National Marine Fisheries Service 2009
Suisun Bay	Older juvenile >10 months	January	December	National Marine Fisheries Service 2009
Feather	Migrant	February	April	Seesholtz 2011; Healey and Vincik 2011
	Prespawn		April	Seesholtz 2011
	Spawner	February	June	Seesholtz 2011; Moyle 2002
	Larvae, post-larvae			
	Post-spawn migration	September	November	Seesholtz 2011; Healey and Vincik 2011
Trinity River	Migrants	June	August	Bensen et al. 2007

Newly hatched green sturgeon are approximately 12.5 to 14.5 millimeters (0.5 to 0.57 inch) long. Green sturgeon are strongly oriented to the river bottom and exhibit nocturnal activity patterns (Cech et al. 2000). After six days, the larvae exhibit nocturnal swim-up activity (Deng et al. 2002). After about 10 days they begin nocturnal downstream migrational movements (Kynard et al. 2005). Juvenile green sturgeon continue to exhibit nocturnal behavior beyond the metamorphosis from larval to juvenile stages. After approximately 10 days, larvae begin feeding and growing rapidly, and young green sturgeon appear to rear for the first 1 to 2 months in the upper Sacramento River between Keswick Dam and Hamilton City (California Department of Fish and Game 2002). Length measurements estimate juveniles to be 2 weeks old (24 to 34 millimeters [0.95 to 1.34 inch] fork length) when they are captured at the Red Bluff Diversion Dam (California Department of Fish and Game 2002; Brown 2007), and three weeks old when captured further downstream at the Glenn-Colusa facility (Van Eenennaam et al. 2001). Growth is rapid as juveniles reach up to 30 centimeters (11.8 inches) the first year and over 60 centimeters (24 inches) in the first 2 to 3 years (Nakamoto et al. 1995).

Juveniles spend 1 to 4 years in freshwater and estuarine habitats before they enter the ocean (Nakamoto et al. 1995). According to Heublein (2006), all adults leave the Sacramento River prior to September. Lindley (2006) found frequent large-scale migrations of green sturgeon along the Pacific Coast. Kelly et al. (2007) reported that green sturgeon enter the San Francisco Estuary during the spring and remain until fall. Juvenile and adult green sturgeon enter coastal marine waters after making significant long-distance migrations with distinct directionality thought to be related to resource availability.

Little is known about juvenile and adult green sturgeon feeding and diet in the ocean. On entering the highly productive ocean environment, green sturgeon grow at a rate of approximately 7 centimeters (2.76 inches) per year until they reach maturity. Male green sturgeon mature at an earlier age and are smaller than females (Van Eenennaam et al. 2006). Green sturgeon spend 3 to 13 years in the ocean before returning to fresh water to spawn

11A.8.5 Threats and Stressors

A number of threats and stressors exist for green sturgeon. Stressor rankings and the certainty associated with these rankings for green sturgeon are provided in Chapter 5 of the BDCP. The discussion below outlines some of the main threats and stressors to green sturgeon. Delta outflow is recognized as important to green sturgeon and is discussed in Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*.

11A.8.5.1 Reduced Spawning Habitat

Access to historical spawning habitat has been reduced by construction of migration barriers, such as major dams, that block or impede access to the spawning habitat. Major dams include Keswick Dam on the Sacramento River and Oroville Dam on the Feather River (Lindley et al. 2004; National Marine Fisheries Service 2005). The Feather River is likely to have supported significant spawning habitat for the green sturgeon population in the Central Valley before dam construction (Figure 2A.8-1) (California Department of Fish and Game 2002). Green sturgeon adults have been observed periodically in the lower Feather River (U.S. Fish and Wildlife Service 1995; Beamesderfer et al. 2004). Results of habitat modeling by Mora et al. (2009) suggested there is potential habitat on the Feather River upstream of Oroville Dam that would have been suitable for sturgeon spawning and rearing prior to construction of the dam. This modeling also suggested sufficient conditions are present in the San Joaquin River to Friant Dam, and in the tributaries such as Stanislaus, Tuolumne, and Merced Rivers upstream to their respective dams, although it is unknown whether green sturgeon ever inhabited the San Joaquin River or its tributaries (Beamesderfer et al. 2004).

11A.8.5.2 Migration Barriers

NMFS reports several potential migration barriers, including structures such as the Red Bluff Diversion Dam, Sacramento Deep Water Ship Channel locks, Sutter Bypass, and Delta Cross Channel gates on the Sacramento River, and Shanghai Bend and Sunset Pumps on the Feather River (71 FR 17757). In the Central Valley, approximately 4.6% of the total river kilometers have spawning habitat characteristics similar to where Northern DPS green sturgeon spawn, with only 12% of this habitat currently occupied by sturgeon (Neuman et al. 2007). Of the 88% that is unoccupied (approx. 4,000 kilometers [2,485 miles]), 44.2% is currently inaccessible due to dams (Neuman et al. 2007).

The Red Bluff Diversion Dam has been identified as a major barrier and impediment to sturgeon migration on the Sacramento River (U.S. Fish and Wildlife Service 1995). Adult sturgeon can migrate past the dam when gates are raised between mid-September and mid-May to allow passage for winter-run Chinook salmon. However, tagging studies by Heublein (2006) found that when the gates were closed, a substantial portion of tagged adult green sturgeon failed to use fish ladders at the dam and were, therefore, unable to access upstream spawning habitats. The Red Bluff Fish Passage Improvement Project constructed a screened pumping plant which allows the Diversion Dam gates to be permanently opened and allow fish passage year round (USBR 2011). A set of locks at the end of the Sacramento River Deep Water Ship Channel at the connection with the Sacramento River "blocks the migration of all fish from the deep water ship channel back to the Sacramento River" (California Department of Water Resources 2005).

The Fremont Weir is located at the upstream end of the Yolo Bypass, a 40-mile (64-kilometer) long basin that functions as a flood control project on the Sacramento River. Green sturgeon are attracted by high floodwater flows into the Yolo Bypass basin and then concentrate behind Fremont Weir, which they cannot effectively pass (California Department of Water Resources 2005). Green sturgeon that concentrate behind the weir are subject to heavy illegal fishing pressure or become stranded behind the flashboards when high flood flows recede (Marshall pers. comm.). Sturgeon can also be attracted to small pulse flows and trapped during the descending hydrograph (Harrell and Sommer 2003:88–93). Methods to reduce stranding and increase passage have been investigated by the California Department of Water Resources (DWR) and CDFW (California Department of Water Resources 2007; Navicky pers. comm.).

It is thought that adult and juvenile green sturgeon use the same migratory routes as Chinook salmon. Delta Cross Channel gate closures occur during the winter and early spring sturgeon migration period (February through May) as required by State Water Resources Control Board (State Water Board) water right Decision 1641 (D-1641). Upstream migrating adult Chinook salmon are known to use the Delta Cross Channel as a migratory pathway when the gates are open (Hallock et al. 1970). When the gates are open, Sacramento River water flows into the central Delta and the Mokelumne and San Joaquin Rivers, providing migration cues. It is possible that attraction to water passing from the Sacramento River into the interior Delta causes delays and straying of green sturgeon, as it does to Chinook salmon (CALFED Bay-Delta Program 2001; McLaughlin and McLain 2004). The Delta Cross Channel completely blocks juvenile and adult sturgeon migration to and from the interior Delta when the gates are closed.

11A.8.5.3 Exposure to Toxins

Exposure of green sturgeon to toxins has been identified as a factor that can lower reproductive success, decrease early life stage survival, and cause abnormal development, even at low concentrations (U.S. Fish and Wildlife Service 1995; Environmental Protection Information Center et al. 2001; Klimley 2002). Water discharges containing metals from Iron Mountain Mine, located adjacent to the Sacramento River, have been identified as a factor affecting survival of sturgeon downstream of Keswick Dam. In addition, storage limitations and limited availability of dilution flows cause downstream copper and zinc levels to exceed salmonid tolerances. Treatment processes and improved drainage management in recent years have reduced the toxicity of runoff from Iron Mountain Mine to acceptable levels. Although the impact of trace elements on green sturgeon reproduction is not completely understood, negative impacts similar to those of salmonids are suspected (U.S. Fish and Wildlife Service 1995; Environmental Protection Information Center et al. 2001; Klimley 2002).

Green sturgeon consume overbite clams (*Potamocorbula amurensis*) and Asian clams (*Corbicula fluminea*), which are known to bioaccumulate selenium rapidly and lose selenium slowly (Linville et al. 2002). Selenium is transferred to the egg yolk where it can cause mortality of larvae. Although chronic and acute exposure to toxics has been identified as a factor adversely affecting various life stages of green sturgeon, the severity, frequency, geographic locations, and population level consequences of exposure to toxics have not been quantified (Linville et al. 2002). However, Linville (2006) observed larvae to have increased skeletal deformities and mortality associated with maternal effects of selenium exposure, while smaller quantities (about 20 milligrams per kilogram [mg/kg]) decreased feeding efficiency and larger quantities (greater than 20 mg/kg) reduced growth rates after four weeks (Lee et al. 2008a).

Methylmercury is another toxic substance that could potentially affect sturgeon development and survival. Between 2002 and 2006, sediment concentrations of methylmercury were highest in the Central Bay, while shallower parts of San Pablo Bay and Suisun Bay also contained levels greater than 0.2 parts per billion (ppb) (San Francisco Estuary Institute 2007). The amount of methylmercury resulting in the death of juvenile green sturgeon ranges between 20 to 40 mg/kg, with greater consumption increasing mortality significantly (Lee et al. 2008b).

11A.8.5.4 Harvest

As a long-lived, late maturing fish with relatively low fecundity and periodic spawning, the green sturgeon is particularly susceptible to threats from overfishing (Musick 1999). Total captures of green sturgeon in the Columbia River Estuary in commercial fisheries between 1985 and 2003 ranged from 46 fish per year to 6,000 (Adams et al. 2007). However, a high proportion of green sturgeon present in the Columbia River, Willapa Bay, and Grays Harbor (as high as 80% in the Columbia River) may be from the Southern DPS (California Department of Fish and Game 2002; Israel 2006). Long-term data indicate that harvest for green sturgeon occurs primarily in the Columbia River (51%), coastal trawl fisheries (28%), the Oregon fishery (8%) and the California tribal fishery (8%). Harvest of green sturgeon dropped substantially from over 6,000 from 1985 to 1989 to 512 in 2003 (Adams et al. 2007). Much of the reduction results from progressively more restrictive regulation in the Columbia River. Coastal trawl fisheries have declined to low levels, thereby lowering the by catch of green sturgeon. In 2003, Klamath and Columbia River tribal fisheries accounted for 65% of total catch (Adams et al. 2007).Green sturgeon are also vulnerable to recreational sport fishing in the Bay-Delta estuary and Sacramento River, as well as other estuaries located in Oregon and Washington. Green sturgeon are primarily captured incidentally in California by sport fishermen targeting the more desirable white sturgeon, particularly in San Pablo and Suisun Bays (Emmett et al. 1991).

To protect spawning Southern DPS green sturgeon, new federal and state regulations, including the June 2, 2010 NMFS take prohibition (75 FR 30714), mandate that no green sturgeon can be taken or possessed in California (California Department of Fish and Game 2007a). If green sturgeon are caught incidentally and released while fishing for white sturgeon, anglers are asked to report it to CDFW on their white sturgeon report card. The level of hooking mortality that results following release of green sturgeon by anglers is unknown. Sport fishing captures have declined through time, but the factors leading to the decline are unknown. CDFW (California Department of Fish and Game 2002) indicates that sturgeon are highly vulnerable to the fishery in areas where sturgeon are concentrated, such as the Delta and Suisun and San Pablo Bays in late winter, and the upper Sacramento River during spawning migration. CDFW prohibits fishing of green sturgeon year round (Fish and Game Code Section 5.81, Title 14). Because many sturgeon in the Columbia River, Willapa Bay, and Grays Harbor are likely from the Southern DPS, additional harvest closures in these areas would likely benefit the Southern DPS.

Poaching (illegal harvest) of sturgeon is known to occur in the Sacramento River, particularly in areas where sturgeon have been stranded (e.g., Fremont Weir) (Marshall pers. comm.), as well as throughout the Bay-Delta (Schwall pers. comm.). Catches of sturgeon are thought to occur during all years, especially during wet years when sturgeon are attracted by high flows to the Fremont Weir. Green sturgeon inhabiting the San Joaquin River portion of the Delta experience heavy fishing pressure, particularly from illegal fishing (U.S. Fish and Wildlife Service 1995). Areas just downstream of Thermalito Afterbay outlet, Cox's Spillway, and several barriers impeding migration on the Feather River may be areas of high adult mortality from increased fishing effort and poaching. Poaching rates in the rivers and estuary and the impact of poaching on green sturgeon abundance and population dynamics are unknown.

11A.8.5.5 Reduced Rearing Habitat

Historical reclamation of wetlands and islands have reduced and degraded the availability of suitable in- and off-channel rearing habitat for green sturgeon. Further, channelization and hardening of levees with riprap has reduced in- and off-channel intertidal and subtidal rearing habitat. The resulting changes to river hydraulics, riparian cover, seasonal floodplain inundation, and geomorphology affect important ecoystem functions (Sweeney et al. 2004). The impacts of channelization and riprapping are thought to affect larval, post-larval, juvenile, and adult stages of sturgeon, as these life stages are dependent on the food web in freshwater and low-salinity regions of the Delta.

11A.8.5.6 Increased Water Temperature

Exposure to water temperatures greater than 63°F (17.2°F) can increase mortality of sturgeon eggs and larvae (Pacific States Marine Fisheries Commission 1992) and temperatures above 69°F (20.6°C) are lethal to embryos (Cech et al. 2000). Temperatures near the Red Bluff Diversion Dam on the Sacramento River historically occur within optimum ranges for sturgeon reproduction; however, temperatures downstream, especially later in the spawning season, were reported to be frequently above 63°F (17.2°F) (U.S. Fish and Wildlife Service 1995). High temperatures in the Sacramento River during the February to June period no longer appear to be a major concern for green sturgeon spawning, egg incubation, and juvenile rearing, as temperatures in the upper Sacramento River are actively managed for Sacramento River winter-run Chinook salmon. The Shasta temperature control device, installed at Shasta Dam in 1997, in combination with improved cold-water pool management and storage in Lake Shasta, have resulted in improved cool water stream conditions in the upper Sacramento River.

Water temperatures in the Feather River may be inadequate for spawning and egg incubation as the result of releases of warmed water from Thermalito Afterbay (Surface Water Resources, Inc. 2003). Warmed water may be one reason why neither green nor white sturgeon are found in the river during low-flow years (California Department of Fish and Game 2002). It is not expected that water temperatures will become more favorable in the near future and this temperature problem will continue to be a factor affecting habitat value for green sturgeon on the lower Feather River (California Department of Fish and Game 2002).

The lack of flow in the San Joaquin River from dam and diversion operations and agricultural return flows contribute to higher temperatures in the mainstem San Joaquin River, offering less water to keep temperatures cool for sturgeon, particularly during late summer and fall. Though these effects are difficult to measure, temperatures in the lower San Joaquin River continually exceed preferred temperatures for sturgeon migration and development during spring months. Temperatures at Stevenson on the San Joaquin River near the Merced River confluence recorded on May 31 (spawning typically occurs from April to June; Table 2A.8-1) between 2000 and 2004 ranged from 77 to 82°F (25 to 27.8°C) (California Department of Water Resources 2007). Juvenile sturgeon are also exposed to increased water temperatures in the Delta during the late spring and summer due to the loss of riparian shading and by thermal inputs from municipal, industrial, and agricultural discharges.

11A.8.5.7 Nonnative species

Recent introductions of invertebrates have greatly affected the benthic fauna in the Delta and Suisun Bay. CDFW (California Department of Fish and Game 2002) reviewed many of the recent nonnative invasive species introductions and the potential consequences to green sturgeon. The most notable species responsible for altering the trophic system of the Delta include *Potamocorbula*, *Corbicula*, and the Chinese mitten crab (*Eriocheir sinensis*). Sturgeon regularly consume *Potamocorbula* and *Corbicula*, which is of particular concern because of the high bioaccumulation rates of these clams (Linville et al. 2002). Although Chinese mitten crabs may be eaten by adult green sturgeon, it is unlikely that they are a major prey item. The Chinese mitten crab population in the Delta has undergone a substantial decline since 2002 and currently occurs in very low abundance (Hieb 2011) and, therefore has not been a major factor affecting green sturgeon during this period.

11A.8.5.8 Dredging

Hydraulic dredging to allow commercial and recreational vessel traffic is a common practice in the Sacramento and San Joaquin Rivers, navigation channels in the Delta, and Suisun, San Pablo, and San Francisco Bays. Such dredging operations pose risks to bottom-oriented fish such as green sturgeon. Studies by Buell (1992) reported approximately 2,000 sturgeon entrained in the removal of one million tons of sand from the bottom of the Columbia River at depths of 60 to 80 feet (18 to 24 meters). In addition, dredging operations can decrease the abundance of locally available prey species, and contribute to resuspension of toxics such as ammonia[6], hydrogen sulfide, and copper during dredging and dredge spoil disposal, and alter bathymetry and water movement patterns (National Marine Fisheries Service 2006).

11A.8.5.9 Reduction in Turbidity

Turbidity levels in the Delta have declined over the past few decades (Jassby et al. 2002), but little is known about the potential effects of reduced turbidity on green sturgeon.

11A.8.5.10 Entrainment

Larval sturgeon are susceptible to entrainment from nonproject water diversion facilities because of their migratory behavior and habitat selection in the rivers and Delta. The overall impact of entrainment of fish populations is typically unknown (Moyle and Israel 2005); however, there is enough descriptive information to predict where green sturgeon may be entrained. Herren and Kawasaki (2001) documented 431 nonproject diversions on the Sacramento River between Sacramento and Shasta Dam. Entrainment information regarding larval and post-larval individual

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[6] Ammonia in water generally forms some amount of ammonium. Therefore, the use of the term *ammonia* implies that both ammonia and ammonium may be present.

green sturgeon is unreliable because entrainment at these diversions has not been monitored and field identification of green sturgeon larvae is difficult. USFWS staff are working on identification techniques and are optimistic that green sturgeon greater than 40 millimeters (1.6 inch) can be identified in the field (Poytress 2006). Sturgeon collected at the Glenn-Colusa Irrigation District diversion located on the upper Sacramento River are not identified to species, but are assumed to primarily consist of green sturgeon because white sturgeon are known to spawn primarily downstream (Schaffter 1997). Although screens at the Glenn-Colusa Irrigation District diversion satisfy both the NMFS and CDFW screening criteria for salmonids, the effectiveness of these criteria is unknown for sturgeon. Low numbers of green sturgeon have also been identified and entrained at the Red Bluff Research Pumping Plant (Borthwick et al. 1999).

In the Feather River, there are eight large diversions greater than 10 cubic feet per second (cfs) and approximately 60 small diversions between 1 and 10 cfs between the Thermalito Afterbay outlet and the confluence with the Sacramento River (U.S. Fish and Wildlife Service 1995). Based on potential entrainment problems of green sturgeon elsewhere in the Central Valley and the presence of multiple screened and unscreened diversions on the Feather River, it is thought that operation of unscreened water diversions on the Feather River are a possible threat to juvenile green sturgeon.

Presumably, juvenile green sturgeon become less susceptible to entrainment as they grow and their swimming ability and capacity to escape diversions improves. The majority of North American green sturgeon captured in the Delta are between 200 and 500 millimeters (7.9 and 19.7 inches) long (California Department of Fish and Game 2002). Herren and Kawasaki (2001) inventoried water diversions in the Delta and counted a total of 2,209 diversions of various types, only 0.7% of which were screened. The majority of these diversions were between 12 and 24 inches (305 and 610 mm) in diameter. The vulnerability of juvenile green sturgeon to entrainment at these unscreened diversions is largely unknown, although in two multiyear studies (Nobriga et al. 2004; Pickard et al. 1982) no green sturgeon were caught. Results of these studies suggest that larger juvenile green sturgeon have a lower risk of entrainment mortality. The largest diversions in the Delta are the State Water Project (SWP) and Central Valley Project (CVP) export facilities, located in the southern Delta, where a low number of juvenile green sturgeon have been recorded as part of fish salvage monitoring (California Department of Fish and Game 2002). The average number of green sturgeon taken per year at the SWP Skinner Fish Facility was 87 individuals between 1981 and 2000, and 20 individuals from 2001 through 2007 (Donnellan pers. comm.). At the CVP Tracy Fish Collection Facility, green sturgeon counts averaged 246 individuals per year between 1981 and 2000, and 53 individuals per year between 2001 and 2007 (Donnellan pers. comm.). This reduction in salvage is consistent with a significant reduction in white sturgeon take at the salvage facilities in the same time periods (National Marine Fisheries Service 2005).

Green sturgeon that are attracted by high flows in the Yolo Bypass move onto the floodplain and eventually concentrate behind Fremont Weir and in various ponds and pools, where they are blocked from further upstream migration (California Department of Water Resources 2005). As the bypass recedes, these sturgeon become stranded behind the flashboards of the weir and can be subjected to heavy illegal fishing pressure (Marshall pers. comm.). Sturgeon can also be attracted to small pulse flows and trapped during the descending hydrograph (Harrell and Sommer 2003:88–93). Methods to reduce stranding and increase passage have been investigated (Navicky pers. comm.).

11A.8.6 Relevant Conservation Efforts

The Anadromous Fish Restoration Program of the Central Valley Project Improvement Act a goal of supporting efforts that lead to doubling the natural production of anadromous fish in the Central Valley at a sustainable, long-term basis, at levels not less than twice the average levels attained during the period of 1967 to 1991. Although most efforts of the Anadromous Fish Restoration Program have focused on Chinook salmon because of their listing history and status, sturgeon may receive some unknown amount of incidental benefit from these restoration efforts. For example, the acquisition of water for flow enhancement on tributaries to the Sacramento River, fish screening for the protection of Chinook salmon and Central Valley steelhead, spawning gravel augmentation, or riparian revegetation and instream restoration projects would likely have some ancillary benefits to sturgeon. The Anadromous Fish Restoration Program has also invested in a green sturgeon research project that has helped improve our understanding of the life history requirements and temporal patterns of the Southern DPS of North American green sturgeon.

Many beneficial actions have originated from and been funded by the CALFED Bay-Delta Program (CALFED), including such projects as floodplain and instream restoration, riparian habitat protection, fish screening and passage projects, research on nonnative invasive species and contaminants, restoration methods, watershed stewardship, and education and outreach programs. Prior Federal Register notices have reviewed the details of the Central Valley Project Improvement Act and CALFED programs and potential benefits for anadromous fish, particularly Chinook salmon and Central Valley steelhead (69 FR 33102). Projects potentially benefiting sturgeon primarily consist of fish screen evaluation and construction projects, restoration evaluation and enhancement activities, and contaminant studies. Two evaluation projects specifically addressed green sturgeon, while the remaining projects primarily address listed salmonids and fishes of the area in general. The new information developed through these research investigations will be used to enhance the understanding of the risk factors affecting population dynamics and recovery, thereby improving the ability to develop effective management measures.

The Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) was formed to guide the implementation of CALFED Ecosystem Restoration Plan elements in the Delta (California Department of Fish and Game 2007b). The DRERIP team has created a suite of ecosystem and species conceptual models, including green sturgeon, that document existing scientific knowledge of Delta ecosystems. The DRERIP team is in the process of using these conceptual models to assess the suitability of actions proposed in the Ecosystem Restoration Plan for implementation. DRERIP conceptual models have been used in the analysis of proposed conservation measures.

In response to concerns about passage impediment to green sturgeon and other migratory species, operations of the Red Bluff Diversion Dam have been modified since its construction in 1964 to reduce the “gates-in” period. In 2009, the Bureau of Reclamation received funding for the Fish Passage Improvement Project at the Red Bluff Diversion Dam. This project built a pumping facility to provide reliable water supply for high-value crops in Tehama, Glenn, Colusa, and northern Yolo Counties while providing year-round unimpeded fish passage. This project eliminates passage issues for sturgeon and other migratory species.

The combination of increased law enforcement and new sport fishing regulations adopted over the past several years specifically to protect sturgeon and reduce their harvest is expected to further reduce illegal fishing practices as well as the effects of incidental harvest of green sturgeon by recreational anglers throughout the range of the species. Mitigation under the Delta Fish Agreement has increased the number of wardens enforcing harvest regulations for steelhead and other fish in the Delta and upstream tributaries by creating the Delta Bay Enhanced Enforcement Program.

11A.8.7 Recovery Goals

On November 12, 2009, NMFS announced its intent to develop a recovery plan for the Southern DPS of North American green sturgeon (*Acipenser medirostris*) and has requested information from the public (74 FR 58245). An outline for the recovery plan was prepared December 2010 (National Marine Fisheries Service 2010), but the plan itself has not yet been completed.

11A.8.8 References Cited

11A.8.8.1 Literature Cited

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11A.9 White Sturgeon (*Acipenser transmontanus*)

11A.9.1 Legal Status

The white sturgeon is not listed under the federal Endangered Species Act (ESA) or the California Endangered Species Act (CESA).

11A.9.2 Species Distribution and Abundance

11A.9.2.1 Range

As a diadromous fish, white sturgeon inhabit riverine, estuarine, and occasionally marine habitats at various stages during their long life. Historically, white sturgeon ranged from Ensenada, Mexico to the Gulf of Alaska. Currently, spawning populations are found in the Sacramento–San Joaquin, Columbia, Snake, and Fraser River systems (Moyle 2002). In California, white sturgeon are most abundant in the San Francisco Bay/Sacramento–San Joaquin River Delta (Bay-Delta) and Sacramento River (Figure 2A.9-1) (Moyle 2002), but they have also been observed in the San Joaquin River system, particularly in wet years (California Department of Fish and Game 2002; Beamesderfer et al. 2004).

11A.9.2.2 Distribution in the Plan Area

The Delta and Suisun Bay serve as a migratory corridor, feeding area, and juvenile rearing area for white sturgeon. These corridors allow the upstream passage of adults and the downstream emigration of juveniles. Adult white sturgeon move from the waters of San Francisco Bay into the Delta and lower Sacramento River during the late fall and winter to spawn. They spawn preferentially in the Sacramento River between the Red Bluff Diversion Dam and Jelly's Ferry Bridge, at river mile 267, in areas characterized by swift currents and deep pools with gravel (U.S. Fish and Wildlife Service 1995; Schaffter 1997; California Department of Fish and Game 2002; Moyle 2002). Adult white sturgeon have been documented in the Yolo Bypass in the toe drain and at the base of Fremont Weir (Webber et al. 2007; Sommer et al. 2013) and in other bypasses in the Sacramento watershed (Healey and Vincik 2011). Larval and juvenile white sturgeon inhabit the lower reaches of the Sacramento and San Joaquin Rivers and the Delta (Stevens and Miller 1970).

The abundance and age structure of the population fluctuates substantially in response to highly variable annual reproductive success. In recent decades the population tends to be dominated by strong year classes produced in years with high spring flows. High spring flows were the norm prior to the major dam building effort on the rim of the Central Valley (Moyle 2002). Recent analyses of the abundance of white sturgeon 117 to 168 centimeters based on harvest data from 2007 to 2009 indicate current populations between about 43,000 and 57,000 fish (DuBois and Gingras 2011). From 2000 to 2009 the abundance of age 15 white sturgeon ranged from 3,252 to 6,539 (DuBois et al. 2011). The abundance of age-15 fish is the metric by which progress toward the Central Valley Project Improvement Act (CVPIA) recovery goal (11,000 fish) is assessed.

11A.9.3 Life Stages

Israel et al. (2009) describe seven life stages of white sturgeon, although the adult stages are considered strategies rather than stages. Some adults migrate in the ocean, but most adult white sturgeon remain in tidally influenced areas of rivers and in estuaries where they feed and grow. Table 2A.9-1 lists the white sturgeon life stages of Israel et al. (2009) and the corresponding terms used in the BDCP.

Table 2A.9-1. White Sturgeon Life Stages

Israel et al. 2009	BDCP
Egg/embryo	Egg/embryo
Larvae	Larvae
Juvenile/young-of-year	Juvenile
Juvenile/sub-adult	Adult/tidal riverine-estuarine feeder
Adult/ocean migrant	Adult/spawning
Adult/tidal riverine-estuarine feeder	
Adult/spawner	

11A.9.4 Life History

White sturgeon spend most of their lives in the brackish portions of the upper estuary, although a small number of individuals move extensively in the ocean (Moyle 2002; Surface Water Resources, Inc. 2004; Welch et al. 2006). Individuals can live over 100 years and can grow to over 19.7 feet (6 meters), but sturgeon greater than 27 years old and over 6.6 feet (2 meters) are rare (Moyle 2002).

Male white sturgeon reach sexual maturity at 10 to 12 years of age, and females reach sexual maturity at 12 to 16 years (Moyle 2002). Maturation is thought to be a function of both photoperiod and temperature (Birstein et al. 1997). White sturgeon can spawn multiple times throughout their lives. Males are believed to spawn every 1 to 2 years, whereas females spawn every 2 to 4 years (Moyle 2002). Chapman et al. (1996) found that female white sturgeon on the Sacramento River produced on average 203,328 eggs. However, Skinner (1962) described a 9.2-foot (280-centimeter), 460-pound (206-kilogram) female white sturgeon that was estimated to yield 4.7 million eggs, a value that greatly exceeds the expected upper limit of the fecundity-weight relationship described by Chapman et al. (1996) (Israel et al. 2009). Other studies indicate that females can produce 100,000 to several million eggs (Pacific States Marine Fisheries Council 1996), with typical females producing approximately 200,000 eggs (Moyle 2002).

Spawning typically occurs between February and June when temperatures are 46 to 66°F (8 to 19°C) (Moyle 2002). Maximum spawning occurs at 58°F (14.4°C) in the Sacramento River (Kohlhorst 1976). It is thought that adults broadcast spawn in the water column in areas with swift current. Spawning success varies from year to year, but is most likely related to temperature and Delta outflow. Spring flows in wet years may be the single most significant factor for white sturgeon year class strength (Beamesderfer et al. 2005). Although the mechanism is unknown, it is hypothesized that higher flows may help disperse young sturgeon downstream, provide increased freshwater rearing habitat, increase spawning activity cued by higher upstream flows, increase nutrients in nursery areas, or increase downstream migration rate and survival through reduced exposure time to predators (Anadromous Fish Restoration Program 1995).

Fertilized eggs sink and attach to the gravel bottom, where they hatch after 4 days at 61°F (16°C) (Beer 1981), though hatching may take up to 2 weeks at lower water temperatures (Pacific States Marine Fisheries Council 1996). Newly hatched larvae are 7.5 to 19.5 millimeters (0.3 to 0.77 inch) long (Kohlhorst 1976) and generally remain in the gravel for 7 to 10 days before emergence into the water column (Moyle 2002). Newly emerged larvae are pelagic for approximately 7 to 10 days until the yolk-sac is absorbed, at which time they begin actively feeding on amphipods and other small benthic macroinvertebrates (Wang 1986). Juvenile white sturgeon feed primarily on algae, aquatic insects, small clams, fish eggs, and crustaceans, but their diet becomes more varied with age (Wang 1986; Pacific States Marine Fisheries Council 1996; Moyle 2002). Since the invasion by the overbite clam (*Potamocorbula amurensis*) in the western Delta and Suisun Bay during the late 1980s, *Potamocorbula* has become a major component of the diet of juvenile and adult white sturgeon.

11A.9.5 Threats and Stressors

A number of threats and stressors exist for white sturgeon. Stressor rankings and the certainty associated with these rankings for white sturgeon are provided in Chapter 5 of the BDCP. The discussion below outlines some of the main threats and stressors to white sturgeon.

11A.9.5.1 Operational Changes in River Flows

Operational changes that have reduced river flows, including spring peak flows, have affected white sturgeon spawning, habitat availability, and prey resources (Israel et al. 2009). Sturgeon recruitment is correlated to flow (Kohlhorst et al. 1991; Beamesderfer and Farr 1997), and the most successful spawning generally occurs in wet and above-normal water years (Fish 2010). Low flows reduce larval dispersal and increase vulnerability to predation (Israel et al. 2009). Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*, presents results of detailed modeling of flow relationships by life stage that indicate the importance of Delta outflow for white sturgeon.

11A.9.5.2 Water Diversions

There is little evidence that the overall population of white sturgeon is influenced by entrainment. Adults are not likely to be entrained due to their large size and benthic habits. Larval sturgeon are more susceptible to entrainment as a result of their migratory behavior in the water column and reduced swimming ability. Herren and Kawasaki (2001) documented 431 water diversions on the Sacramento River between Sacramento and the Shasta Dam. In the Feather River, there are eight diversions greater than 10 cubic feet per second (cfs) and approximately 60 small diversions between 1 and 10 cfs between the Thermalito Afterbay outlet and the confluence with the Sacramento River (U.S. Fish and Wildlife Service 1995). White sturgeon have been reported in low numbers in fish salvage at both the State Water Project (SWP) and Central Valley Project (CVP) export facilities. White sturgeon observed in fish salvage have predominantly been juvenile and sub-adult life stages. Occasionally, adult white sturgeon have been observed impinged on the trash racks at the CVP intake; it has been hypothesized that these large adults were in weakened conditions or had previously died from stresses associated with spawning, angler mortality, or other causes before being impinged at the export intake. Given the large number of diversions, it is possible that larval white sturgeon are vulnerable to entrainment at these diversions; however, actual entrainment mortality and potential effects on the abundance and population dynamics of white sturgeon are unknown because most of the larval population is upstream of the south Delta export facilities. Appendix 5.B, *Entrainment,* includes a discussion of white sturgeon entrainment.

11A.9.5.3 Habitat Loss

11A.9.5.3.1 Spawning Habitat

Access to historical spawning habitat has been reduced by construction of barriers to upstream migration that block or impede access to spawning and juvenile rearing habitat. Major dams include

Keswick Dam and Shasta Dam on the Sacramento River and Oroville Dam on the Feather River (Lindley et al. 2004; National Marine Fisheries Service 2005). White sturgeon adults have been observed periodically in the Feather River (U.S. Fish and Wildlife Service 1995; Beamesderfer et al. 2004). Habitat modeling by Mora et al. (2009) suggests there is suitable habitat for sturgeon in the upstream reaches of the Feather River that have been blocked by Oroville Dam. This modeling also suggests that suitable conditions are present in the San Joaquin River upstream of Friant Dam, and in the tributaries such as Stanislaus, Tuolumne, and Merced Rivers upstream to their respective dams.

Other potential migration barriers include structures such as the Red Bluff Diversion Dam, Sacramento Deep Water Ship Channel locks, Sutter Bypass, and Delta Cross Channel Gates on the Sacramento River, and Shanghai Bend and Sunset Pumps on the Feather River (70 *Federal Register* [FR] 17386). The Red Bluff Diversion Dam was a migration barrier for sturgeon on the Sacramento River (U.S. Fish and Wildlife Service 1995). Adult sturgeon could migrate past the Red Bluff Diversion Dam when gates are raised between mid-September and mid-May to allow passage of winter-run Chinook salmon. However, tagging studies by Heublein et al. (2006) found that, when the gates were closed, a substantial portion of tagged adult green sturgeon failed to use the fish ladders at the dam and were, therefore, unable to access upstream spawning habitats. The same behavioral response may be true for white sturgeon. However, the new pumping plant was built and allows the gates to be open year round, allowing migration (USBR 2011). A set of locks at the end of the Sacramento River Deep Water Ship Channel at the connection with the Sacramento River reportedly blocks the migration of all fish from the deep water ship channel back to the Sacramento River (California Department of Water Resources 2005).

Delta Cross Channel gate closures occur during the winter and early spring months (February through May) during sturgeon migration. The seasonal closure of the Delta Cross Channel gates is required by the State Water Resources Control Board water right Decision 1641 (D-1641) as a measure designed to improve the survival of downstream migrating juvenile Chinook salmon. Upstream migrating adult Chinook salmon are known to use the Delta Cross Channel as a migratory pathway when the gates are open (Hallock et al. 1970). When the gates are open, Sacramento River water flows into the central Delta providing migration cues. It is likely that attraction to flows passing into the central Delta from the Sacramento River causes migration delays and straying of white sturgeon, as it does to Chinook salmon (CALFED Bay-Delta Program 2001; McLaughlin and McLain 2004). Gate closures completely block juvenile and adult sturgeon migration.

The Fremont Weir is located at the upstream end of the Yolo Bypass, a 40-mile (64 kilometer)-long basin that functions as a flood control facility on the Sacramento River. When the Yolo Bypass is inundated by flood water, white sturgeon are attracted into the bypass and become trapped behind the Fremont Weir, which acts as a barrier and impediment to upstream migration (California Department of Water Resources 2005). Sturgeon that are trapped by the weir are then subject to heavy legal and illegal fishing pressure, or become stranded behind the flashboards when the flows recede. The current Fremont and Sacramento weirs create stranding and poaching problems for white sturgeon and green sturgeon (Israel et al. 2009; Israel and Klimley 2008). Sturgeon can also be attracted to small pulse flows and trapped during the descending hydrograph (Harrell and Sommer 2003). Efforts to improve passage and redesign weirs would reduce poaching and stranding. Methods to reduce stranding and increase passage have been investigated by DWR and CDFW. Between 2002 and 2006, approximately 50 sturgeon (no species identification given) were rescued over the course of four rescue operations at the Fremont Weir. In 2011, 14 green sturgeon and 19 white sturgeon were rescued at the Fremont Weir (Healey and Vincik 2011).

Exact white sturgeon spawning locations in Feather River are unknown; however, based on angler catches, most spawning is believed to occur downstream of Thermalito Afterbay and upstream of Cox's Spillway, just downstream of Gridley Bridge. Potential physical barriers to upstream migration include the rock dam associated with Sutter Extension Water District's sunrise pumps, shallow water caused by a head cut at Shanghai Bend, and several shallow riffles between the confluence of Honcut Creek upstream to the Thermalito Afterbay outlet (U.S. Fish and Wildlife Service 1995). These structures are likely to present barriers or impediments during low-flow periods that block and or delay upstream sturgeon migration to spawning habitat.

11A.9.5.3.2 Rearing Habitat

Historical reclamation of wetlands and islands has reduced and degraded suitable in- and off-channel rearing habitat for white sturgeon. Furthermore, the channelization and hardening of levees with riprap has reduced in- and off-channel intertidal and subtidal rearing habitat as well as seasonal inundation of floodplains. The resulting changes to river hydraulics, riparian cover, and geomorphology affect important ecosystem functions (Sweeney et al. 2004). Because juvenile and adult white sturgeon feed primarily on benthic organisms such as clams and shrimp, habitat-related impacts of reclamation, channelization, and riprapping would be expected to contribute to ecosystem related impacts, such as changes in the availability of food sources and altered predator densities. The impacts of channelization and riprapping are thought to affect larval, post-larval, juvenile, and adult stages of sturgeon, as these life stages are dependent on the freshwater and estuarine foodwebs in the rivers and Delta.

The availability of rearing habitat is affected by water quality, including temperature and dissolved oxygen levels. Dissolved oxygen also affects the temperature tolerance of sturgeon, and is therefore important for sturgeon occurrence and habitat use throughout Delta habitats. Depressed levels of dissolved oxygen (less than 5 milligrams per liter [mg/L]) can also lead to increased stress levels, decreased feeding activity, and elevated mortality in sturgeon (Crocker and Cech 1997; Secor and Nkilitschek 2001; Israel and Klimley 2008; Israel et al. 2009).

11A.9.5.4 Dredging

Hydraulic dredging to allow commercial and recreational vessel traffic is a common practice in the navigational channels of the San Francisco, San Pablo, and Suisun Bays; the Delta; and the Sacramento and San Joaquin Rivers. White sturgeon are at risk of entrainment from dredging, with young-of-the-year fish at greatest risk (Boysen and Hoover 2009). Studies by Buell (1992) reported approximately 2,000 sturgeon entrained in the removal of one million tons of sand from the bottom of the Columbia River at depths of 60 to 80 feet (18 to 24 meters). In addition, dredging operations can result in the resuspension of toxics such as ammonia[7], hydrogen sulfide, and copper as a result of both dredging and dredge spoil disposal, and alter channel bathymetry and current patterns (National Marine Fisheries Service 2006).

11A.9.5.5 Water Temperature

Water temperature is considered important and potentially limiting for all life stages of white sturgeon (Israel et al. 2009). Juvenile and adult white sturgeon are tolerant of higher temperatures,

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[7] Ammonia in water generally forms some amount of ammonium. Therefore, the use of the term *ammonia* implies that both ammonia and ammonium may be present.

although they appear to show signs of stress at temperatures at and above 68°F (20°C) (Cech et al. 1984; Geist et al. 2005). Elevated water temperatures can reduce the suitability of spawning habitat and white sturgeon egg and embryo development and survival. Exposure to water temperatures greater than 63°F (17.2°C) has also been shown to increase sturgeon egg and larval mortality (Pacific States Marine Fisheries Commission 1992).

Water temperatures in the upper Sacramento River near the Red Bluff Diversion Dam historically occurred within optimum ranges for sturgeon reproduction; however, temperatures downstream, especially later in the spawning season, were reported to be frequently above 63°F (17.2°C) (U.S. Fish and Wildlife Service 1995). Concern regarding exposure to high temperatures in the Sacramento River during the February to June period has been reduced in recent years because temperatures in the upper Sacramento River are actively managed for Sacramento River winter-run Chinook salmon. The Shasta temperature control device, (installed at Shasta Dam in 1997), cold water pool management in Lake Shasta, and higher reservoir storage have all contributed to cooler water temperature conditions in the upper Sacramento River where white sturgeon spawning and juvenile rearing are thought to occur.

Water temperatures in the lower Feather River may be inadequate for sturgeon spawning and egg incubation as the result of releases of warmed water from Thermalito Afterbay (Surface Water Resources, Inc. 2003). The warmed water may be one reason that neither green nor white sturgeon are found in the river in low-flow years (California Department of Fish and Game 2002). Exposure to elevated water temperatures in the Feather River downstream of Thermalito Afterbay is thought to be a factor affecting habitat value and availability for sturgeon spawning and juvenile rearing on the lower Feather River (California Department of Fish and Game 2002).

Reduced flow on the San Joaquin River resulting from dam and diversion operations contributes to seasonally elevated water temperatures in the mainstem San Joaquin River, particularly during late summer and fall. Although these effects are difficult to measure, water temperatures in the lower San Joaquin River during spring months continually exceed preferred temperatures for sturgeon migration and development. Temperatures at Stevenson on the San Joaquin River near the Merced River confluence as recorded on May 31 (spawning typically occurs February to June) between 2000 and 2004 ranged from 77 to 82°F (25 to 27.8°C) (California Department of Water Resources 2007). Juvenile sturgeon are also exposed to increased water temperatures in the Delta during the late spring and summer, in part as a result of the loss of riparian shading and by thermal inputs from municipal, industrial, and agricultural discharges. Seasonally elevated water temperature in the San Joaquin River and in the Delta has been identified as a factor affecting habitat value and availability for sturgeon migration, spawning, and juvenile rearing.

11A.9.5.6 Turbidity

Turbidity levels in the Delta have decreased over the past few decades (Jassby et al. 2002). This reduction may have had detrimental effects on white sturgeon. Gadomski and Parsley (2005) found that larval white sturgeon predation by prickly sculpin was greater with reduced turbidity. However, larval sturgeon are found close to spawning locations generally upstream of the Delta, where turbidity is already lower than in the Delta.

The relationship between turbidity and the vulnerability of various life stages of white sturgeon to predation has not been established the Delta. The dense colonization of local areas in the Delta by introduced species of submerged aquatic vegetation (SAV) such as Brazilian waterweed (*Egeria* *densa*) has been shown to be associated with increased water clarity (e.g., resulting from trapping and settlement of suspended sediments). Increased water clarity may contribute to increased vulnerability of sturgeon to predation. However, juvenile white sturgeon are expected to be less vulnerable to predation than other estuarine fish due to their scutes and protective armoring. In addition, the large size of subadult and adult white sturgeon further reduces their vulnerability to predation. As a result of these factors, the potential increase in vulnerability to predation due to localized reductions in turbidity is expected to be minor relative to other covered fish species.

11A.9.5.7 Exposure to Toxins

Water quality in the Sacramento and San Joaquin Rivers and the Delta is influenced by a variety of point and nonpoint source pollutants from urban, industrial, and agricultural land uses. Runoff from residential, agricultural, and industrial areas introduces pesticides, oil, grease, heavy metals, other organics, and nutrients that contaminate drainage waters and deteriorate the quality of aquatic habitats necessary for white sturgeon survival (National Marine Fisheries Service 1996; Central Valley Regional Water Quality Control Board 2007).

Organic contaminants from agricultural returns, urban and agricultural runoff from storm events, and high concentrations of trace elements, such as boron, selenium, and molybdenum, have been identified as factors that decrease sturgeon early life stage survival, causing abnormal development and high mortality in yolk-sac fry sturgeon at concentrations of only a few parts per billion (ppb) (U.S. Fish and Wildlife Service 1995; California Regional Water Quality Control Board 2004). Principal sources of organic contamination in the Sacramento River are rice field discharges from Butte Slough, Reclamation District 108, Colusa Basin Drain, Sacramento Slough, and Jack Slough (U.S. Fish and Wildlife Service 1995).

In recent years, changes have been made in the composition of herbicides and pesticides used on agricultural crops in an effort to reduce potential toxicity to aquatic and terrestrial species. Modifications have also been made to water system operations and discharges related to agricultural wastewater (e.g., agricultural drainage water system lock-up and holding prior to discharge) and municipal wastewater treatment and discharges. Concerns remain, however, regarding the toxicity to sturgeon of contaminants absorbed by sediments, such as pyrethroids and other chemicals including selenium and mercury.

Potamocorbula and other introduced clams that are now prominent in the diet of sturgeon are benthic filter feeders that can accumulate various toxic substances, such as selenium, mercury, and other compounds, in their tissue. *Potamocorbula*, due to its high filtration efficiency, accumulates selenium in high concentrations and loses it slowly (Luoma and Presser 2000; Linville et al. 2002). As a result, concentrations of selenium in white sturgeon have been observed at greater than threshold levels at which toxic effects have been observed in other fish species (Lemly 2002). Dietary selenium in high concentrations can adversely affect white sturgeon survival, activity, and growth (Tashjian et al. 2006).

The extent to which toxic pollution has affected the population of white sturgeon is unknown. White sturgeon is a long-lived species that feeds on invertebrates, such as clams and shrimp, and is vulnerable to the effects of toxicant bioaccumulation on the health and condition of sub-adult and adult sturgeon and their reproductive success in the estuary. However, sturgeon do not readily concentrate lipid-soluble toxins such as polychlorinated biphenyls (PCBs). Greenfield et al. (2003) found that dichlorodiphenyltrichloroethane (DDT) and chlordane concentrations in white sturgeon tissues have declined since the 1980s, while selenium concentrations have remained elevated. High levels of selenium can also be found in some white sturgeon prey (Johns and Luoma 1988; White et al. 1988), including *Potamocorbula* (Urquhart and Regalado 1991), as well as in sturgeon muscle, liver, and eggs (White et al. 1987, 1988, 1989; Kroll and Doroshov 1991; Urquhart and Regalado 1991). Early life history stages are especially sensitive to contaminant uptake (Kruse and Scarnecchia 2002), but the effects on the different life history stages of white sturgeon of contaminants, other than selenium, at concentrations found in the San Francisco Bay estuary are unknown, as are any additive or synergistic effects of multiple contaminants.

11A.9.5.8 Invasive Aquatic Vegetation

Introductions of nonnative invasive plant species such as water hyacinth (*Eichhornia crassipes*) and *Egeria* have altered habitat in the Delta and Suisun Bay and have affected local assemblages of fish in the Delta (Nobriga et al. 2005). *Egeria* forms thick “walls” along the margins of channels and shallow water habitat in the Delta. This growth may prevent juvenile sturgeon from accessing shallow water habitat along channel edges. By reducing water velocities near plants, these species reduce turbidity in the water column, potentially exposing sturgeon to higher predation risk. Dissolved oxygen levels beneath the mats often drop below suitable levels for fish due to the increased amount of decaying vegetative matter produced from the overlying mat and diel respiration by aquatic plants.

11A.9.5.9 Harvest

White sturgeon is a popular game species in the Delta and Sacramento River and supports a commercial fishery in estuaries in Oregon and Washington. In California, the recreational fishery for white sturgeon is open all year, but anglers are limited to three fish per year between 46 inches and 66 inches total length, and CDFW has established large closure areas (Section 27.90, Title 14 California Code of Regulations). Nevertheless, some illegal harvest occurs, particularly in areas where sturgeon have been stranded (e.g., Fremont Weir), as well as throughout the Delta.

The effects of legal and illegal harvest on the population dynamics and abundance of white sturgeon in the Delta are largely unknown. The small population of white sturgeon inhabiting the San Joaquin River experiences heavy fishing pressure, particularly from illegal fishing (U.S. Fish and Wildlife Service 1995). In addition, areas just downstream of Thermalito Afterbay outlet, Cox’s Spillway, and several barriers impeding sturgeon migration on the Feather River, may be areas of high adult mortality from fishing and poaching. Poaching of white sturgeon females is a type of poaching that could be particularly detrimental to the white sturgeon population because it targets the oldest and largest adults with the highest fecundity, which affects both current and future stocks.

11A.9.6 Relevant Conservation Efforts

The Central Valley Project Improvement Act’s Anadromous Fish Restoration Program has a goal of supporting efforts that lead to doubling the natural production of anadromous fish in the Central Valley on a sustainable, long-term basis, at levels not less than twice the average abundance reported during the period of 1967 to 1991. Though most efforts of the program have focused on Chinook salmon as a result of their listing history and status, sturgeon may receive some unknown incidental amount of benefit from these restoration efforts. For example, the acquisition of water for flow enhancement on tributaries to the Sacramento River, spawning gravel augmentation, fish screening for the protection of Chinook salmon and Central Valley steelhead, or riparian revegetation and instream restoration projects would likely have ancillary benefits to sturgeon.

Many beneficial actions have originated and been funded by the CALFED Bay-Delta Program (CALFED), including such projects as floodplain and instream restoration, riparian habitat protection, fish screening and passage projects, research regarding nonnative invasive species and contaminants, restoration methods, watershed stewardship, education, and outreach programs. Both the Central Valley Project Improvement Act and CALFED programs that target anadromous fish, particularly Chinook salmon and Central Valley steelhead (69 FR 33102), also may benefit sturgeon. Activities include fish screen evaluation and construction projects, restoration evaluation and enhancement activities, contamination studies, and dissolved oxygen investigations related to the San Joaquin River Deep Water Ship Channel.

New sport fishing regulations adopted over the past several years are designed to reduce sturgeon legal harvest rates. In addition, increased enforcement is expected to reduce illegal harvest. Collectively, these actions should reduce the impact of overall harvest on the white sturgeon population (Section 27.90, Title 14 California Code of Regulations).

11A.9.7 Recovery Goals

No recovery plan has been prepared for white sturgeon because the species is not listed under the ESA or CESA.

11A.9.8 References Cited

11A.9.8.1 Literature Cited

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11A.10 Pacific Lamprey (*Entosphenus tridentatus*)

11A.10.1 General

Pacific lamprey is the most widely distributed lamprey species on the west coast of the United States. The species occurs from Hokkaido Island, Japan (Morrow 1980) along the Pacific Rim to Rio Santo Domingo, Baja California, Mexico (Ruiz-Campos and Gonzalez-Guzman 1996). A single individual was caught in 1889 offshore of Clarion Island, Revillagigedo Islands, Mexico, approximately 386 kilometers (294 miles) southwest of Cabo San Lucas (Renaud 2008). Individuals inhabit major river systems, including the Columbia, Fraser-Trinity, Klamath, Eel, and Sacramento-San Joaquin Rivers and tributaries, as well as smaller coastal streams. Oceanic adults are thought to remain relatively close to the mouths of their home spawning streams where host/prey concentrations may be higher (Moyle 2002). Although still widely found in many of its native areas, it does not occur in the numbers that it once did. Large runs today are rare as evidenced from declining tribal fisheries for this species. In general, populations south of San Luis Obispo are scattered and irregular, although a regular run occurs on the Santa Clara River (Swift et al. 1993). Populations may exist in other rivers, but are often overlooked and have been the subject of few targeted sampling efforts (Moyle 2002). The species is usually absent from highly altered or polluted streams within its geographic range, although it appears to be persistent in currently occupied suitable streams (Moyle 2002).

11A.10.2 Legal Status

The Pacific lamprey is not listed under the California Endangered Species Act (CESA) or federal Endangered Species Acts (ESA).

A broad group of west coast conservation organizations petitioned the U.S. Fish and Wildlife Service (USFWS) on January 27, 2003 to list Pacific lamprey, along with three other lamprey species on the West Coast, as threatened or endangered (Klamath-Siskiyou Wildlands Center et al. 2003). However, the petition was declined in a 90-day finding on December 27, 2004, citing insufficient evidence that listing was warranted (69 *Federal Register* [FR] 77158).

11A.10.3 Distribution and Abundance

In the Central Valley, Pacific lamprey occurs in the Sacramento and San Joaquin Rivers (Moyle 2002) and many of their tributaries including the Stanislaus, Tuolumne, Merced, and King Rivers (Brown and Moyle 1993) (69 FR 77158) (Figure 2A.10-1). Individuals emigrating from Sacramento and San Joaquin River watersheds pass through the Plan Area during winter and spring on their way to the Pacific Ocean. Emigrating adults pass through the Plan Area on their way upstream towards spawning grounds between March and June. It is unknown to what extent Pacific lamprey use the Plan Area for purposes other than a migration corridor, but some studies (Brown and Michniuk 2007) have found ammocoetes within Sacramento–San Joaquin River Delta (Delta) sloughs, especially in the North Delta subregion. Adults migrate within the ocean, but it seems that most adult Pacific lamprey remain in tidally influenced areas of rivers and within estuaries where they feed and grow.

Population trends are unknown in California, although anecdotal evidence indicates that populations have been in decline (Moyle 2002) (69 FR 77158). There are no monitoring programs that target Pacific lamprey in the Delta and those that catch Pacific lamprey do not catch them regularly enough to establish trends through time. In addition, Pacific lamprey are inconspicuous and often overlooked, and ammocoetes can be difficult to distinguish from ammocoetes of the co-occurring river lamprey (Webb pers. comm.).

11A.10.4 Life Stages

Moyle (2002) describes five general life stages of Pacific lamprey. Streif (2008) described seven similar life stages. Table 2A.10-1 compares the Pacific lamprey life stages of Moyle (2002), Streif (2008), and the BDCP.

Table 2A.10-1. Pacific Lamprey Life Stages

Moyle 2002	Streif 2008	BDCP
Egg/embryo	Eggs	Egg/embryo
Larvae (ammocoetes)	Ammocoetes	Larvae (ammocoetes)
Juveniles (macropthalmia)	Macropthalmia	Juveniles (macropthalmia)
Adult/ocean predator	Adult/parasitic	Adult/ocean predator
Adult/spawner	Adult/spawner	Adult/spawner

11A.10.5 Life History

Pacific lamprey are anadromous, beginning their migration into fresh water towards upstream spawning areas primarily between early March and late June, although upstream movements in January and February have also been observed (Moyle 2002). Most upstream migration occurs at night and in pulses. The habitat requirements of Pacific lamprey have not been well studied, but, like salmonids, spawning adults need clean, gravelly riffles in permanent streams to spawn successfully

(Moyle 2002). There is some evidence that Pacific lamprey in larger river systems, such as the Klamath and Eel Rivers, have distinct runs similar to Chinook salmon (Moyle 2002).

Both sexes contribute to nest construction by removing larger stones from gravel or cobble substrate, creating a shallow depression. These simple nests occur in gravelly substrata at a depth of 30 to 150 centimeters (12 to 59 inches) with moderately swift currents and water temperatures typically of 12 to 18°C (53.6 to 64.4°F) (Moyle 2002). External fertilization of eggs occurs just in front of the nest, after which the fertilized eggs wash into the nest. Fecundity is unknown, but has been estimated at 98,000 to 238,400 eggs per female (Close et al. 2002). Spawning is repeated until both individuals are spent. Adults typically die after spawning.

It is unknown whether migrating adults cue solely on ammocoete (larvae) pheromones or on other upstream cues to guide them to natal streams to spawn. It is thought that if they cue solely on ammocoete pheromones, extirpation of local populations could have large effects on recolonization of natal streams (Luzier et al. 2009).

Eggs hatch into ammocoetes after approximately 19 days at 15°C (59°F) (Moyle 2002). The ammocoetes spend a short time in the nest, and then drift downstream, where they live in silty backwaters and eddies with muddy or sandy substrate into which they burrow. Ammocoetes remain in fresh water for approximately 5 to 7 years, where they feed on algae, organic material, and microorganisms. Meeuwig et al. (2004) found significant death or deformation of eggs and early stage ammocoetes in water greater than 22°C (72°F). Therefore, degraded streams with a water temperature greater than 22°C during early and midsummer while lamprey spawn and young ammocoetes develop could pose a problem for Pacific lamprey in the Sacramento–San Joaquin drainage (Luzier et al. 2009). Ammocoetes are found throughout all of the Delta, although no abundance estimates exist from Delta sampling programs.

Ammocoetes begin metamorphosis into macropthalmia (juveniles) when they reach 14 to 16 centimeters (5.5 to 6.3 inches) total length. Individuals develop external features (eyes, oral disc, and color changes) and experience internal and physiological changes that prepare them for their predatory life stage in the ocean (McPhail and Lindsey 1970). Downstream migration begins upon completion of this metamorphosis, generally coinciding with high-flow events in winter and spring (Moyle 2002).

Adults spend 3 to 4 years in the ocean in British Columbia, but in more southern areas this time period is likely shorter (Moyle 2002). Adults remain close to the mouths of the rivers from which they came, likely because their prey is most abundant in estuaries and other coastal areas (Moyle 2002). Individuals prey on a wide variety of fishes, including salmon, Pacific herring, and flatfishes in the ocean (Beamish 1980). Reduced availability of host/prey organisms in the ocean as a result of poor ocean conditions may negatively affect lamprey survival and growth, although very little is known about the oceanic stage of Pacific lamprey (Luzier et al. 2009).

11A.10.6 Threats and Stressors

A number of threats and stressors exist for Pacific lamprey. Stressor rankings and the certainty associated with these rankings for Pacific lamprey are provided in Chapter 5 of the BDCP. The discussion below outlines some of the main threats and stressors to Pacific lamprey.

11A.10.6.1 Habitat Loss and Habitat-Changing Structures

The high density and limited mobility of lamprey ammocoetes in streams can potentially make them more vulnerable to channel alterations such as channelization, loss of riffle and side channels, and scouring (Streif 2007; Luzier et al. 2009). Loss or alteration of habitat can also limit spawning if it occurs in spawning reaches.

Artificial barriers, including dams, culverts, water diversions, tidal gates, and other barriers, can impede or completely block the upstream migration of adults to spawning grounds. These structures also can impede or completely block the downstream migration of ammocoetes and macropthalmia towards the ocean (Luzier et al. 2009). Lamprey tend to out-migrate deeper in the water column such that traditional spill gates meant to aid migration of salmonids may not be effective for lamprey and may block passage (Moursund et al. 2003). Lamprey adults may have difficulty passing over barriers using ladders and other passage structures designed for salmonids, possibly due to high water velocity, sharp angles, culverts with drop-offs, or insufficient resting areas (Kostow 2002). Pacific lamprey populations cannot persist for more than a few years above impassable barriers (Beamish and Northcote 1989).

Rapid changes in stream flows resulting from reservoir management can dewater streambeds and strand ammocoetes residing in the substrate. Water diversions and instream construction projects, such as culvert replacements, may also dewater reaches of streams and strand ammocoetes (Streif 2007). Because Pacific lamprey ammocoetes burrow in upstream sediments for 5 to 7 years in high densities, a dewatering event may affect multiple age classes burrowing together in a single stream reach (Luzier et al. 2009). Hydroelectric projects and water diversions may entrain or impinge weak-swimming macropthalmia (Moursund et al. 2003).

Dredging associated with channel or irrigation screen maintenance and mining may affect many age classes at once due to their “colonial” nature and long upstream life stage (5 to 7 years) (Luzier et al. 2009). Beamish and Youson (1987) found that only 3 to 26% of lamprey that pass through a dredge survive. Further, it has been suggested that suction dredge mining was responsible for the decline or even loss of populations in some basins (Kostow 2002).

11A.10.6.2 Climate Change

Future climate change is expected to further increase water temperatures and modify the timing of flow-related environmental cues upon which Pacific lamprey rely for life history events (e.g., out-migration, spawning) (Luzier et al. 2009).

11A.10.6.3 Toxins

Ammocoetes spend 5 to 7 years living in silty areas that accumulate high levels of toxins. As a result, lamprey tend to have high body burdens of toxins relative to other fish species (Haas and Ichikawa 2007; Bettaso and Goodman 2008). Despite this apparent tolerance for high levels of toxins, lamprey are susceptible to toxicity (Kostow 2002).

11A.10.6.4 Predation

Mammals, birds, and other fish species consume lamprey at all life stages (Luzier et al. 2009). Pacific lamprey are thought to be preyed upon in the ocean by sharks, other fish, otters, seals, and sea lions (Roffe and Mate 1984; Moyle 2002). Ammocoetes are consumed by terrestrial mammals and birds, fish, and other species. Many nonnative species, including striped bass, sturgeon, centrarchids, and catfish, are believed to consume juvenile and adult lamprey and may pose a threat to population sizes (Streif 2007; Luzier et al. 2009; Baxter et al. 2008).

11A.10.6.5 Harvest

The extent to which harvest has a population-level effect on Pacific lamprey has not been well studied, but could represent a large proportion of spawning adults because Pacific lamprey adults and ammocoetes are harvested for use as bait to catch other species (Luzier et al. 2009). In addition, Pacific lamprey is important to tribes on the Pacific Coast for sustenance, medicine, and ceremonial purposes (Close et al. 2002). The use of Pacific lamprey for food and commercial purposes has declined from historical levels, and Washington and Oregon have banned harvest for bait. However, harvest has not declined in California, where there are no regulations on lamprey harvest (69 FR 77158).

11A.10.7 Relevant Conservation Efforts

Along with several tribes, state and federal agencies are increasingly incorporating Pacific lamprey into management and monitoring plans to increase the overall body of knowledge and conserve the species. There has been work in the Columbia River Basin to modify new or existing ladders and structures to facilitate lamprey passage, such as creating holding areas where lamprey can rest (Columbia River Basin Lamprey Technical Workgroup 2004). The Pacific Lamprey Conservation Initiative, led by USFWS, was initiated in 2007 to “facilitate communication and coordination relative to the conservation of Pacific lampreys throughout their range” (U.S. Fish and Wildlife Service 2007). The CALFED Bay-Delta Program Ecosystem Restoration Program designated the entire lamprey family as “Enhance and/or Conserve” (CALFED Bay-Delta Program 2000). This designation indicates that the program will undertake actions to conserve and enhance their abundance and distribution and the community diversity in which they live for their long-term stability.

11A.10.8 Recovery Goals

A recovery plan has not been prepared for Pacific lamprey because the species is not listed under the ESA or CESA.

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11A.10.9.2 Personal Communication

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11A.11 River Lamprey (*Lampetra ayresii*)

11A.11.1 General

River lamprey is an anadromous species that occurs from near Juneau, Alaska, to San Francisco Bay, California (Moyle 2002). Outside of California, there are widely scattered and isolated populations throughout its range. River lamprey are common in British Columbia, the center of their geographic range. In California, river lamprey is found in the Central Valley, Napa River, Sonoma Creek, Alameda Creek, Salmon Creek, and in tributaries of the lower Russian River (Figure 2A.11-1). In the Central Valley, river lamprey is found in small numbers in the lower Sacramento and San Joaquin River drainages, including the Stanislaus and Tuolumne Rivers. They may exist in other tributaries of these rivers, but are often overlooked and have been the subject of few targeted sampling efforts (Moyle 2002). Population trends are unknown in California, although declines are thought to have occurred concurrently with freshwater habitat degradation (Moyle 2002).The species appears to be more abundant in the Sacramento–San Joaquin River system than in other streams in California.

11A.11.2 Legal Status

The river lamprey is not listed under the federal Endangered Species Act (ESA) or the California Endangered Species Act (CESA). On January 27, 2003, a broad group of West Coast conservation organizations petitioned the U.S. Fish and Wildlife Service (USFWS) to list river lamprey, along with three other lamprey species on the West Coast, as threatened or endangered (Klamath-Siskiyou Wildlands Center et al. 2003). However, the petition was declined in a 90-day finding on December 27, 2004, citing insufficient evidence that listing was warranted (69 *Federal Register* [FR] 77158).

11A.11.3 Distribution and Abundance

River lamprey individuals outmigrating from Sacramento and San Joaquin River watersheds pass through the Sacramento–San Joaquin River Delta (Delta) on their way to the Pacific Ocean, and emigrating adults pass through the Plan Area on their way upstream towards spawning grounds. The extent to which river lamprey use the Plan Area for purposes other than a migration corridor is unknown. However, outmigrating lamprey macropthalmia (juveniles) in the final stages of metamorphosis to adults hold just upstream of salt water until late spring. In most years, except for very wet years when the low-salinity zone is below the Carquinez Straight, this location would be in the Plan Area.

There are no monitoring programs that target river lamprey in the Delta and those that catch river lamprey do not catch them regularly enough to establish trends through time. River lamprey are inconspicuous, often overlooked, and ammocoetes (larvae) can be difficult to distinguish from ammocoetes of the co-occurring Pacific lamprey.

11A.11.4 Life Stages

Moyle (2002) describes seven life stages of river lamprey. Table 2A.11-1 compares the life stages of Moyle (2002) with those of the BDCP.

Table 2A.11-1. River Lamprey Life Stages

Moyle 2002	BDCP
Egg/embryo	Egg/embryo
Larvae/ammocoetes	Ammocoetes
Macropthalmia (juveniles)	Macropthalmia (juveniles)
Adult/ocean predator	Adult/ocean predator
Adult/spawner	Adult/spawner

11A.11.5 Life History

The biology of the river lamprey has not been well studied in California. As a result, much of this account is derived from information known for river lamprey from British Columbia. The fish in these two locations may have dissimilar life histories because of differences in physical factors (e.g., temperature, hydrology).

River lamprey are anadromous, but spend most of their lives in fresh water. Adults spend only 3 to 4 months in the ocean, migrating to freshwater in fall in search of suitable spawning sites, often returning to their natal streams (Moyle et al. 1995; Moyle 2002). Exact spawning locations are not known, although spawning habitat requirements are thought to be similar to those of salmonids. Spawning occurs from February through June in gravelly riffles in which individuals dig saucer-shaped depressions (Moyle 2002). Adults die after spawning. Fecundity is not well documented, but a study of two females in Cache Creek reported that one female about 23 centimeters (9 inches) total length produced approximately 11,400 eggs and another of 17.5 centimeters (7 inches) total length produced approximately 37,300 eggs (Vladykov and Follett 1958).

The eggs hatch into ammocoetes that remain in fresh water for approximately 3 to 5 years in silty or sandy low-velocity backwaters or stream edges where they bury into the substrate, tail first, and filter-feed on algae, detritus, and microorganisms (Moyle 2002). Ammocoetes begin metamorphosis into macropthalmia and then adults during summer at approximately 12 centimeters (4.7 inches) total length. This process takes 9 to 10 months during which individuals may shrink in length by up to 20% (Moyle 2002).

Prior to entering the ocean, macropthalmia congregate just upstream of salt water until their esophagus opens (Beamish and Youson 1987). Once the esophagus is opened, new adults can properly osmoregulate and can then enter the ocean (Moyle 2002). Adults spend approximately 3 to 4 months in the ocean where they grow rapidly to 25 to 31 centimeters (9.8 to 12.2 inches) total length. If the ammocoete stage is 3 to 5 years, the total life span of river lamprey is estimated to be 6 to 7 years (Moyle et al. 1995).

River lamprey adults are parasitic during both freshwater and saltwater phases. Adults feed on a variety of host fish species that are of small to intermediate sizes (4 to 12 inches [10.2 to 30.5 centimeters] total length) (Moyle et al 1995), the most common of which are thought to be herring and juvenile salmon (Beamish and Youson 1987). In Canada, predation by river lamprey is a significant cause of salmon mortality (Beamish and Neville 1995). Individuals feed by attaching to the back of their prey above the lateral line and eating the muscle tissue, even after the host fish dies (Moyle 2002). More than one lamprey can attach to a host salmon (Beamish and Youson 1987).

The habitat requirements of river lamprey are not well documented. It is thought that adults need clean, gravelly riffles in permanent streams to spawn successfully. These requirements are thought to be similar to those of salmonids. Ammocoetes live in silty backwaters and eddies with muddy or sandy substrate into which they burrow (Moyle et al. 1995). Ammocoetes require water temperatures lower than 25°C (77°F) (Moyle et al. 1995).

Although generally considered anadromous, river lamprey can live in fresh water as adults. For example, the population of river lamprey living in land-locked upper Sonoma Creek may spend their entire lives in fresh water. Most adults remain in tidally influenced areas of rivers and in estuaries where the concentration of potential host fishes is greatest.

11A.11.6 Threats and Stressors

A number of threats and stressors exist for River lamprey. Stressor rankings and the certainty associated with these rankings for River lamprey are provided in Chapter 5 of the BDCP. The discussion below outlines some of the main threats and stressors to River lamprey. There have been no formal evaluations conducted that assess the threats and stressors to river lamprey. Therefore, much of the following discussion has been derived from the co-occurring Pacific lamprey.

11A.11.6.1 Habitat Loss and Habitat-Changing Structures

The primary threat to river lamprey is thought to be loss or degradation of habitat resulting from dams, diversions, toxics, stream channelization, dredging, and urbanization (Moyle et al. 1995; Luzier et al. 2009). Dams have altered flows in channels and limited access to spawning grounds. Stream channelization, dredging, and diversions have altered flow patterns and rates in channels. Urbanization has degraded habitat by increasing loads of certain toxics, changing runoff patterns, and altering the configuration of some channels. Future climate change is expected to further increase water temperatures and modify the timing of flow-related environmental cues upon which lamprey rely for life history events (e.g., outmigration, spawning).

Large dams and other habitat modifications remain barriers to migration. Lamprey may have difficulty passing over barriers using ladders and other passage structures designed for salmonids, possibly due to high water velocity, sharp angles, culverts with drop-offs, or insufficient rest areas (Kostow 2002). There has been some work in the Columbia River basin to modify new or existing ladders and structures to facilitate lamprey passage, such as creating holding areas where lamprey can rest (Columbia River Basin Lamprey Technical Workgroup 2004).

11A.11.7 Relevant Conservation Efforts

There have been very few efforts to conserve river lamprey in the Central Valley of California. The CALFED Bay-Delta Program Ecosystem Restoration Program designated the entire lamprey family as Enhance and/or Conserve (CALFED Bay-Delta Program 2000). This designation indicates that the program will undertake actions to conserve and enhance their abundance and distribution and the community diversity in which they live for their long-term stability.

River lamprey is currently listed as a covered species under the *Butte Regional Conservation Plan*. (Butte County Association of Government 2012), but specific conservation measures have not yet been written.

11A.11.8 Recovery Goals

A recovery plan has not been prepared for this species and no recovery goals have been established because the species is not listed under the ESA or CESA.

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