Appendix 11A Aquatic Species Life Histories

Appendix 11A Aquatic Species Life Histories

The species descriptions in this appendix were adapted from recent documents such as the Department of Water Resources (DWR) (2019) Incidental Take Permit (ITP) Application for Long-Term Operation of the State Water Project (SWP) and its associated Final Environmental Impact Report (EIR) (California Department of Water Resources 2020), the Biological Assessment (BA) and associated Final Environmental Impact Statement (EIS) for the Reinitiation of Consultation on the Coordinated Long-Term Operations of the Central Valley Project (CVP) and SWP (Reclamation 2019), and the California WaterFix BA (ICF International 2016a) and ITP Application (ICF International 2016b). Updates to some descriptions have been provided to reflect newer information.

11A.1 Species Descriptions

A species' listing status may only apply to a distinct population segment (DPS) or evolutionarily significant unit (ESU). The designation of a DPS is dependent on the discreteness of a population with respect to the remainder of the species to which it belongs and its significance to the species. An ESU represents a population of a species that is substantially reproductively isolated from other populations and contributes an important evolutionary legacy of the species.

11A.1.1. Delta Smelt

11A.1.1.1. Legal Status

Delta smelt (*Hypomesus transpacificus*) was listed as a threatened species under the California Endangered Species Act (CESA) in 1993. An emergency petition was filed in February 2007 with 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. A 12-month finding on a petition to reclassify the delta smelt as an endangered species was completed by the California Department of Fish and Wildlife (CDFW) on April 7, 2010. After reviewing all available scientific and commercial information, the U.S. Fish and Wildlife Service (USFWS) determined that reclassifying the delta smelt from threatened to endangered was warranted but was precluded by other higher priority listing actions (U.S. Fish and Wildlife Service 2010).

11A.1.1.2. Life History and General Ecology

Delta smelt are endemic to the San Francisco Estuary and Sacramento–San Joaquin Delta (Delta) where the species primarily occupies open-water habitats in Suisun Bay, Suisun Marsh, and the Delta. On occasion, delta smelt distribution can extend up the Sacramento River to about Garcia Bend in the Pocket-Greenhaven neighborhood of Sacramento, the Sacramento Deepwater Ship Channel, up the San Joaquin River from Antioch to areas near Stockton, up the lower Mokelumne River system, and west throughout the Napa River. On rare occasion, delta smelt have been detected in San Francisco Bay, as far downstream as Berkeley (Merz et al. 2011).

Delta smelt is primarily an annual species, completing its life cycle in 1 year, which typically occurs from April to the following April. In captivity, delta smelt can survive to spawn at 2 years of age (Lindberg et al. 2013), but age-2 delta smelt are now rare in the wild (Bennett 2005; Damon et al. 2016).

Typically, delta smelt complete their entire life cycle within the low-salinity zone of the Upper San Francisco Estuary, in the tidal freshwater region of the Cache Slough Complex or move between the two regions of fresh water and low salinity (Bennett 2005; Sommer and Mejia 2013; Hobbs et al. 2019).[1] Komoroske et al. (2016) found that delta smelt can acclimate to salinities greater than 6 parts-per-thousand (ppt) in the laboratory, but observations of delta smelt presence in waters having salinities exceeding 6 ppt in the wild are comparatively rare (92% of fish caught are at salinity < 6 ppt; Komoroske et al. 2016). This could be because the osmoregulatory costs at such high salinities are too high to support growth and survival (Komoroske et al. 2016), or the discrepancy between field observations and laboratory observations may be evidence that delta smelt's distribution in the wild is due to a factor or factors other than salinity per se (U.S. Fish and Wildlife Service 2019:122).

Delta smelt spawning may occur at night with several males attending a female that broadcasts her eggs onto bottom substrate (Bennett 2005; Lindberg et al. 2020). Although preferred spawning substrate is unknown, spawning habits of the delta smelt's closest relative, surf smelt (*Hypomesus pretiosus*), in addition to experimental trials, suggest that sand or small pebbles may be the preferred substrate (Bennett 2005; Lindberg et al. 2020). Hatching success peaks at water temperatures of 15°C to 16°C (59.0 °F to 60.8°F), ceasing when water temperatures exceed 20°C (68.0°F) (Bennett 2005). Water temperatures suitable for spawning occur most frequently from March to May, but ripe female delta smelt have been observed as early as January and larvae have been collected as late as July (Damon et al. 2016). Most spawning occurs at 9°C to 18°C (48.2°F to 64.4°F) (Damon et al. 2016). Delta smelt appear to have one spawning season for each generation, which makes the timing and duration of the spawning season important every year. Damon et al. (2016) found all pre-spawn females achieved spawning size around April, which would result in only one spawn per female, with subsequent spawning events being rare except in exceptional years when the thermal spawning window extends past May. Prior studies suggested that spawning locations change based on hydrological conditions (reviewed by Bennett 2005:13). However, a more recent study indicated that the majority of regional movement from juvenile and subadult rearing locations to spawning areas occurs by January, spawning habitat locations are relatively constant within and between years, and no substantial further restructuring of the population at regional scales occurs after fish move to spawning locations (Polansky et al. 2018). The main spawning locations are in the lower Sacramento and San Joaquin Rivers, as well as the north Delta including the Cache Slough complex and Sacramento Deep Water Ship Channel (Polansky et al. 2018).

Although adult delta smelt can spawn more than once, as noted above, most spawning is complete by the time water temperature reaches 18°C (64.4°F) (Damon et al. 2016). The egg stage averages about 10 days before the embryos hatch into larvae (Bennett 2005). The larval

[1] The low-salinity zone is frequently defined as waters with a salinity range of about 0.5 to 6 parts per thousand (Kimmerer 2004).

stage averages about 30 days. Metamorphosing post-larvae appear in monitoring surveys from April into July of most years (Bennett 2005). By July, most delta smelt have reached the juvenile life stage. Delta smelt collected during the fall are considered subadults. Sampling for adult delta smelt by the Spring Kodiak Trawl survey begins in January, which generally aligns with the time period at which maturity is reached (Kurobe et al. 2016). Many delta smelt disperse to landward[2] habitats sometime after the first significant precipitation event of the winter for staging while sexual maturity is completed (Grimaldo et al. 2009; Sommer et al. 2011; Polansky et al. 2018). Some adult delta smelt exhibit very limited dispersal during the spawning season (Murphy and Hamilton 2013; Polansky et al. 2018).

In the wild, larval delta smelt are presumed to be surface-oriented, exhibiting greater dispersion during the night (Bennett 2005). In laboratory experiments, newly hatched larval delta smelt are able to manipulate their position in tanks, but there is no evidence to suggest that they can swim against prevailing currents (Swanson et al. 1998). Juvenile delta smelt vary their position in the water column with respect to tides, water quality, and bathymetry; presumably these movements facilitate maintenance in favorable habitats (Feyrer et al. 2013). Adult delta smelt appear to use tidal migration and/or move horizontally toward shore during spawning migrations to upstream habitats (Bennett and Burau 2015). Laboratory studies of delta smelt of 32–68 millimeters (mm) standard length (SL) gave mean critical swimming velocity of around 28 centimeters (cm) per second, generally comparable to other fishes of similar size (Swanson et al. 1998).

From March through June, larval delta smelt rely heavily first on juvenile and then adult stages of the calanoid copepods *Eurytemora affinis* and *Pseudodiaptomus forbesi*, as well as cladocerans (Nobriga 2002; Hobbs et al. 2006; Slater and Baxter 2014) and *Sinocalanus doerrii*. Nobriga (2002) found that delta smelt larvae expressed positive selection for *E. affinis* and *P. forbesi*, consuming these prey species in greater proportion than available in the environment. Such selection was not noted for other zooplankton prey. Regional differences in food use occur, with *E. affinis* and *P. forbesi* being major prey items downstream in the low-salinity zone with a transition to *S. doerrii* and cyclopoid copepods as major prey items upstream into the Cache Slough Complex. Juvenile delta smelt (June through September) rely extensively on calanoid copepods such as *E. affinis* and *P. forbesi*, especially in fresh water (salinity < 1 ppt) and the Cache Slough Complex, but there is great variability among regions (Interagency Ecological Program 2015). Larger fish are also able to take advantage of mysids, cladocerans, and amphipods (Moyle et al. 1992; Lott 1998; Feyrer et al. 2003; Slater et al. 2019). The presence of several epibenthic species in diets therefore indicates that food sources for this species are not solely connected to pelagic pathways.

11A.1.1.3. Distribution and Abundance

The California Department of Fish and Wildlife (CDFW) conducts four fish surveys from which it develops indices of delta smelt's relative abundance. Each survey has variable capture efficiency (Mitchell et al. 2017) and the frequency of zero catches of delta smelt is very high, largely due to the species' rarity (Latour 2016; Polansky et al. 2018) or because the surveys are carried out independent of other factors that affect catch, such as tide (Bennett and Burau 2015)

[2] Note that 'landward' in this context does not necessarily mean 'upstream', as there could be lateral movements (Murphy and Hamilton 2013).

and channel location (Feyrer et al. 2013). In addition, detection probability decreases with increasing water clarity (Peterson and Barajas 2018).

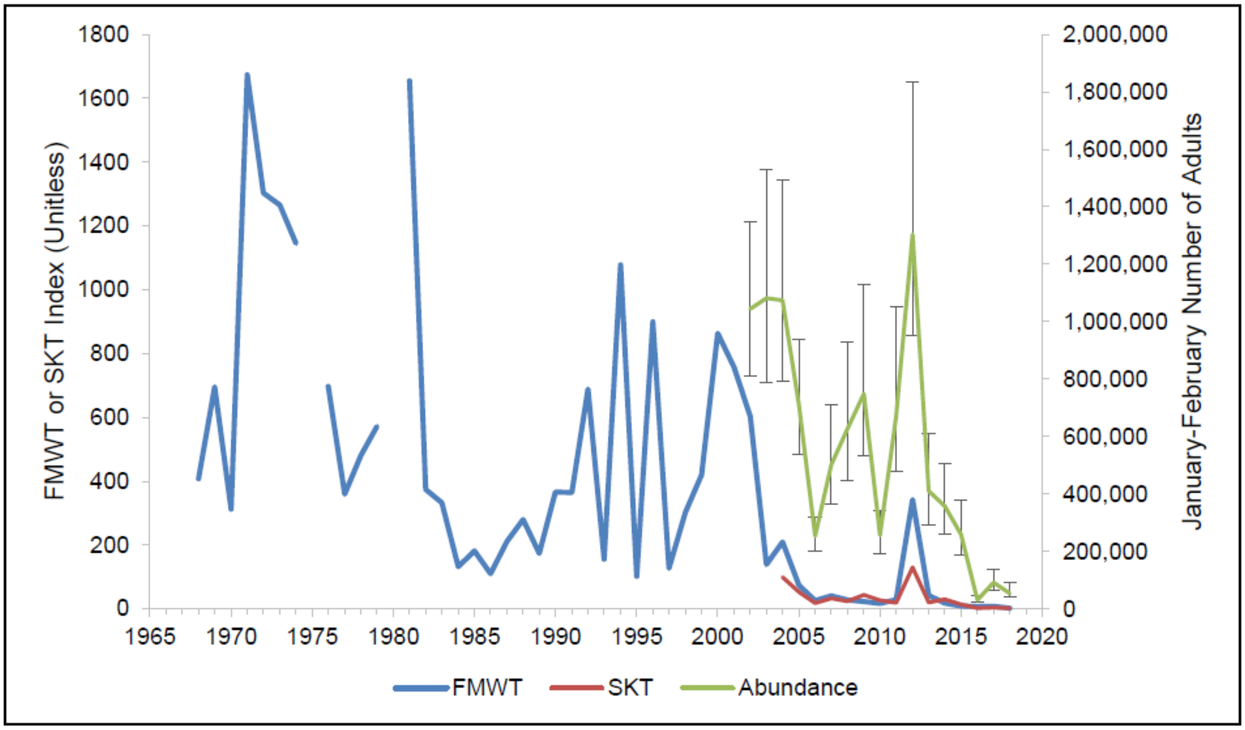
Information for delta smelt distribution and abundance can also be ascertained from other surveys that target salmonids. Since 2016, USFWS has implemented a smelt monitoring program called the Enhanced Delta Smelt Monitoring (EDSM) program. This program measures the abundance and distribution of all life stages of delta smelt using a generalized random tessellation stratified design. Delta smelt population abundance estimates are derived from this monitoring.

The distribution of the delta smelt population varies with life stage, season, and environmental conditions (Bennett 2005; Sommer and Mejia 2013; Murphy and Hamilton 2013; Hobbs et al. 2019). Subadult and adult delta smelt typically make landward movements soon after "first flush" periods of initial winter precipitation and runoff, when turbidities elevate over 10 Nephelometric Turbidity Units (NTU) (Grimaldo et al. 2009). Larval delta smelt can be broadly distributed depending on hydrologic conditions during March and April. During wet years, larval delta smelt are generally distributed seaward than in drier years. In contrast, during drier years, larval delta smelt are concentrated in the Delta. Juvenile delta smelt distribution is generally centered in the "North Delta Arc," which extends from Cache Slough to Suisun Bay and Suisun Marsh (Merz et al. 2011; Murphy and Hamilton 2013).

Trawl abundance indices indicate that the relative abundance of delta smelt has declined substantially since the 1980s. The decline in abundance reflects decades of habitat change and marginalization by nonnative species that prey on and outcompete delta smelt. 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).

Data derived from the CDFW Fall Midwater Trawl (FMWT) surveys are used for detecting and roughly scaling interannual trends in delta smelt abundance. The abundance indices derived from the FMWT closely mirror trends in catch per unit effort (Kimmerer and Nobriga 2008; Polansky et al. 2019), but do not presently support statistically reliable population abundance estimates, though substantial progress has been made in this regard (Newman 2008). The FMWT indices have ranged from 1,673 in 1970 to 0 in 2019 and 2020, the lowest indices on record. The Summer Townet (STN) survey index was 0 in all but one year (2017) during 2015–2020. Indices from the two surveys show a similar pattern of delta smelt relative abundance that is higher prior to the mid-1980s and very low in the past decade. A recent analysis combining these and several other surveys into an 8-survey index suggested that the decline in delta smelt, as well as longfin smelt and striped bass, occurred in the early- to mid-1980s rather than the early 2000s as previously thought (Stompe et al. 2020).

The CDFW Spring Kodiak Trawl (SKT) survey monitors the adult spawning stock of delta smelt and serves as an indication for the relative number and distribution of spawners in the system. The 2018 SKT abundance index was 2.1, the second lowest on record at that time; the 2020 SKT abundance index was 0, the lowest on record. All CDFW relative abundance indices show a declining trend since the early 2000s (Figure 11A-1).



Source: Reclamation 2019:2–70.

Figure 11A-1. Delta Smelt Fall Midwater Trawl Index, Spring Kodiak Trawl Index, and January–February Spring Kodiak Trawl Abundance Estimate (with 95% Confidence Interval), Water Years 2002–2018

As previously noted, considerable progress has been made on estimating absolute abundance of delta smelt, including adults (Polansky et al. 2019). It has been acknowledged that the estimates are affected by factors such as fish behavior and local habitat features such as turbidity influencing catchability (Polansky et al. 2019:721–722). However, a recent simulation analysis suggested that the effects of turbidity on catchability may be limited (Tobias 2021). The 2018 absolute abundance estimate of delta smelt adults was the second lowest; however, the confidence intervals overlap so strongly that it cannot be stated whether 2018 had higher adult abundance than 2016 (Figure 11A-1). The January through February 2016 point estimates are the lowest since the SKT survey began in 2002 and suggest delta smelt experienced increased natural mortality in the extreme drought conditions during 2013–2015. While the estimate may have increased slightly in 2017, it appears to have decreased again in 2018. The continued low spawning stock of delta smelt relative to historical estimates suggest the population continues to be vulnerable to key threats (described below), especially when these stressors are occurring in consecutive years (e.g., drought) or across sequential life stages (e.g., high water temperatures).

The frequency of occurrence (percentage of samples) of delta smelt by life stage and region from monitoring in the San Francisco Estuary and Delta as assessed by Merz et al. (2011) is provided in Table 11A-1.

Table 11A-1. Average Annual Frequency (Percent) of Delta Smelt Occurrence by Life Stage, Interagency Ecological Program Monitoring Program, and Region

Life Stage:	Average Annual Frequency (%)										
	Larvae (<15 mm)	**Sub-Juvenile (≥15, <30 mm)**		**Juvenile (30–55 mm)**			**Subadult (>55 mm)**	**Mature Adults (>55 mm)**		**Pre-Spawning[a]**	**Spawning[a]**
Monitoring Program:	**20-mm**	**20-mm**	**STN**	**20-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**
Region/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)	17.8	18.3	1.3	17.5	26.9	4.3	4.3	NS	4.3	23.3	5.6
Suisun Bay (NW)	2.2	8.9	1.1	21.7	34.8	7.3	10.0	NS	8.7	23.3	5.6
Suisun Bay (SE)	19.5	24.9	11.0	20.9	45.7	11.0	12.1	NS	6.5	28.3	6.9
Suisun Bay (NE)	17.8	19.2	33.6	29.7	66.7	20.3	29.3	NS	28.3	48.3	13.9
Grizzly Bay	16.3	27.6	17.9	42.9	72.8	15.0	19.6	NS	30.4	30.0	5.6
Suisun Marsh	21.4	33.6	14.2	18.5	19.2	22.8	27.2	NS	NS	62.0	23.1
Confluence	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	16.5	37.0	43.3	26.2	55.5	22.9	37.1	NS	18.8	54.4	17.8
Upper Sacramento River	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	17.2	47.3	NS	54.3	NS	9.8	26.7	NS	NS	33.9	21.1
Lower San Joaquin River	28.0	24.5	4.1	5.1	5.6	2.6	3.5	0.9	12.6	30.6	9.7

Life Stage:	**Average Annual Frequency (%)**											
	Larvae (<15 mm)	**Sub-Juvenile (≥15, <30 mm)**		**Juvenile (30–55 mm)**			**Subadult (>55 mm)**	**Mature Adults (>55 mm)**		**Pre-Spawning[a]**	**Spawning[a]**
Monitoring Program:	**20-mm**	**20-mm**	**STN**	**20-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**
Region/Time Period:	Apr–Jun	Apr–Jul	Jun–Aug	May–Jul	Jun–Aug	Sep–Dec	Sep–Dec	Dec–May	Jan–May	Jan–Apr	Jan–May
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	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	NS	NS	NS	NS	NS	NS	NS	0.2	NS	NS	NS
Sacramento Valley	NS	NS	NS	NS	NS	NS	NS	0.2	NS	NS	NS

Source: Merz et al. 2011; California Department of Fish and Wildlife n.d.

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; NE = northeast; NW = northwest; SKT = Spring Kodiak Trawl; STN = Summer Townet; SE = southeast; SW = southwest.

[a] Gonadal stages of male and female delta smelt found in Spring Kodiak Trawl database were classified by CDFW 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: females 1–3; males 1–4.

Mature adults, spawning: Reproductive stages: females 4; males 5.

11A.1.1.4. Stressors

Delta smelt are believed to be limited by a number of stressors, including water temperature, water quality, prey availability, entrainment at water diversions, increasing frequency and duration of droughts, and contaminants (Sommer et al. 2007; Miller et al. 2012; Wagner et al. 2011; Interagency Ecological Program Management Analysis and Synthesis Team 2015; Fong et al. 2016; Hamilton and Murphy 2020). Since 2010, several conceptual models (Interagency Ecological Program Management Analysis and Synthesis Team 2015) and empirical models (Thomson et al. 2010; Maunder and Deriso 2011; Miller et al. 2012; Rose et al. 2013a; Hamilton and Murphy 2018) have explored life cycle models for the delta smelt to identify and describe the reasons for the population decline. Some of these models have recreated a trend observed in abundance indices, but each model has applied different methodology and predictive covariates. Collectively, these modeling efforts generally support water temperature, water clarity, and prey availability as key factors that limit delta smelt populations, but water diversions and predation may also have substantial impacts as well. The threats discussed below may be directly or indirectly affected by water operations.

All life stages of delta smelt are vulnerable to entrainment at the south Delta export facilities. In general, delta smelt salvage increases when certain conditions co-occur, principally when adult delta smelt move into the south Delta, when turbidity exceeds 10 to 12 NTU, and with increasing net Old and Middle River (OMR) flow reversal (i.e., more negative net OMR flows). Based on field and salvage data, Kimmerer (2008) calculated that up to 25% of the larval and juvenile delta smelt population and up to 50% of the adult delta smelt population can be entrained at the CVP and SWP annually, in years with periods of high exports. Methods to calculate proportional loss estimates have since been debated (Kimmerer 2011; Miller 2011) and work on entrainment estimation has continued (e.g., Smith 2019; Smith et al. 2020), modeling efforts suggest that entrainment losses have the potential to adversely affect the delta smelt population (Kimmerer 2011; Maunder and Deriso 2011; Rose et al. 2013a, 2013b; Kimmerer and Rose 2018). Data on the distribution of the population (see Murphy and Hamilton 2013) suggest that entrainment is likely to be at the low end of the estimated range in most years. As a result of investigations into entrainment loss, entrainment risk has been limited by restrictions on export pumping (e.g., U.S. Fish and Wildlife Service 2008:280–282; U.S. Fish and Wildlife Service 2019:40–49).

Delta smelt are most vulnerable to entrainment when, as adults, they move from brackish water into fresh water or as larvae, when they move from fresh water in the southern and central Delta into the brackish water of Suisun Bay. While some delta smelt live year-round in fresh water far from the CVP and SWP, most rear in the low-salinity regions of the estuary. The timing, direction, and geographic extent of the spawning movements of adult delta smelt affect their entrainment risk (Sweetnam 1999; Sommer et al. 2011). Unlike the years prior to the 1990s, when high salvage of adult and juvenile delta smelt occurred at high, intermediate, or low export levels, the risk of entrainment for fish that move into the central Delta and south Delta is currently highest when net Delta outflow is at intermediate levels (about 20,000 to 75,000 cubic feet per second [cfs]) and OMR flow is more negative than -5,000 cfs (U.S. Fish and Wildlife Service 2008). In contrast, when adult delta smelt move upstream to the Sacramento River and into the Cache Slough region or do not move upstream at all, entrainment risk is appreciably lower. During extreme wet years, very few delta smelt (all life stages) are salvaged because the distribution shifts seaward away from the footprint of the SWP and CVP (Grimaldo et al. 2009).

Hierarchical modeling has recently been developed to characterize the potential for entrainment losses of vulnerable delta smelt life stages (Smith 2019; Smith et al. 2020).

The Interagency Ecological Program Management Analysis and Synthesis Team delta smelt conceptual model report found statistically significant relationships of spring Delta outflow (represented by X2) and prior indices of parental stock (FMWT or SKT indices) as predictors of larval/early juvenile delta smelt 20-mm Survey abundance indices for the post-Pelagic Organism Decline (Sommer et al. 2007) era (Interagency Ecological Program Management Analysis and Synthesis Team 2015:153–162). This report stressed that the "results are preliminary and included for illustrative purposes only; peer-reviewed publications of these analyses need to be completed before they can be used to draw any conclusions" (Interagency Ecological Program Management Analysis and Synthesis Team 2015:152).

Throughout the year, Delta outflow affects the location of the low-salinity zone within the upper estuary landscape. Higher Delta outflows (or low X2) expand the low-salinity zone, while lower outflows constrict the extent of the low-salinity zone (Feyrer et al. 2011; Bever et al. 2016). During the summer and fall, it has been hypothesized that environmental conditions improve for delta smelt as X2 moves seaward and the low-salinity zone expands habitat area (Interagency Ecological Program Management Analysis and Synthesis Team 2015). The overlap of the low-salinity zone with Suisun Marsh/Bay results in a considerable increase in a habitat index calculated by Feyrer et al. (2011). However, others (e.g., Manly et al. 2015) have questioned the use by Feyrer et al. (2011) of outflow and X2 location as an indicator of delta smelt habitat because other factors may be influencing survival. Murphy and Weiland (2019) found that the low-salinity zone is not a reliable indicator of delta smelt habitat and reported that delta smelt can be found in the lower Sacramento River, east of the Delta in largely freshwater conditions, as well as in western regions of the Delta, such as Suisun Bay, where salinity levels are typically higher. As both these conditions bound the range of the species, X2 does not determine the location of other important resources such as food or predators and therefore is not, by itself, a reliable surrogate for delta smelt habitat. Recent work suggested that summer/early fall Delta outflow provides a *P. forbesi* subsidy from the upper Delta to the western portion of the low-salinity zone (Kimmerer et al. 2018; Hamilton et al. 2020), resulting in low prey abundance in the low-salinity zone, where mortality rate is high because of clam grazing; without subsidy from the Delta, abundance of *P. forbesi* would be 0 (Kimmerer et al. 2019). Kimmerer et al. (2018) did not find a statistically significant relationship between *P. forbesi* density in the Delta and Delta outflow, whereas Hamilton et al. (2020) found statistically significant decreases in mean total copepod biomass with increasing September/October flow during higher flow conditions at most monitoring locations they examined in the San Francisco Estuary and Delta (discussed further below). Variability in water temperature and turbidity are primarily driven by climate, but in general, Suisun Bay and Suisun Marsh tend to support more suitable levels of water temperature and turbidity than the Delta.

Delta smelt is considered a pelagic species, and their physical habitat is generally defined by water quality (Bennett 2005; Feyrer et al. 2007; Nobriga et al. 2008) with some association to bathymetric features (Feyrer et al. 2013) and velocity (Bever et al. 2016). Recent analyses indicate water body type and depth are also physical indicators of habitat quality, and seasonal prey density is an indicator of biological habitat quality (Hamilton and Murphy 2020). Researchers have assumed that delta smelt primarily occupy the upper 2 meters of the water column, but recent work shows that juvenile delta smelt occupy the lower bottom half of the water column or move horizontally during ebb tides (Feyrer et al. 2013). As previously mentioned, after first flush and initial dispersal, adult delta smelt appear to hold their position geographically (Polansky et al. 2018).

Multiple field and modeling studies have established the association between elevated turbidity and the presence and abundance of delta smelt. Sommer and Mejia (2013) and Nobriga et al. (2008) found that late larval and juvenile delta smelt are strongly associated with turbid water, a pattern that continues through fall (Feyrer et al. 2007). Long-term declines in turbidity may also be a key reason that juvenile delta smelt now rarely occur in the south Delta during summer (Nobriga et al. 2008). Thomson et al. (2010) found decreases in turbidity were a significant predictor of delta smelt decline in abundance over time. Grimaldo et al. (2009) found that the presence of adult delta smelt at the fish salvage facilities was linked, in part, with high turbidity associated with first flush events. Turbidity may also serve as a behavioral cue for small-scale (lateral and vertical movements in the water column) and larger-scale (migratory) delta smelt movements (Bennett and Burau 2015). The decline in turbidity appears to be attributable to a decline in sediment supply from upstream, trapping by invasive submerged aquatic vegetation (SAV), and a long-term decrease in wind speed (Hestir et al. 2016; Bever et al. 2018).

Upper water temperature limits for juvenile delta smelt survival are based on laboratory studies and corroborated by field data. Based on the critical thermal maximum (CTmax), juvenile delta smelt acclimated to 17°C (62.6°F) could not tolerate temperatures higher than 25.4°C (77.7°F) (Swanson et al. 2000). However, for juvenile delta smelt acclimated to 11.9°C (53.4°F), 15.7°C (60.3°F), and 19.7°C (67.5°F), consistently higher CTmax values were estimated—27.1°C (80.9°F), 28.2°C (82.8°F), and 28.9°C (84.0°F), respectively (Komoroske et al. 2014), which corresponded closely to the maximum water temperatures recorded in the STN and FMWT surveys. Swanson et al. (2000) used wild-caught fish, while Komoroske et al. (2014) used hatchery-reared fish, which may have contributed to the differences in results. Based on the STN survey (Nobriga et al. 2008) and the 20-mm Townet survey (Sommer and Mejia 2013), most juvenile delta smelt were predicted to occur in field samples when water temperature was below 25°C (77.0°F). In a multivariate autoregressive modeling analysis with 16 independent variables, Mac Nally et al. (2010) found that high summer (June through September) water temperature had a negative effect on delta smelt subadult abundance in the fall. Water temperature was also one of several factors affecting delta smelt life stage dynamics in the state-space model of Maunder and Deriso (2011) and in an individual-based delta smelt life cycle model (Rose et al. 2013a, 2013b).

Harmful algal blooms, in particular *Microcystis*, are hypothesized to potentially have negative effects on delta smelt (Brooks et al. 2012). While recent research has resulted in improved understanding of the factors influencing the quantity, toxicity, and location of harmful algal blooms, there are still many uncertainties about their direct and indirect effects on delta smelt relative to other factors and about what can be done to prevent them. There is no routine quantitative monitoring program in place that specifically targets harmful algae. The STN and FMWT surveys now include qualitative, visual assessment of *Microcystis*, but other quantitative techniques that detect additional harmful species and their toxicity are increasingly available (e.g., solid phase adsorption tracking) (Wood et al. 2011). Available studies in the Delta suggest that retention time and water temperature are key environmental correlates with *Microcystis* bloom amplitude and that once established, *Microcystis* is likely to be resistant to even very high flows as long as water quality (in particular water temperature) is favorable (Lehman et al. 2020).

Changes in phytoplankton production, alterations in phytoplankton species abundances observed, and the invasion of *Potamocorbula* may have had important consequences for consumer species preyed upon by delta smelt. For example, there has been a decrease in mean zooplankton size (Winder and Jassby 2011) and a long-term decline in calanoid copepods, including a major step-decline in the abundance of the copepod *E. affinis*. These changes are possibly due to predation by *Potamocorbula* (Kimmerer et al. 1994) or to indirect effects of clam grazing on copepod food supply. Predation by *Potamocorbula* may also have been important for other zooplankton species (Kimmerer 2008).

The interaction of *Potamocorbula* grazing with the water's nutrient composition is also thought to have importance for delta smelt prey availability. As summarized by USFWS (2019:115), diatoms (i.e., phytoplankton prey of delta smelt's zooplankton prey) preferentially take up ammonium over nitrate but grow more slowly using ammonium. Consumption of diatoms by *Potamocorbula* prevents sufficient diatom metabolization of ammonium to lower levels that would allow more rapid diatom growth rates and greater diatom abundance for consumption by delta smelt zooplankton prey. The largest source of dissolved ammonium in the Bay-Delta is the Sacramento Regional Wastewater Treatment Plant, for which facility upgrades reducing ammonium concentrations beginning in 2023 should demonstrate how important this nutrient source is to limiting diatom production in the Bay-Delta (U.S. Fish and Wildlife Service 2019:115). A recent analysis concluded high ammonium loading is not a driver of low productivity in the San Francisco Bay-Delta (Strong et al. 2021).

In addition to a long-term decline in calanoid copepods and mysids (Orsi and Mecum 1986) in the Upper San Francisco Estuary, there have been numerous introductions of copepod species (Winder and Jassby 2011).The calanoid copepod *P. forbesi* was first observed in the estuary in the late 1980s and has replaced *E. affinis* as the most common delta smelt prey during the summer. It may have a competitive advantage over *E. affinis* because of its more selective feeding ability. Selective feeding may allow *P. forbesi* to utilize the remaining high-quality algae in the system while avoiding increasingly more prevalent low-quality and potentially toxic food items such as *Microcystis* (Mueller-Solger et al. 2006; Ger et al. 2010). After an initial rapid increase in abundance, *P. forbesi* declined somewhat in abundance from the early 1990s in the Suisun Bay and Suisun Marsh regions, but maintained its abundance, with some variability, in the central and south Delta (Winder and Jassby 2011).

The abundance of a more recent invader, the cyclopoid copepod *Limnoithona tetraspina*, significantly increased in the Suisun Bay region beginning in the mid-1990s. It is now the most abundant copepod species in Suisun Bay and the confluence region of the estuary (Bouley and Kimmerer 2006; Winder and Jassby 2011). Gould and Kimmerer (2010) found that it grows slowly and has low fecundity. Based on these findings they concluded that the population success of *L. tetraspina* must be due to low mortality and that this small copepod may be able to avoid the visual predation to which larger copepods are more susceptible. It has been hypothesized that *L. tetraspina* is an inferior food for pelagic fishes, including delta smelt, because of its small size, generally sedentary behavior, and ability to detect and avoid predators

(Bouley and Kimmerer 2006; Gould and Kimmerer 2010). Nevertheless, this copepod has been found in the guts of delta smelt when *Limnoithona* spp. occurs at extremely high densities relative to other zooplankton (Slater and Baxter 2014). Larval delta smelt will consume and grow on *L. tetraspina*, but growth is slower than with *P. forbesi* (Kimmerer et al. 2011). It remains unclear if consuming this small prey is energetically beneficial for delta smelt at all sizes or if there is a breakpoint above which larger delta smelt receive little benefit from such prey. *Acartiella sinensis*, a calanoid copepod species that invaded at the same time as *L. tetraspina*, also reached considerable densities in Suisun Bay and the western Delta over the last decade (Hennessy 2010), although its suitability as food for delta smelt remains unclear.

In addition to the previously mentioned subsidy of *P. forbesi* to the low-salinity zone from the Delta that has been positively related to Delta outflow (Kimmerer et al. 2018, 2019), Hamilton et al. (2020) conducted modeling of potential Delta Sacramento and San Joaquin river flow management actions that suggested increasing flows in fall (September and October) of wetter years generally could have negative effects to copepod biomass, whereas increases in flows in the spring (April and May) of drier years could provide regional increases in biomass, particularly in the lower Sacramento and San Joaquin Rivers. The latter result is consistent with earlier studies showing X2 to be negatively correlated with *E. affinis* density (Kimmerer 2002). In addition to *Potamocorbula* grazing, recent studies have suggested that south Delta exports also negatively affect phytoplankton or zooplankton productivity (Hammock et al. 2019a; Kimmerer et al. 2019). Tidal wetlands have been suggested to confer substantial benefits to the foraging success of delta smelt, on the basis of observed stomach fullness increased with increasing adjacent tidal wetland area (Hammock et al. 2019b).

Modeling suggests that delta smelt declines are negatively associated with metrics assumed to reflect the abundance of predators in the estuary (Maunder and Deriso 2011; Miller et al. 2012; Hamilton and Murphy 2018). These metrics are composites of the relative abundance of Mississippi silverside (*Menidia audens*), largemouth bass (*Micropterus salmoides*) and other centrarchids; these species are potential predators of concern because of their increasing abundance (Bennett and Moyle 1996; Brown and Michniuk 2007; Thomson et al. 2010) and because of inverse correlations between largemouth bass abundance and delta smelt abundance (Nobriga and Feyrer 2007; Thomson et al. 2010; Maunder and Deriso 2011). These correlations could represent predation on delta smelt by largemouth bass or, alternatively, the very different responses of the two species to changing habitat within the Delta (Moyle and Bennett 2008). Largemouth bass readily eat delta smelt when the opportunity exists (Ferrari et al. 2014). However, there is little evidence that largemouth bass are major consumers of delta smelt due to low spatial co-occurrence (Nobriga et al. 2005; Baxter et al. 2010). Thus, the inverse correlations between these species may not be mechanistic. Rather, they may reflect adaptation to, and selection for, different environmental conditions.

Moyle et al. (2016) suggested that Mississippi Silversides currently are the most important predators of delta smelt early life stages, as reflected in recent studies of delta smelt DNA in the prey consumed by silversides (Baerwald et al. 2012; Schreier et al. 2016). Mississippi silversides may also compete with delta smelt for prey and may be at an advantage over delta smelt because they spawn repeatedly throughout late spring, summer, and fall (Bennett 2005). The closely related smelt species wakasagi (*Hypomesus nipponensis*) occurs in the Delta and has prompted concern because of its broader environmental tolerance than delta smelt (Swanson et al. 2000), which could lead to its outcompeting delta smelt and hybridizing with delta smelt.

From 1963 through 1964, Stevens (1966) evaluated seasonal variation in the diets of juvenile striped bass (*Morone saxatilis*) throughout the Delta; only age-2 and age-3 striped bass contained more than trace amounts of delta smelt. The highest reported predation on delta smelt was 8% of the age-2 striped bass diet by volume during the summer. Thomas (1967) reported on spatial variation in the striped bass diet composition based on collections throughout the San Francisco Estuary and the Sacramento River above tidal influence. Delta smelt accounted for 8% of the spring diet composition and about 16% of the summer diet composition in the Delta. Although delta smelt are rare in the stomachs of striped bass (Nobriga and Feyrer 2007; Nobriga et al. 2013), a recent examination suggested that striped bass are important to controlling delta smelt because historical data indicate that declines in delta smelt before the current monitoring program began were driven by the invasion of striped bass into the estuary (Nobriga and Smith 2020).

The anticipated effects of climate change on the San Francisco Estuary and watershed, such as warmer water temperatures, greater salinity intrusion, lower snowpack contribution to spring outflows from the Delta, and the potential for frequent extreme drought (Knowles and Cayan 2002; Dettinger 2005), indicate challenges to maintaining a sustainable delta smelt population (Brown et al. 2013, 2016). A rebound in relative abundance during the very wet and cool conditions during 2011 indicated that delta smelt retained some population resilience (Interagency Ecological Program Management Analysis and Synthesis Team 2015). Examination of genetic effective population size during 2011–2014 found that delta smelt were not declining because of genetic factors and were not at immediate risk of losing genetic diversity (Finger et al. 2017). Since 2012, declines to record low population as estimated by abundance indices have been broadly associated with the 2012–2016 drought, and wetter conditions in 2017 and 2019 did not produce a rebound in delta smelt numbers similar to that seen in 2011. A more recent evaluation of effective population size has not been conducted since this further decline.

Central California's warm summers appear to be a source of energetic stress for delta smelt and warm springtime temperatures are assumed to compress the duration of their spawning season (Rose et al. 2013a; Moyle et al. 2016). Central California's climate is anticipated to get warmer (Cayan et al. 2009). Warmer estuary temperatures likely present a significant conservation challenge for delta smelt (Brown et al. 2013, 2016). Mean annual water temperatures within the Delta are expected to increase steadily during the second half of this century (Cloern et al. 2011).

11A.1.2. Longfin Smelt—Bay-Delta DPS

11A.1.2.1. Legal Status

On June 26, 2009, the commission ruled to list the status of longfin smelt as threatened under CESA. Longfin smelt is not listed under ESA, but listing has been found to be warranted for the San Francisco Bay/Sacramento–San Joaquin Delta (Bay-Delta) DPS (77 Code of Federal Regulations Part 19756).

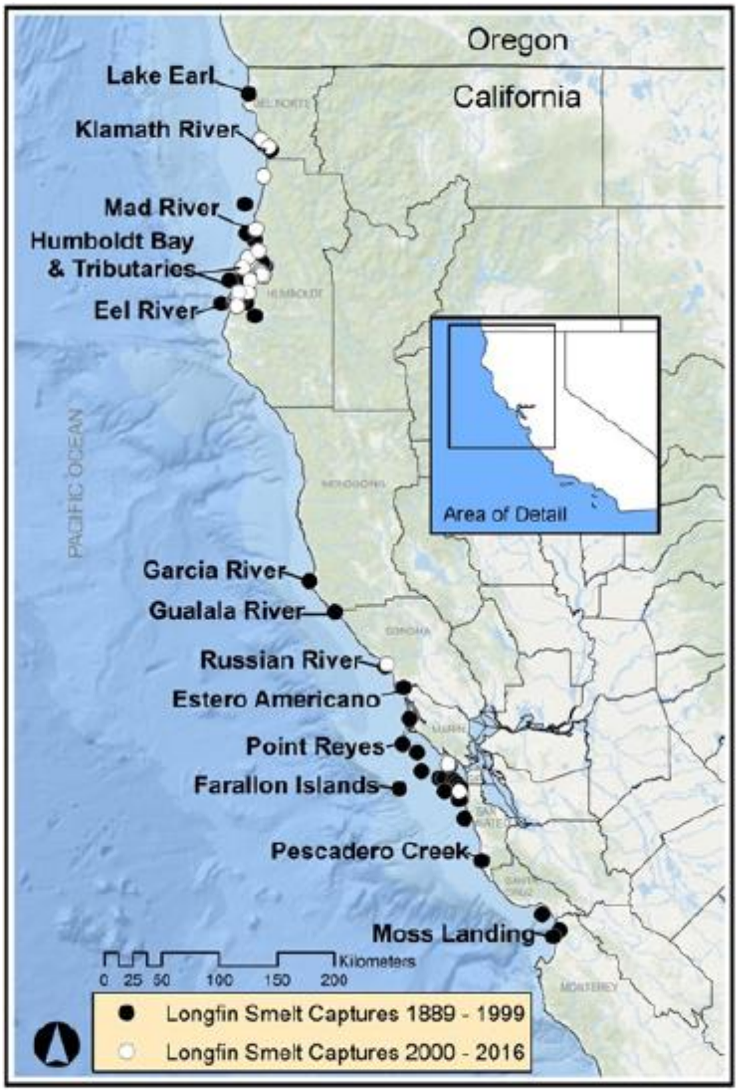
11A.1.2.2. Life History and General Ecology

The longfin smelt (*Spirinchus thaleichthys*) is a small, euryhaline, anadromous, and semelparous fish with a life cycle of approximately 2 to 3 years (Rosenfield 2010). Longfin smelt reach 90 to 110 mm SL, with a maximum size of 120 to 150 mm SL (Moyle 2002; Rosenfield and Baxter 2007). Longfin smelt belongs to the true smelt family Osmeridae and is one of three species in the *Spirinchus* genus; the night smelt (*Spirinchus starksi*) also occurs in California, and the shishamo (*Spirinchus lanceolatus*) occurs in northern Japan (McAllister 1963:10, 15). Delta smelt and longfin smelt hybrids have been observed in the San Francisco Estuary and Delta, although these offspring are not thought to be viable because delta smelt and longfin smelt are not closely related taxonomically or genetically (Fisch et al. 2013). Longfin smelt reside and rear in San Francisco Bay and in the nearshore ocean outside the Golden Gate (Garwood 2017). They spawn in tidal fresh water in the estuary’s low-salinity zone where brackish and fresh waters meet (Grimaldo et al. 2017) and in freshwater in tributaries to the Bay (Lewis et al. 2020). Longfin smelt can be distinguished from other California smelt by their long pectoral fins that 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, 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, in Prince William Sound, Alaska, to the San Francisco Estuary (Lee et al. 1980) and have been detected as far south as Monterey Bay (Garwood 2017).

Longfin smelt are periodically caught in the nearshore ocean, suggesting that some individuals disperse out into the Gulf of Farallones to feed and then return to the estuary (Rosenfield and Baxter 2007). Longfin smelt have been documented in Humboldt Bay, the Eel River estuary, the Klamath River estuary, Russian River, and in smaller river estuaries from the central and northern coast of California, including Pescadero Creek, Garcia River, Gualala River, and Mad River (Figure 11A-2) (Moyle 2002; Pinnix et al. 2004; Garwood 2017). It is not known what portion of ocean-bound fish return to San Francisco Bay each year or to other coastal streams north and south of San Francisco Bay (Rosenfield and Baxter 2007; Nobriga and Rosenfield 2016).

Genetic isolation exists between the population segment of longfin smelt in the San Francisco Estuary and more northern breeding populations (Stanley et al. 1995; Israel and May 2010). Due to the low likelihood of southward migration from more northern breeding populations as close as Humboldt Bay, USFWS determined that listing as a distinct population segment is warranted (U.S. Fish and Wildlife Service 2012). The Bay-Delta distinct population segment of longfin smelt occurs throughout the San Francisco Bay and the Delta, and in coastal waters west of the Golden Gate Bridge. Within the San Francisco Estuary and Central Valley watershed, they have been observed, north as far as the town of Colusa on the Sacramento River, east as far as Lathrop on the San Joaquin River, and south as far as Alviso and Coyote Sloughs in the southern San Francisco Bay as well as various tributaries in northern San Francisco Bay (Merz et al. 2013; Hobbs et al. 2015; Lewis et al. 2020).

In Lake Washington, longfin smelt spawn over sandy substrate, but spawning substrates are unknown in the San Francisco Estuary. Longfin smelt eggs are adhesive and demersal (Moyle 2002). Evidence from Grimaldo et al. (2017) suggests spawning habitats include open shallow water and tidal marshes. Longfin smelt produce between 1,900 and 18,000 eggs, with greater fecundity in fish with greater lengths (California Department of Fish and Game 2009a). Incubation times for egg development range between 25 and 42 days (Rosenfield 2010). Evidence for individuals spawning multiple times in a season has not been investigated but given that longfin smelt have such a broad spawning window (5–6 months), some females may undergo repeated spawning events. Newly hatched larvae have been observed in salinities up to 12 practical salinity units (psu) with peak observations occurring between 2 and 4 psu (Grimaldo et al. 2017). Early juvenile longfin smelt (20–40 mm SL) are found in salinities up to 30 psu, but most are found in salinities between 2 and 18 psu (MacWilliams et al. 2016). By late summer, late juveniles can tolerate full seawater.



Source: Garwood 2017.

Note: Locations with black circles have not necessarily been sampled since 1999, so there is no implication regarding changes in occurrence over time intended by this figure.

Figure 11A-2. Locations of Longfin Smelt Captures, 1889–2016, Excluding the San Francisco Estuary and Delta

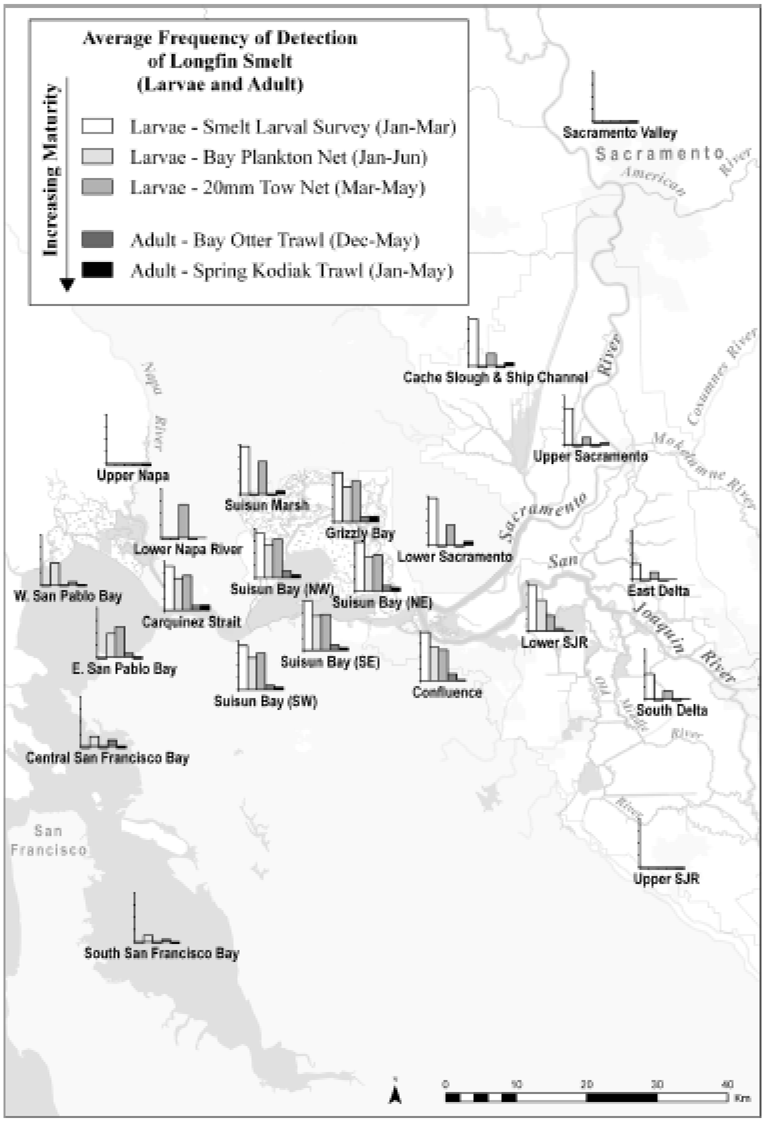
Longfin smelt are anadromous and semelparous, moving from saline to brackish or fresh water for spawning from November to May (Grimaldo et al. 2017; Lewis et al. 2020). Longfin smelt usually live for 2 years, spawn, and then die, although some individuals may spawn as 1-year-old or 3-year-old fish before dying (Rosenfield 2010). Age-2 adults appear to move into spawning areas during the late fall and early winter (Rosenfield and Baxter 2007). Spawning occurs at temperatures that range from 5°C (41.0°F) to 15°C (59.0°F) (Grimaldo et al. 2017). Peak spawning takes place in January and February of most years, when water temperatures are between 5°C (41.0°F) and 11°C (51.8°F). CDFW Smelt Larval Survey (SLS) data show that spawning appears to be centered in brackish water (2 to 4 psu), however, special studies that cover regions seaward of the SLS extent found newly hatched larvae in salinities up to 12 psu and concentrations of larvae peak between 2 and 4 psu (Grimaldo et al. 2017, 2020). Hobbs et al. (2010) provides evidence that larvae with the greatest recruitment success to later life stages are those that reared in salinities around 2 ppt.

Newly hatched longfin smelt larvae appear to be surface-oriented and probably have little ability to control their position in the water column before they develop their air bladder (Bennett et al. 2002). Once their air bladder is developed (approximately 12 mm SL), they can control their position in the water column by undergoing reverse diel vertical migrations or tidal vertical migration, depending on flow conditions (Bennett et al. 2002). Bennett et al. (2002) suggested that the ability of longfin smelt to undergo tidal vertical migrations allows them to maintain their position on the axis of the estuary. During the first few months of their lives (approximately January through May), longfin smelt primarily prey on calanoid copepods such as *P. forbesi* and *E. affinis* before switching to mysids as soon as they are large enough to feed on them (Slater 2008; Baxter et al. 2010). Mysid density is positively related to spring Delta outflow (negatively related to spring X2) (Mac Nally et al. 2010), although note that Kimmerer (2002) found a changing relationship to X2 for the mysid *Neomysis mercedis* (negative prior to 1987; positive following 1987).

11A.1.2.3. Distribution and Abundance

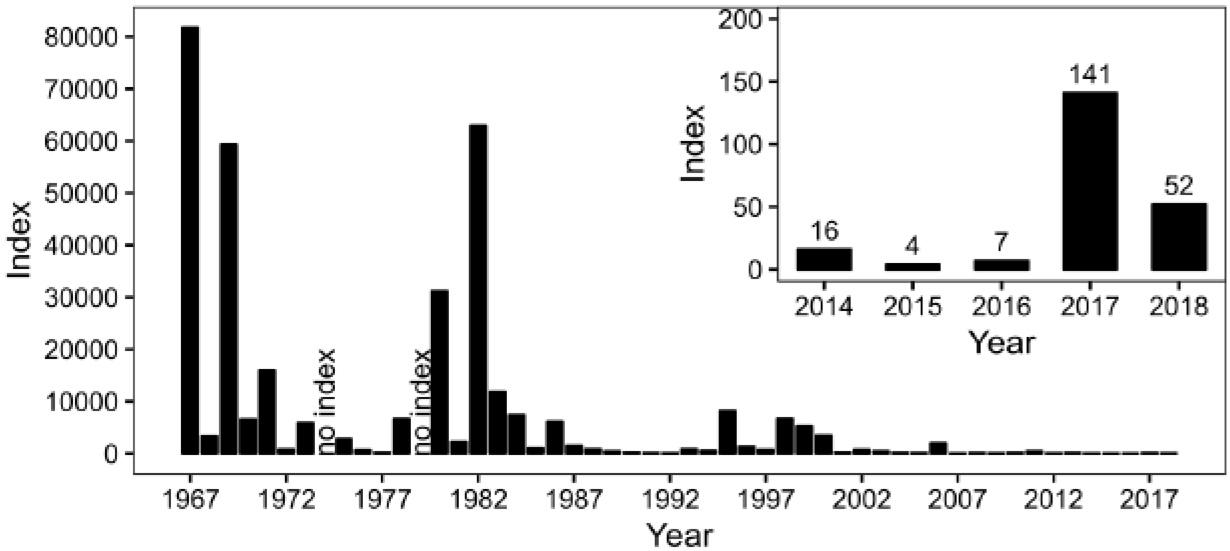
During late summer and early fall, juvenile and adult longfin smelt within the San Francisco Estuary are more common throughout San Francisco Bay than in other landward areas (Rosenfield and Baxter 2007; MacWilliams et al. 2016), although the extent of marine migration has yet to be quantified. During the spawning period in late fall and early winter, adults are more commonly found in San Francisco Bay tributaries and marshes (Lewis et al. 2020; Grimaldo et al. 2020), Suisun Bay, and the Delta (Rosenfield and Baxter 2007). Larval longfin smelt are broadly distributed throughout San Francisco Bay and its associated tributaries during wet years (MacWilliams et al. 2016; Lewis et al. 2020; Parker et al. 2017; Grimaldo et al. 2020). Analyses of multiple surveys by Merz et al. (2013) found that larvae were more frequently detected in the Delta in drier years than in wet years (Figure 11A-3; however, the limited extent of the SLS to landward regions does not account for potential spawning in tributaries of San Francisco Bay (Lewis et al. 2020). In long-term channel surveys, albeit limited to regions landward of San Pablo Bay, more than 50% of the measured larval abundance in any given year between 2009 and 2015 occurred in Suisun Bay and Suisun Marsh (Grimaldo et al. 2017). Some juveniles and adults are believed to move to the coastal ocean during the summer and fall (Rosenfield and Baxter 2007; MacWilliams et al. 2016).

Abundance indices for the longfin smelt population have undergone a decline over time. For example, there was an approximate thirty-fold reduction in the fall midwater trawl index since the early 1980s; although note that these indices do not sample large portions of the area occupied by the species (Figure 11A-4) (Rosenfield and Baxter 2007; Sommer et al. 2007; Kimmerer et al. 2009) and an index of 2-year-olds based on the San Francisco Bay Study midwater and otter trawl went down from a mean of 1,931 in 1980–1986 (prior to the *Potamocorbula* invasion) to a mean of 918 during 1987–2002, with a further decline following the onset of the Pelagic Organism Decline to a mean of 422 during 2003–2013 (Nobriga and Rosenfield 2016). The rate of decline of the population suggested by abundance indices has been particularly steep, especially since the onset of the Pelagic Organism Decline (Sommer et al. 2007; Thomson et al. 2010), although a recent analysis of an integrated dataset featuring eight different surveys suggests that the original decline dates back to the early to mid-1980s (Stompe et al. 2020). Although the population has declined, the slope of the relationship between winter-spring flow and fall longfin smelt abundance indices remains unchanged, suggesting that flow or hydrological conditions are strong drivers of their population abundance (Kimmerer et al. 2009; Maunder et al. 2015; Nobriga and Rosenfield 2016). The intercept of this relationship has dropped nearly twofold, possibly because of declining food supply related to *Potamocorbula* (Kimmerer et al. 2009).



Source: Merz et al. 2013.
Note: To calculate the annual frequency of longfin smelt detection in a region, the percentage of sampling events where longfin smelt were observed is divided by the total number of sampling events for the region. In this graphic, where no column/bar is shown in the bar graph for a region, the average annual frequency of detection for the given longfin smelt life stage(s) was zero. Where the column is below the x-axis, a survey did not sample in that region (e.g., the Smelt Larval Survey, which does not include stations west of Carquinez Strait).

Figure 11A-3. Average Annual Frequency of Longfin Smelt Detection (%) for Larval and Adult Life Stages by Region and Interagency Ecological Program Survey Type



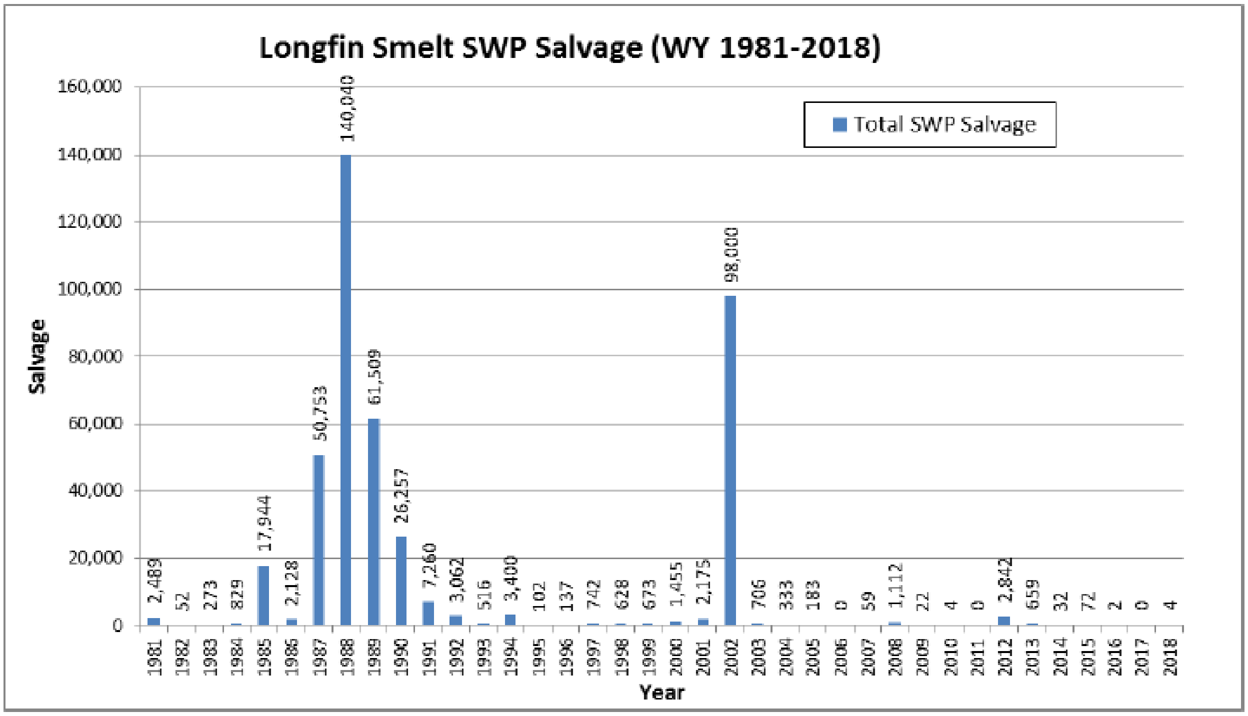
Source: White 2019.

Figure 11A-4. Longfin Smelt Fall Midwater Trawl Abundance Index, 1967–2018

11A.1.2.4. Stressors

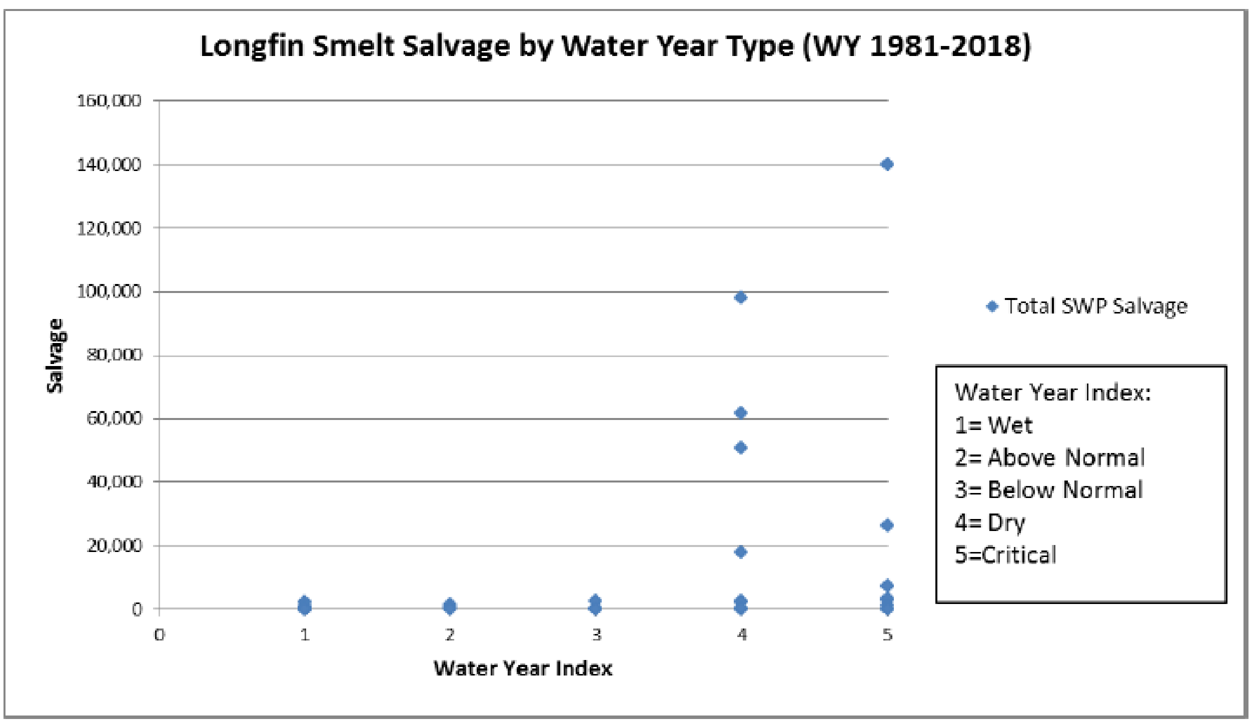
There are several threats to longfin smelt. The USFWS (2012) determination that listing is warranted for the Bay-Delta DPS concluded that reductions in freshwater flow and introduced species are threats, and that ammonium may be a threat. The discussion below also describes other threats that have been noted (e.g., California Department of Fish and Game 2009a), although as discussed further below, not all have been concluded to be of significance to the species (e.g., entrainment).

Longfin smelt are vulnerable to entrainment at the south Delta export facilities. The annual number of longfin smelt salvaged has been generally low since the 1980s, except in some years (1988, 2002), as illustrated for the SWP salvage facility in Figure 11A-5. In general, longfin smelt entrainment risk increases with reverse OMR flow (Grimaldo et al. 2009), and salvage can be higher in drier years compared to wetter years (as illustrated for the SWP salvage facility in Figure 11A-6), probably as a result of the landward shift in distribution in drier years. Figure 11A-7 shows the distribution of larval and juvenile longfin smelt salinity tolerance in water years of varying runoff. It is important to note that the data presented do not report catch of Longfin Smelt smaller than 40 mm fork length and the methodology does not efficiently collect Longfin Smelt larger than 11–12 mm fork length. This leaves a potential gap in which fish 12–39 mm fork length are not accounted for.



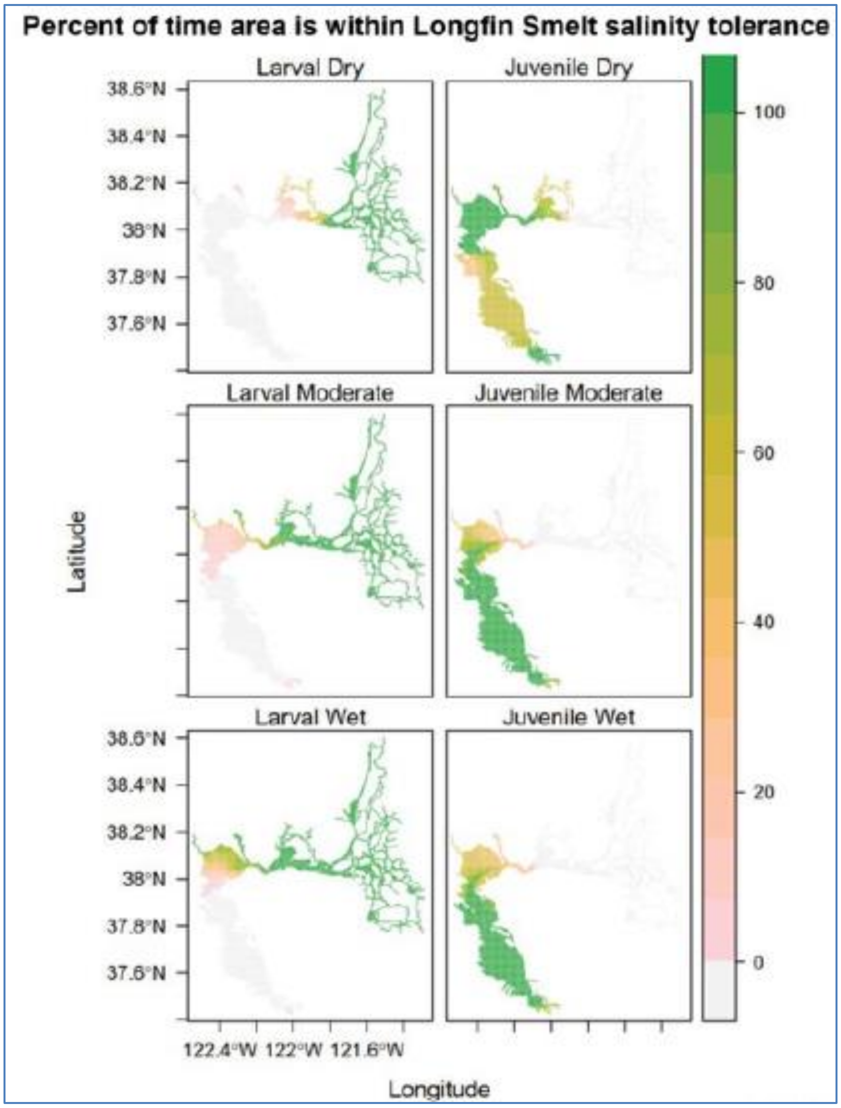
Source: California Department of Water Resources 2020:2-15

Figure 11A-5. Salvage at the State Water Project John E. Skinner Delta Fish Protective Facility, 1981-2018



Source: California Department of Water Resources 2019:2-15

Figure 11A-6. Salvage at the State Water Project John E. Skinner Delta Fish Protective Facility by Water Year Type, 1981-2018



Source: California Department of Water Resources 2019:2–16.

Note: The larval maps span January 1–March 31 and the juvenile maps span April 1–August 31. Salinities are within the tolerable range for longfin smelt based on 10th- and 90th-percentile salinities for catches in the Smelt Larval Survey (larval) and the Bay Study (juvenile). The three water years are 2014 (labeled as "dry"; Sacramento Valley runoff = 4.29 million acre-feet [MAF] (October–March) and 7.46 MAF [total water year]), 2011 (labeled as "moderate"; Sacramento Valley runoff = 12.68 MAF (October–March) and 25.21 MAF [total water year]), and 2006 (labeled as "wet"; Sacramento Valley runoff = 18.06 MAF (October–March) and 32.09 MAF [total water year]) (all runoff values based on California Data Exchange Center [2020]). The color scale is the percentage of days in the evaluated range that met the salinity tolerance criteria (green = 100%; grey = 0% days in salinity tolerance range). Note that "tolerance" is not taken to mean physiological tolerance, but as described above, the 10th–90th percentile salinity of longfin smelt catches.

Figure 11A-7. Distribution of Larval and Juvenile Longfin Smelt Salinity Tolerance in 2014 (Labeled "Dry"), 2011 (Labeled "Moderate"), and 2006 (Labeled "Wet") Water Years

Larval longfin smelt are also susceptible to entrainment at the south Delta export facilities; however, because the salvage facilities generally do not sample fish smaller than 20 mm SL, it is difficult to ascertain how many larvae are entrained (California Department of Fish and Game

2009a). Larval entrainment at the SWP is likely higher during drier periods compared to wetter periods, but overall larval entrainment risk is likely low because most longfin smelt hatch downstream of the Delta (Grimaldo et al. 2017). Overall, the effect of entrainment on the longfin smelt population has not been found to be important (Maunder et al. 2015), perhaps because a small fraction of the population is estimated to be entrained on an annual basis (California Department of Water Resources 2019:4-48, 4-55).

As previously described, longfin smelt abundance indices are positively correlated with winter-spring Delta outflow or negatively correlated with winter-spring X2 (Jassby et al. 1995; Kimmerer 2002; Kimmerer et al. 2009; Baxter et al. 2010; Mac Nally et al. 2010; Thomson et al. 2010; Mount et al. 2013; Nobriga and Rosenfield 2016) or positively correlated with general indicators of hydrological conditions (e.g., watershed runoff) (Maunder et al. 2015). Numerous mechanisms have been proposed for this relationship, including lower entrainment losses, advection to suitable habitat, reduced predation due to elevated turbidity, increased retention in favorable habitats, and access to marsh habitats that are unsuitable during drier periods.

The effect of entrainment appears to be unimportant (Maunder et al. 2015) or at least has diminished in recent decades, since longfin smelt population-level entrainment losses are low (see discussion above). Vertical retention via estuarine circulation is still hypothesized to be an important mechanism that retains age-0 longfin smelt in high-quality habitats during higher flows (Kimmerer et al. 2009), but horizontal retention in large, shallow bays is now hypothesized to be an important feature that enhances longfin smelt survival and abundance during higher flows based on new data that targeted larval and juvenile longfin smelt in shallow and marsh habitats (Grimaldo et al. 2020).

Kimmerer et al. (2009) concluded that habitat volume, as defined by salinity and water clarity, may be partly responsible for the longfin smelt abundance relationship with Delta outflow (X2), but that other mechanisms such as outflow-driven retention, are more important. With respect to habitat availability, although freshwater flow affects dynamic habitat availability, recent investigations by Grimaldo et al. (2017) of stationary habitat found that larval longfin smelt were relatively abundant in tidal marsh and shallow open waters of the low-salinity zone. This work suggests that stationary shallow habitat also provides key rearing habitat for larval longfin smelt, a situation that increased when San Pablo Bay and the south San Francisco Bay became freshwater to low-salinity habitat during wet years.

Adult longfin smelt use tidal marshes for spawning (Lewis et al. 2020). Larval longfin smelt use marsh and shoal habitats as rearing habitat (Grimaldo et al. 2017; Grimaldo et al. 2020). Juvenile longfin smelt are mostly found in deeper channels, often exhibiting diel movements, presumably to reduce predation risk (Bennett et al. 2002).

The salinity distribution in the San Francisco Estuary is not solely dependent on Delta outflow. For example, MacWilliams et al. (2016) showed that salinity in San Francisco Bay was influenced by tributaries as well (e.g., in south San Francisco Bay). Figure 11A-7 shows the availability of habitat for larval and juvenile longfin smelt based on longfin smelt salinity "tolerance"[3] in water years of varying hydrology. Habitat suitability is represented by the percentage of time when a specific location is within the salinity range where 80% of larval and juvenile longfin smelt were observed in the CDFW SLS and Bay Study surveys, respectively. Note that these surveys do include the full range occupied by the species and therefore limit the scope of inference regarding distribution.

Turbidity levels have declined in the Delta (Cloern et al. 2011). Although delta smelt has often been the focus for potential effects of turbidity reduction, some of the same mechanisms appear to be as important for longfin smelt (Mahardja et al. 2017). For example, young juvenile longfin smelt distribution in spring is negatively associated with water clarity (Kimmerer et al. 2009) and trends in abundance are also negatively associated with water clarity in fall (Thomson et al. 2010). Greater water clarity could reflect changes in catchability during surveys (fish are better able to avoid trawls when water is clearer) (Latour 2016) thereby resulting in potential detection biases between bottom-fishing gear, such as the otter trawl, and midwater trawls (Rosenfield and Baxter 2007) used in surveys that suffer from mismatches in location and timing with the longfin smelt spawning season (Mahardja et al. 2017).

Longfin smelt have experienced a significant decline in food resources in recent decades (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. This may contribute to an observed lower population abundance and a downward shift in the flow-abundance index relationship, particularly after the introduction of the invasive clam *Potamacorbula amurensis* (Feyrer et al. 2003; Nobriga and Rosenfield 2016). Other factors possibly affecting food resources include ammonium, which was found to be negatively associated with longfin smelt abundance indices in the population dynamics model of Maunder et al. (2015).

The effect of nonnative predators, such as Mississippi silversides (*Medinia beryllina*) and striped bass, has been identified as a potential threat to longfin smelt populations (Sommer 2007; Rosenfield 2010), with potentially large predation losses even if the predation rate is low (California Department of Fish and Game 2009a). A composite index of predatory fish density in Central Bay and San Pablo Bay was found to be negatively associated with trends in longfin smelt abundance in population dynamics modeling by Maunder et al. (2015). Competition also occurs with species such as age-0 striped bass or American shad (*Alosa sapidissima*) (Feyrer et al. 2003), although the effect of competition on the longfin smelt population is unknown.

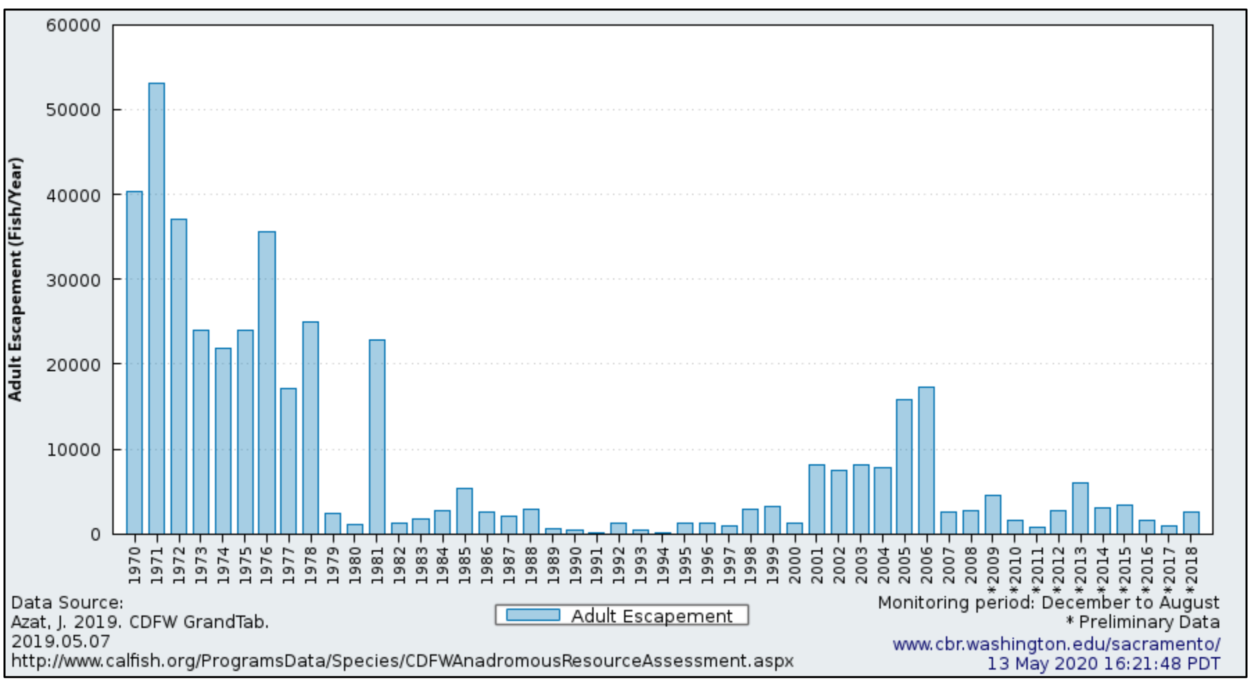
Water temperature tends to limit the upstream distribution of longfin smelt in the warmer months (Baxter et al. 2010) and spring (April–June) water temperature has been negatively correlated with survival (Maunder et al. 2015). By analogy with delta smelt (Brown et al. 2013, 2016), climate change could result in detrimental effects on longfin smelt ecology related to factors such as maturation and spawning season length and timing, as well as reduction in habitat extent; potential negative physiological effects of climate change have been demonstrated (Jeffries et al. 2016).

[3] As noted in Figure 2-5, "tolerance" is not taken to mean physiological tolerance, but as described above, the 10th–90th percentile salinity of longfin smelt catches.

11A.1.3. Winter-Run Chinook Salmon—Sacramento River ESU

11A.1.3.1. Legal Status

On May 16, 1989, the California Fish and Game Commission listed the Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*) ESU as endangered under CESA due to persistent long-term declines (Figure 11A-8). The National Marine Fisheries Service (NMFS), under an emergency interim rule, listed the Sacramento River winter-run Chinook salmon ESU as a threatened species under the federal ESA in August 1989 (54 FR 32085). In 1994, NMFS reclassified the ESU as endangered due to several factors: the continued decline and increased variability of run sizes including expected weak returns due to small year classes in 1991 and 1993, and continuing threats to the species (59 FR 440). The ESU consists of one population in the mainstem of the upper Sacramento River in California's Central Valley below Keswick Dam, though efforts to reintroduce the run in Battle Creek have had success in recent years with at least 700 subadults and adults returning in 2020 as a result of juvenile releases undertaken in 2018 and 2019 (U.S. Fish and Wildlife Service 2020). NMFS reaffirmed the listing of the Sacramento River winter-run Chinook salmon ESU as endangered on June 28, 2005 (70 FR 37160), and expanded the ESU to include winter-run Chinook salmon produced by the Livingston Stone National Fish Hatchery (LSNFH) artificial propagation program in the ESU.

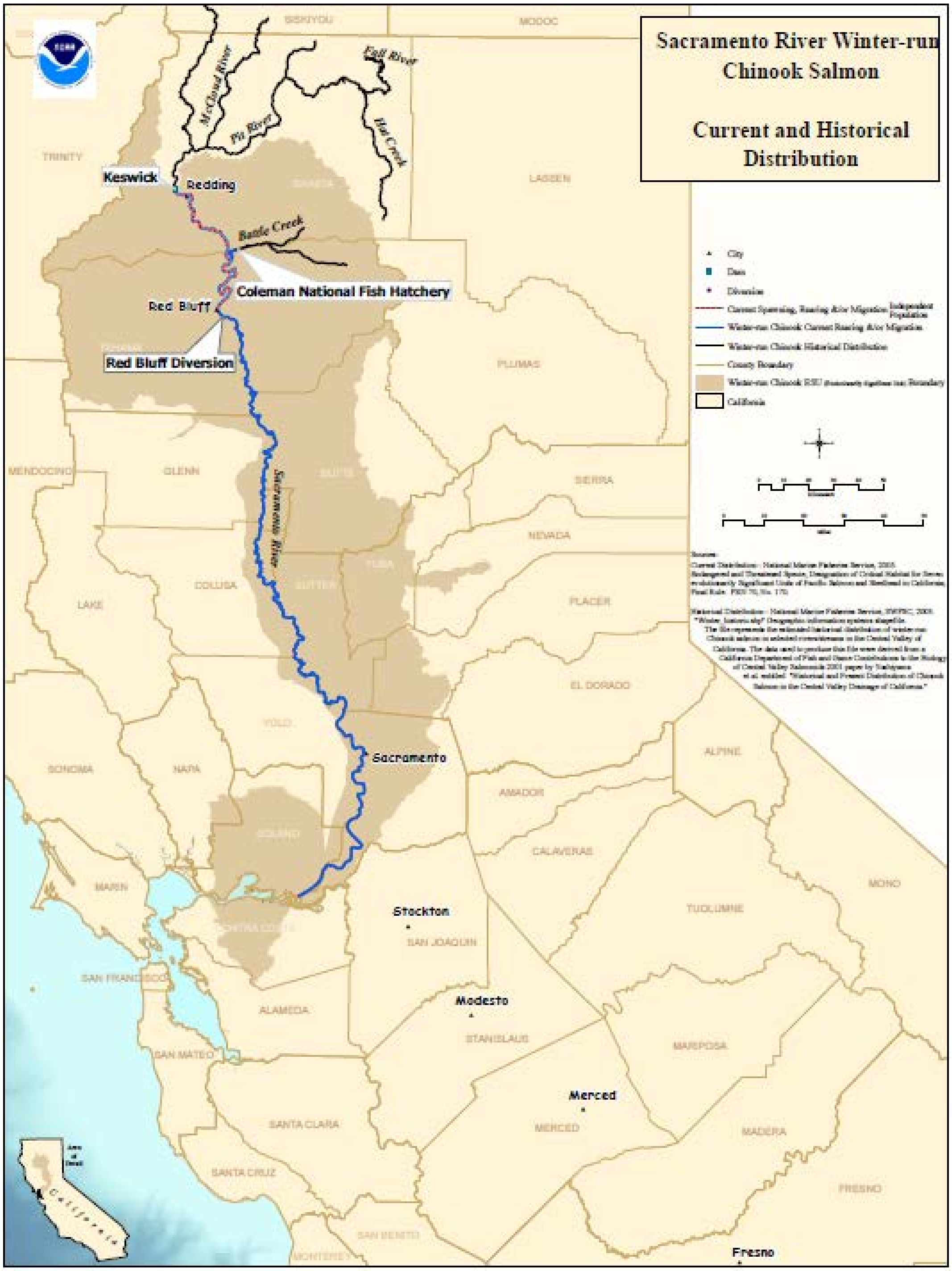


Source: Columbia Basin Research, University of Washington 2020.

Figure 11A-8. Winter-Run Chinook Salmon Adult Annual Escapement in the Central Valley, 1970–2018

11A.1.3.2. Life History and General Ecology

Adult Sacramento River winter-run Chinook salmon enter the San Francisco Bay in November to begin their spawning migration and continue upstream from December through early August to the extent of anadromy at the base of Keswick Dam (Figure 11A-9). Winter-run Chinook salmon spawn in the upper mainstem Sacramento River from mid-April through August, peaking in June and July. All known winter-run Chinook salmon production currently occurs either in the mainstem Sacramento River or LSNFH (California Department of Fish and Game 2004) although a nascent reintroduction effort in Battle Creek led to the return of at least 700 subadults and adults in 2020 (U.S. Fish and Wildlife Service 2020). Current spawning is confined to the mainstem of the Sacramento River above Red Bluff Diversion Dam (RBDD) (River Mile [RM] 243) and below Keswick Dam (RM 302) (National Marine Fisheries Service 2014). Until recent years, salmon passage was not possible above the Coleman Hatchery barrier weir located on Battle Creek.



Source: National Marine Fisheries Service 2014:12.

Figure 11A-9. Current and Historical Sacramento River Winter-Run Chinook Salmon Distribution

In addition to the Sacramento River, juveniles have also been found to rear in areas such as the lower American River, lower Feather River, Battle Creek, Mill Creek, Deer Creek, and the Delta (Phillis et al. 2018). Phillis et al. (2018) found with isotope data that 44% to 65% of surviving adults reared in nonnatal habitats as juveniles. The lower reaches of the Sacramento River, the Delta, and San Francisco Bay serve as migration corridors for both smolts and adults and are thought to serve as juvenile rearing habitat. Juvenile winter-run Chinook salmon begin to enter the Delta in October and smolt outmigration continues until April. Timing of smolt movement is thought to be strongly correlated with winter rain events that result in pulse flows in the Sacramento River (del Rosario et al. 2013). Fry and smolts are known to use the San Francisco Estuary as rearing habitat before entering the ocean (Sturrock et al. 2015). In addition to monitoring salvage of winter-run Chinook salmon at the Tracy Fish Collection Facility (TFCF) and the John E. Skinner Delta Fish Protective Facility (Skinner Fish Facility) in the south Delta, temporal occurrence of each life stage in the project area is monitored using screw trapping data in the rivers, trawls, and beach seines in the estuary and, more recently, acoustic tagging using a network of receivers located throughout the extent of their range, from Keswick Dam to the Golden Gate Bridge (e.g., Klimley et al. 2017). General life stage timing for winter-run Chinook salmon is summarized in Tables 11A-2 and 11A-3.

Table 11A-2. Temporal Occurrence of Sacramento River Winter-Run Chinook Salmon by Life Stage in the Sacramento River

Relative Abundance	High (▼)			Medium (⊠)			Low (#)			None (-)		
Adults Freshwater	Month											
Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sacramento River basin [a,b]	⊠	⊠	⊠	⊠	⊠	⊠	⊠	-	-	-	⊠	⊠
Upper Sacramento River spawning [c]	-	-	-	-	#	▼	▼	⊠	-	-	-	-
Juvenile Emigration	Month											
Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sacramento River at Red Bluff [d]	#	#	#	-	-	-	#	⊠	⊠	⊠	⊠	⊠
Sacramento River at Knights Landing [e]	▼	⊠	#	-	-	-	-	-	-	#	⊠	▼
Sacramento trawl at Sherwood Harbor [f]	⊠	▼	▼	#	-	-	-	-	-	-	⊠	▼
Midwater trawl at Chipps Island [f]	⊠	⊠	▼	▼	#	-	-	-	-	-	-	#

Sources: [a] Yoshiyama et al. (1998), Moyle (2002) ; [b] Myers et al. (1998); [c] Williams (2006); [d] Martin et al. (2001); [e] Knights Landing Rotary Screw Trap Data, CDFW (1999-2019); [f] Delta Juvenile Fish Monitoring Program, USFWS (1995-2019), del Rosario et al. (2013).

Source: National Marine Fisheries Service 2019:67.

Table 11A-3. Temporal Occurrence of Sacramento River Winter-Run Chinook Salmon by Life Stage in the Delta

Relative Abundance	High (▼)			Medium (⊠)			Low (#)		None (-)			
Life-Stage	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult [1]	⊠	▼	▼	▼	⊠	⊠	-	-	-	-	⊠	⊠
Juvenile [2]	#	⊠	▼	⊠	-	-	-	-	-	#	#	⊠
Salvaged [3]	⊠	▼	▼	#	#	#	-	-	-	-	-	#

[1] Adults enter the Bay November to June (Hallock and Fisher 1985) and are in spawning ground at a peak time of June to July (Vogel and Marine 1991).
[2] Juvenile presence in the Delta was determined using Delta Juvenile Fish Monitoring Program data.
[3] Months in which salvage of wild juvenile winter-run at State and Federal pumping plants occurred (National Marine Fisheries Service 2016c).

Source: National Marine Fisheries Service 2019:68.

11A.1.3.3. Distribution and Abundance

Relative distribution, abundance, and migration timing in the Delta is inferred from salvage monitoring data, Knight's Landing and Tisdale rotary screw traps, the USFWS Delta Juvenile Fish Monitoring Program, the EDSM program, Sherwood and Mossdale Trawls, and the Chipps Island Trawl. Juvenile mortality in the Delta from predation by piscivorous nonnative fishes and conditions that increase risk of mortality of salmonids have been at the forefront of special studies (e.g., Demetras et al. 2016) and reviews (Grossman 2016; Lehman et al. 2019). Special studies are also underway to describe rearing in Delta bays and marshes and identify variation in quality of rearing habitat. Attachment 1 provides graphical summaries of juvenile winter-run Chinook salmon monitoring, sampling and salvage timing in the Central Valley, as produced by the Central Valley Prediction Assessment of Salmon database (SacPAS).

11A.1.3.4. Stressors

Construction of Keswick and Shasta Dams for agricultural, municipal, and industrial water supply eliminated access to approximately 200 river miles of historical holding and spawning grounds above Keswick Dam (Yoshiyama et al. 1996). Rearing habitat quantity and quality has been reduced in the upper mainstem Sacramento River as a result of channel modification and levee construction (Lindley et al. 2009). Without access to historical coldwater spawning tributaries above Shasta Dam, persistence of the winter-run Chinook salmon ESU is dependent on maintaining adequate coldwater pool in Shasta Reservoir to maintain suitable temperatures for winter-run Chinook salmon egg incubation, fry emergence, and juvenile rearing, especially in critically dry years and extended droughts. Warm water releases during 2014 and 2015 contributed to 5.9% and 4.2% egg-to-fry survival rates to RBDD, respectively. As part of a coordinated drought response, measures taken to preserve Shasta Reservoir's coldwater pool included relaxing Wilkins Slough navigational flow requirements, relaxing D-1641 Delta water quality requirements, and delaying Settlement Contractor depletions into the fall.

Much of the historical floodplain habitat has been developed or converted, which has decreased shallow water habitat with high residence time needed for food production (Jeffres et al. 2008; Katz et al. 2017; Ahearn et al. 2006). Juveniles have access to floodplain habitat in the Yolo Bypass only during mid- to high water years, and the quantity of floodplain available for rearing during drought years is currently limited. The *Yolo Bypass Salmonid Habitat Restoration and Fish Passage Implementation Plan*, *Long-Term Operation of the Central Valley Project and State Water Project Biological Opinion Reasonable and Prudent Alternative Actions I.6.1 and I.7* (Yolo Bypass Restoration Plan) includes notching the Fremont Weir, which will provide access to floodplain habitat for juvenile salmon over a longer period (California Department of Water Resources and Reclamation 2012). Shoreline armoring and development have reduced access to floodplain rearing habitat for rearing juveniles in the Sacramento River and Delta (Boughton and Pike 2013). Floodplain availability has the potential to increase valuable prey resources and resilience in Chinook salmon (Goertler et al. 2018a, 2018b). Recent studies suggest Chinook salmon migration survival through the Yolo Bypass is comparable to that in the Sacramento River (Johnston et al. 2018; Pope et al. 2018); entry into the bypass over Fremont Weir may vary considerably even when river flow into the bypass is substantial, possibly as a function of fish cross-channel position in the Sacramento River (Pope et al. 2018); and travel time in low-flow years is more variable in the bypass than in the river (Johnston et al. 2018).

Juvenile migration corridors are affected by reverse OMR flows that are exacerbated by south Delta export facility operations at the CVP and SWP pumping plants (discussed further in Section 11A.1.4, *Spring-Run Chinook Salmon*). Bidirectional flow in the Sacramento River at Georgiana Slough associated with lower Sacramento River inflow to the Delta can cause juvenile Chinook salmon to enter into the interior Delta in greater numbers than with unidirectional flow at high Sacramento River inflow, which results in greater travel times and lower survival (Perry et al. 2013, 2018; see additional discussion in Section 11A.1.4). Although the Perry (2013 and 2018) and other studies have typically used hatchery-origin juvenile late fall–run Chinook salmon large enough to bear acoustic tags, the general movement patterns are assumed to be representative of other races including wild-origin winter-run juveniles. The movement of juvenile Chinook salmon into Georgiana Slough reflects the combination of their river cross-sectional distribution and the splitting of water remaining in the Sacramento River and water entering Georgiana Slough as represented by the critical streakline (Hance et al. 2020). Modeling suggests south Delta exports have little influence on the proportion of Sacramento River flow entering Georgiana Slough (Cavallo et al. 2015).

Stressors thought to be of very high importance to winter-run Chinook salmon by NMFS (2014:27) include blockage of historical staging and spawning habitat by Shasta and Keswick Dams; flow fluctuations, water pollution, and water temperature impacts in the upper Sacramento River during embryo incubation; loss of juvenile rearing habitat in the form of lost natural river morphology and function, and lost riparian and instream cover; predation during juvenile rearing and outmigration; ocean harvest; and south Delta entrainment. A very recent potential threat identified for winter-run is Thiamine Deficiency Complex, possibly the result of the oceanic diet of adults transferring negative effects to juveniles (National Oceanic Atmospheric Administration Fisheries 2020a). Recent temperature modeling shows higher sensitivity to increases in water temperature because it leads to exponential increases in oxygen demand with a rise in temperature during the final weeks of egg-embryo maturation before the alevin stage (Martin et al. 2017; Anderson 2018). Recent individual-based modeling of winter-run Chinook salmon in the upper Sacramento River (Keswick Dam to RBDD) by Dudley (2018) suggested that the leading causes of mortality are superimposition (i.e., a female salmon making a redd on top of an existing redd) and predation. Additionally, Dudley (2019) suggested that turbidity reduces predation and carrying capacity for larger juveniles is often reached.

Climate experts predict physical changes to ocean, river, and stream environments along the U.S. West Coast that include warmer atmospheric temperatures, diminished snow pack resulting in altered stream flow volume and timing, lower late summer flows, a continued rise in stream temperatures, and increased sea-surface temperatures and ocean acidity resulting in altered marine and freshwater food-chain dynamics (Williams et al. 2016). Climate change and associated changes in water temperature, hydrology, and ocean conditions are generally expected to have substantial effects on Chinook salmon populations in the future (National Marine Fisheries Service 2014; Lindley et al. 2009). Because the winter-run Chinook salmon rely on coldwater pool in Shasta Reservoir to maintain spawning conditions in the mainstem Sacramento River, this run is particularly at risk from global warming. Drought years are predicted to occur with greater frequency in the Sacramento Valley with climate change (Purkey et al. 2008). Increased water temperature associated with lower flows favors nonnative competitors and predators that are adapted to warm water because predation rates increase in response to elevated metabolic rates of predators (Petersen and Kitchell 2001). Increasing the frequency of dry years also reduces turbidity because sediment loads are not mobilized and transported downstream. Juvenile salmon are thought to use turbid water to avoid detection by predators (Gregory and Levings 1998). Increased prevalence of submerged aquatic vegetation (SAV) in the Delta reduces water flow and therefore also reduces turbidity, which has the effect of creating cover for predators and making passing salmon easier for predators to detect (Hestir et al. 2016). Finally, climate change is projected to increase the variability of ocean conditions, such as the North Pacific Gyre Oscillation, the Pacific Decadal Oscillation, and El Nino Southern Oscillations (Di Lorenzo et al. 2010). Anomalies, such as the warm water blob in the North Pacific, disrupt upwelling processes, which drive plankton production in the California Current (Leising et al. 2015). Juvenile salmon distribution is associated with oceanic plankton distribution, and mismatches in space and time that reduce access to marine prey aggregations are thought to influence early marine survival of Central Valley salmon populations (Hassrick et al. 2016). Recent studies highlight the importance of forage availability, upwelling, and thermal fronts on juvenile Chinook salmon feeding in the ocean (Sabal et al. 2020).

11A.1.4. Spring-Run Chinook Salmon—Central Valley ESU

11A.1.4.1. Legal Status

Spring-run Chinook salmon (*Oncorhynchus tshawytscha*), which were historically the most abundant run in the Central Valley, are now remnant in Antelope, Battle, Big Chico, Butte, Clear, Cottonwood, Deer, and Mill Creeks, the Feather River Fish Hatchery, and the Yuba River (NMFS 2016). Spring-run Chinook salmon were extirpated from most rivers by mining or dam construction (Williams 2006). Due to the small number of these populations remaining and the significant hybridization with fall-run Chinook salmon that has occurred in the mainstem of the Sacramento (Moffett 1949) and Feather Rivers (Lindley et al. 2004), spring-run Chinook salmon were listed as threatened under CESA in 1999. Native spring-run Chinook salmon have been extirpated from the San Joaquin River watershed, which represented a large portion of their historical range (see below for discussion regarding reintroduced spring-run Chinook salmon in the San Joaquin River). The Central Valley spring-run Chinook salmon ESU was listed as threatened under the ESA in 1999 because of the reduced range and small size of remaining spring-run Chinook salmon populations (64 FR 50393). On June 28, 2005, NMFS published the final hatchery listing policy (70 FR 37204) and reaffirmed the threatened status of the ESU (70 FR 37160). The ESU consists of naturally spawned spring-run Chinook salmon originating from the Sacramento River and its tributaries, and also from the Feather River Fish Hatchery Spring-Run Chinook Program (National Marine Fisheries Service 2016).

11A.1.4.2. Life History and General Ecology

Spring-run Chinook salmon share some similar life history and habitat requirements as those described for winter-run Chinook salmon, with differences primarily in the duration and time of year that the spring-run Chinook salmon ESU occupies freshwater habitat. Adult spring-run Chinook salmon enter fresh water as sexually immature fish between mid-February and July and remain in deep cold pools in proximity to spawning areas until late summer and early fall, when they are sexually mature and ready to spawn, depending on water temperatures (California Department of Fish and Game 1998; National Marine Fisheries Service 2009).

Spawning occurs in gravel substrate in relatively fast-moving, moderately shallow riffles or along banks with relatively high water, which promotes higher oxygen levels and reduced deposition of fines. Adult spawning conditions, incubation, and emergence from gravel is dependent on cold water temperatures (Myrick and Cech 2004). Fry emerge from gravels from November to March (Williams 2006). Post-emergent fry inhabits calm, shallow waters with fine substrates; fry depend on fallen trees, undercut banks, and overhanging riparian vegetation for refuge (Healey 1991).

Juvenile spring-run Chinook salmon can have highly variable outmigration timing based on various environmental factors (National Marine Fisheries Service 2009). Some juveniles begin outmigrating soon after emergence from gravel, whereas others oversummer and outmigrate as yearlings with the onset of intense fall storms (California Department of Fish and Game 1998). The outmigration period for spring-run Chinook salmon can extend from November to early May (National Marine Fisheries Service 2009:94) or June (California Department of Fish and Game 1998:III-9), with residency in the Delta probably lessening as the season progresses into the late spring months (California Department of Fish and Game 1998:III-9). Peak movement of yearling spring-run Chinook salmon in the Sacramento River at Knights Landing occurs in December and again in March and April (National Marine Fisheries Service 2009:94).

Juveniles prefer stream margin habitats with enough depth and velocities to provide suitable cover and foraging opportunities during rearing and downstream movement. Off-channel areas and floodplains can provide important rearing habitat. A greater availability of prey and favorable rearing conditions in floodplains increases juvenile growth rates compared with conditions in the mainstem Sacramento River, which can lead to improved survival rates during both their migration through the Delta and later in the marine environment (Sommer et al. 2001).

General life stage timing for spring-run Chinook salmon is summarized in Tables 11A-4 and 11A-5.

Table 11A-4. Temporal Occurrence of Central Valley Spring-Run Chinook Salmon by Life Stage in the Sacramento River

Relative Abundance	High (▼)								Medium (⊠)								Low (#)						None (-)		
(a) Adult Migration	Month																							
Location	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Sac. River Basin [a,b]	-	-	-	-	⊠	⊠	⊠	⊠	▼	▼	▼	▼	⊠	⊠	⊠	⊠	⊠	⊠	#	-	-	-	-	-
Sac. River Mainstem [b,c]	-	#	#	#	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	#	#	-	-	-	-	-	-	-	-
Adult Holding [a,b]	-	-	#	#	⊠	⊠	▼	▼	▼	▼	▼	▼	▼	▼	▼	⊠	⊠	#	#	-	-	-	-	-
Adult Spawning [a,b,c]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	#	⊠	▼	▼	⊠	#	-	-	-	-
(b) Juvenile Migration	Month																							
Location	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Sac. River at Red Bluff Diversion Dam [c]	▼	▼	#	#	#	#	#	#	#	-	-	-	-	-	-	-	-	-	-	-	▼	▼	▼	▼
Sac. River at Knights Landing [h]	⊠	⊠	⊠	⊠	▼	▼	▼	▼	⊠	⊠	-	-	-	-	-	-	-	-	-	-	⊠	⊠	▼	▼

Sources: [a] Yoshiyama et al. (1998); [b] Moyle (2002); [c] Myers et al. (1998); [d] Lindley et al. (2004); [e] California Department of Fish and Game (1998); [f] McReynolds et al. (2007); [g] Ward et al. (2003); [h] Snider and Titus (2000b)

Note: Yearling spring-run Chinook salmon rear in their natal streams through the first summer following their birth. Downstream emigration generally occurs the following fall and winter. Most young-of-the-year spring-run Chinook salmon emigrate during the first spring after they hatch.

Source: National Marine Fisheries Service 2019:83.

Table 11A-5. Temporal Occurrence of Central Valley Spring-Run Chinook Salmon by Life Stage in the Delta

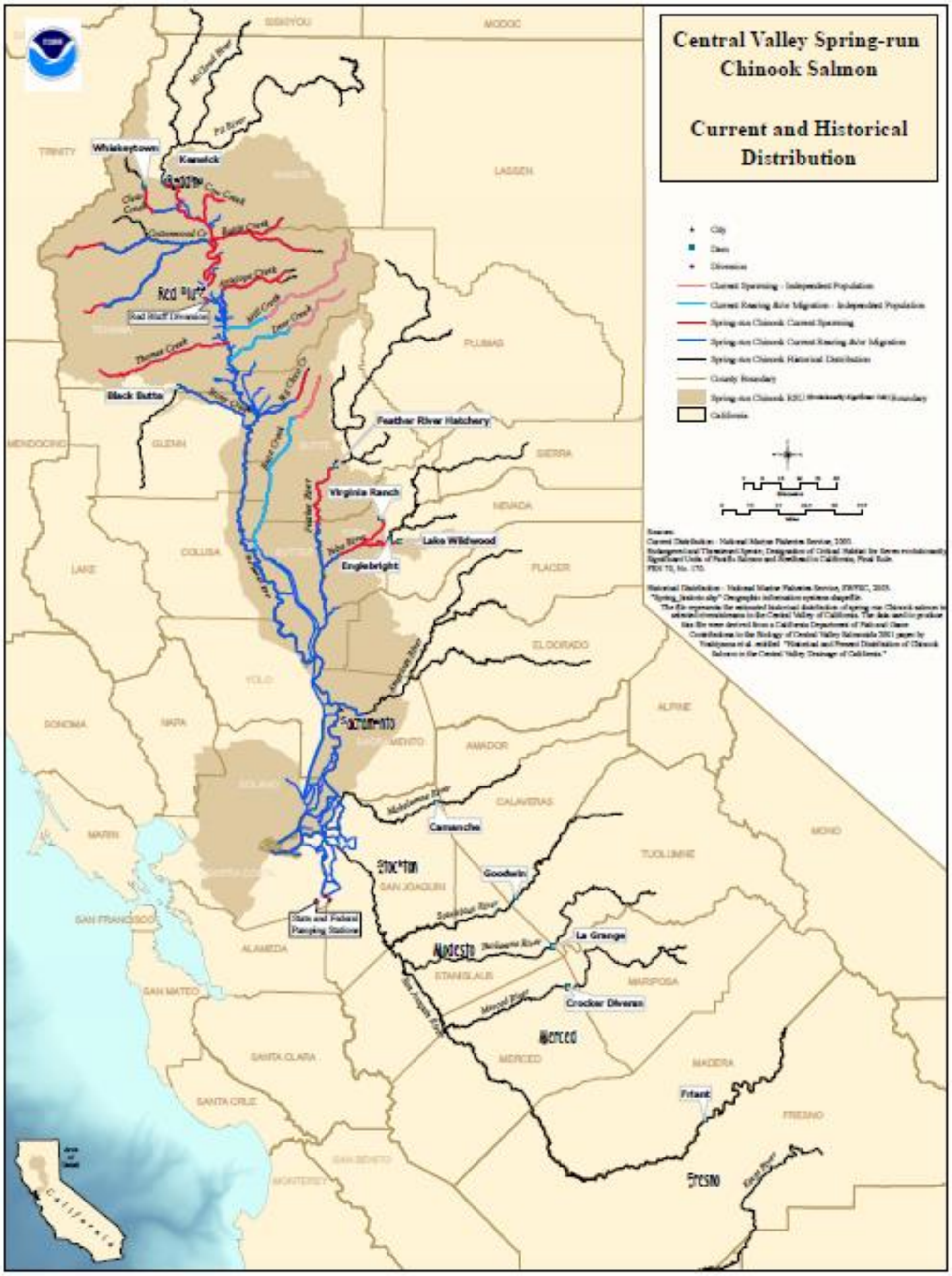
Relative Abundance	High (▼)				Medium (☒)			Low (#)			None (-)	
Life Stage	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult [1]	☒	▼	▼	▼	☒	☒	-	-	-	-	-	-
Juvenile [2]	#	#	#	▼	☒	-	-	-	-	-	-	#
Salvaged [3]	#	#	☒	▼	☒	-	-	-	-	-	-	-

[1]*Adults enter the Bay late January to early February* (California Department of Fish and Game 1998) *and enter the Sacramento River in March* (Yoshiyama et al. 1998). *Adults travel to tributaries as late as July* (Lindley et al. 2004). *Spawning occurs September to October* (Moyle 2002).
[2]*Juvenile presence in the Delta based on Delta Juvenile Fish Monitoring Program data.*
[3]*Juvenile presence in the Delta based on salvage data* (National Marine Fisheries Service 2016a).

Source: National Marine Fisheries Service 2019:84.

11A.1.4.3. Distribution and Abundance

Spring-run Chinook salmon were historically the dominant run of salmon in the Central Valley. The Central Valley drainage is estimated to have supported annual runs of spring-run Chinook salmon as large as 600,000 fish between the late 1880s and 1940s (California Department of Fish and Game 1998). Following construction of major dams, annual runs were estimated to be no more than 26,000 fish in the 1950s and 1960s (Azat 2012; Yoshiyama et al. 1998). Dams on the Sacramento River blocked upstream passage of spring-run Chinook salmon to historically available spawning habitat and confined them to a much smaller area of the watershed (Figure 11A-10). Today, only the mainstem Sacramento River and Butte, Mill, and Deer Creeks maintain wild spring-run Chinook salmon populations. In most years, some adults return to Antelope, Big Chico, Little Chico, Beegum, Battle, and Clear Creeks, but these populations are not considered self-sustaining. Recent surveys have documented very few spring-run Chinook salmon in the Stanislaus, Tuolumne, and Merced Rivers. Nearly 50,000 adults were counted in the San Joaquin River (Fry 1961) before the construction of Friant Dam (completed in 1942). The San Joaquin River watershed populations were essentially extirpated by the 1940s, with only small remnants of the run persisting through the 1950s in the Merced River (Hallock and Van Woert 1959; Yoshiyama et al. 1998).



Source: National Marine Fisheries Service 2014:32.

Figure 11A-10. Current and Historical Central Valley Spring-Run Chinook Salmon Distribution

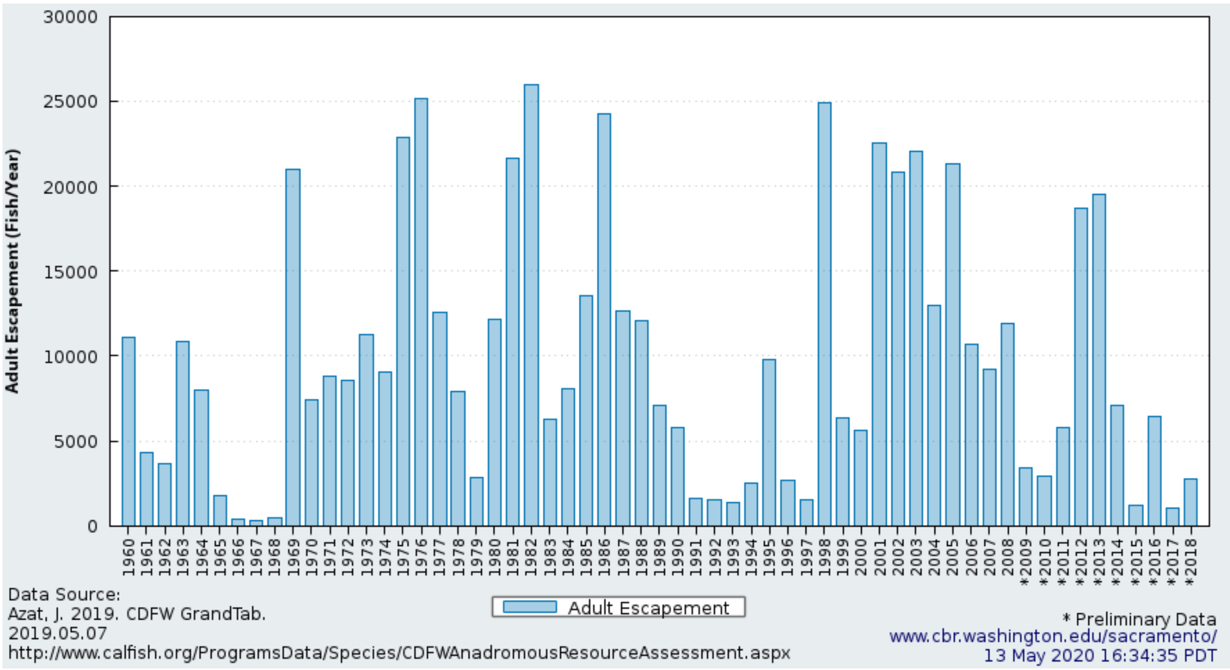
Spring-run Chinook salmon populations historically occupied the headwaters of all major river systems in the Central Valley up to any natural barrier, such as an impassable waterfall (Yoshiyama et al. 1998). The Sacramento River was used by adults as a migratory corridor to spawning areas in upstream tributaries and headwater streams (California Department of Fish and Game 1998). The most complete historical record of spring-run Chinook salmon migration timing and spawning is contained in reports to the U.S. Fish Commissioners of Baird Hatchery operations on the McCloud River (California Department of Fish and Game 1998). Spring-run Chinook salmon migration in the upper Sacramento River and tributaries extended from mid-March through the end of July with a peak in late May and early June. Baird Hatchery intercepted returning adults and spawned them from mid-August through late September. Peak spawning occurred during the first half of September. The average time between the end of spring-run Chinook salmon spawning and the onset of fall-run Chinook salmon spawning at Baird Hatchery from 1888 through 1901 was 32 days.

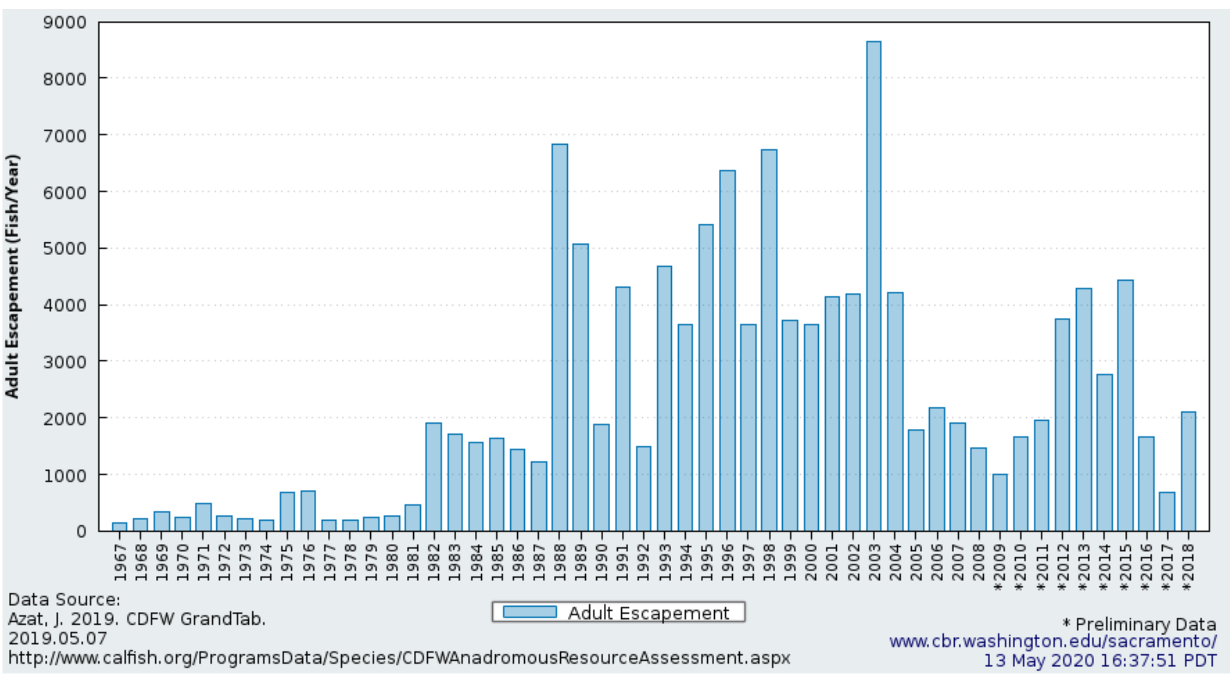
The Central Valley spring-run Chinook salmon ESU has displayed broad fluctuations in adult abundance. Estimates of spring-run Chinook salmon in the Sacramento River and its tributaries have ranged from 1,105 in 2017 to 25,890 in 1982. This estimate does not include in-river or hatchery spawners in the lower Yuba and Feather Rivers because CDFW's GrandTab does not distinguish between fall-run Chinook salmon and spring-run Chinook salmon in these rivers.

Since 1995, spring-run Chinook salmon annual run size estimates typically have been dominated by Butte Creek returns. Three of the tributaries producing naturally spawned spring-run Chinook salmon (Mill, Deer, and Butte Creeks), Butte Creek has produced an average of two-thirds of the total production over the past 10 years (California Department of Water Resources and Reclamation 2017; California Department of Fish and Wildlife 2018b). During recent years, spring-run Chinook salmon escapement estimates (excluding in-river spawners in the Yuba and Feather Rivers) have ranged from 23,696 in 2013 to 1,796 in 2017 throughout the tributaries to the Sacramento River surveyed (California Department of Fish and Wildlife 2018a).

Spring-run Chinook salmon population estimates remain low. In-river escapement was estimated to be 6,453 in 2016; 1,059 in 2017; and 2,774 in 2018 (Figure 11A-11). During these years, escapement to hatcheries ranged from 691 (2017) to 2,110 (2018) (Figure 2-9). In addition, fish monitoring is conducted throughout the year at the TFCF and the Skinner Fish Facility. Based on length-at-date criteria, during water year 2017, 26,551 wild (non-fin-clipped) juvenile spring-run and 963 hatchery (fin-clipped) spring-run Chinook salmon were observed at the TFCF and Skinner Fish Facility, and 9,487 wild juvenile spring-run and 1,010 hatchery spring-run were observed during water year 2018. Note, however, that length-at-date criteria for spring-run Chinook salmon are particularly prone to error because of the high overlap in lengths with the more abundant fall-run Chinook salmon, suggesting that actual spring-run entrainment is considerably lower than length-at-date criteria (Harvey et al. 2014). Fish monitoring is also conducted at the Rock Slough Intake by the Contra Costa Water District (CCWD). No spring-run Chinook salmon have been collected in CCWD's Fish Monitoring Program at the Rock Slough Intake since 2008.

Spring-run Chinook salmon are being reintroduced to the San Joaquin River as part of restoration efforts. In 2013, NMFS designated the Central Valley spring-run Chinook salmon reintroduced to the San Joaquin River as an experimental nonessential population in accordance with Section 10(j) of the ESA (78 FR 79622). This allows for the release of threatened California Central Valley spring-run Chinook salmon outside their current range. The population is considered an experimental, nonessential population (meaning that if the population does not survive, it will not threaten the whole ESU), because the population is geographically separate from the protected population of the same species (National Oceanic and Atmospheric Administration Fisheries 2020b). NMFS accounts for south Delta salvage of these reintroduced juveniles so that the reintroduction does not impose more than *de minimus* effects on water users (e.g., Strange 2020).





Source: Columbia Basin Research, University of Washington 2020.
Note: Vertical axis scale differs between upper and lower panel.

Figure 11A-11. Spring-Run Chinook Salmon Adult In-River (Upper) and Hatchery (Lower) Annual Escapement in the Central Valley, 1970–2018

Attachment 1 provides graphical summaries of juvenile spring-run Chinook salmon monitoring, sampling and salvage timing in the Central Valley, as produced by the Central Valley Prediction Assessment of Salmon database (SacPAS).

11A.1.4.4. Stressors

As discussed in Section 1.1.3, *Winter-Run Chinook Salmon—Sacramento River ESU*, accessible habitat for spring-run Chinook salmon has been negatively affected by inadequate flows and increased water temperatures from dam and water diversion operations on streams throughout the Sacramento River Basin. In Deer, Mill, and Antelope Creeks, losses of suitable spawning gravel, the development of deep channels and levees, pollutants and siltation from urban development, mining, and water diversions are also stressors on spring-run Chinook salmon Centra Valley ESU (National Marine Fisheries Service 2014).

The degradation and simplification of aquatic habitat in the Central Valley have reduced the resiliency of spring-run Chinook salmon to respond to additional stressors such as an extended drought, ocean harvest, and poor ocean conditions. Levee construction and maintenance projects have simplified riverine habitat and have disconnected rivers from the floodplain (National Marine Fisheries Service 2016).

Spring-run Chinook salmon migration survival and routing is linked to flow management, particularly at junctions where fish can route into the interior Delta and become entrained by the export facilities in the south Delta, demonstrated by data from acoustically tagged late fall–run Chinook salmon juveniles (e.g., Perry et al. 2018).

Increased exports can influence the direction and velocity of flow in the south Delta, with high exports causing stronger reversal in flows nearer the export facilities. When Sacramento River Basin-origin fish route into the interior Delta via Georgiana Slough or the Delta Cross Channel (DCC) and enter the south Delta, entrainment from reverse flows in OMR may result in longer travel time and indirect mortality (i.e., predation) and direct mortality through loss at the export facilities, as suggested by studies of movement pathways of radio-tagged juveniles (see summary by Vogel 2011:103–105).

Flow in the south Delta tends to be more complex than in the north Delta because of the influence of radial gate operations at the head of Clifton Court Forebay and the influence of exports on OMR dynamics, as described above. This is further complicated by the presence of temporary barriers at the Head of Old River, lower inflow from the San Joaquin River, and greater tidal excursion. Highly channelized levee characteristics maintained for water conveyance diminish the potential for the Delta to function as rearing habitat for juvenile salmonids.

As discussed for winter-run Chinook salmon, juveniles have access to floodplain habitat in the Yolo Bypass only during mid- to high water years, and the quantity of floodplain available for rearing during drought years is currently limited but notching of Fremont Weir with The Yolo Bypass Salmonid Habitat Restoration and Fish Passage Implementation Plan will provide access to floodplain habitat for juvenile salmon over a longer period (California Department of Water Resources and Reclamation 2012).

Recent work by the Collaborative Adaptive Management Team's (CAMT) Salmonid Scoping Team (SST) suggests that high correlations between inflows and exports make it difficult to evaluate their effects on salmon survival independently using statistical methods (Buchanan et al. 2018). There are very few observations of salmon survival at high export rates, which makes it difficult to determine if there is a relationship, but most acoustic tagging studies show support for a positive relationship between flow and survival (Perry et al. 2010, 2018; Michel et al. 2012). A key conclusion of the SST (2017:ES-5–ES-7) is that water export operations contribute to salmonid mortality in the Delta via direct mortality at the facilities, but direct mortality does not account for the majority of the mortality experienced in the Delta; the mechanism and magnitude of indirect effects of water project operations on Delta mortality outside the facilities is uncertain.

Temporary barriers are installed by DWR in the south Delta for the purpose of stabilizing and increasing water surface elevations to facilitate agriculture irrigation. A temporary barrier at the Head of Old River is designed to reduce movement of migrating salmonids into Old River, which would include the experimentally reintroduced spring-run Chinook salmon as part of the San Joaquin River Restoration Program. Conceptual models identified by the CAMT's SST predict that survival to Chipps Island will be higher with the barriers in place along the SJR by providing physical mechanisms for fish to be routed into the interior Delta via HOR. Changes in flows resulting from the barrier installation are also expected to benefit salmonid route selection and migration rates, although localized predation around the barriers themselves is expected to increase.

Results of Chinook salmon survival and migration studies in the Sacramento and San Joaquin Rivers and Delta suggest that relationships between river flow and migration rates are more complicated than in the Pacific Northwest, where flow is more unidirectional (Zabel et al. 1998; Smith et al. 2002). Higher survival of acoustically tagged wild-origin spring-run Chinook salmon smolts from Mill Creek was observed in a wet year (2017) compared to historic drought conditions in 2015 (Notch et al. 2020). Cordoleani et al. (2018, 2019) found higher survival for wild-origin smolts (spring-run and fall-run) in 2016 than 2015 correlated with greater flow in 2016 than 2015, and they found higher survival in 2017 than the prior two years correlated with greater flow in 2017 than those years. Cordoleani et al. (2019:1) summarized their results to note that release date and Delta flow were significantly correlated with survival rates and that the results were largely driven by 2017 data, for which fish were released a month later than those in 2015 and 2016, and Delta flow and smolt survival were significantly higher than in the previous two years. They also noted that more tagging years including additional measurements of environmental covariates (such as turbidity) are required to robustly identify the influence of various factors on Butte Creek spring-run Chinook outmigrant smolt survival (Cordoleani et al. 2019:1).

As previously described in the winter-run Chinook salmon account, routing down Georgiana Slough has also been shown to increase when unidirectional flow gives way to tidal influences and flow becomes more bidirectional, particularly below 20,000 cfs at Freeport (Perry et al. 2018). There is a positive correlation between through-Delta survival of acoustically tagged late fall–run Chinook salmon and Sacramento River flow entering the Delta (Perry et al. 2018).

Historically, wherever spring-run Chinook salmon and fall-run Chinook salmon populations overlapped, they were temporally segregated and genetic integrity was maintained. However, because of difficulties associated with holding adults over the summer in the Feather River, fish were left in the river until spawning, which presumably led to mixing with fall-run Chinook salmon in the hatchery (Williams 2006:33). Loss of life history diversity limits a species' ability to deal with environmental change, such as timing of ocean productivity, and leads to increased vulnerability through a weakened portfolio effect (Carlson and Satterthwaite 2011).

Climate change may pose similar threats to spring-run Chinook salmon as were described for winter-run Chinook salmon, with increasingly high water temperatures and changes to ocean conditions being limiting factors. Like winter-run Chinook salmon, spring-run Chinook salmon are particularly vulnerable to these limiting factors because their life history is adapted to streams with snowmelt runoff, with relatively dependable, sustained high flows that allow fish to ascend to high enough elevations where water temperatures remain tolerably cool through the summer. Snowmelt runoff is relatively more important in the San Joaquin River and its major tributaries, where historically spring-run Chinook salmon were more abundant. Recoveries of coded wire tags and genetic samples suggest that spring-run Chinook salmon have a more northerly ocean distribution and mature later than winter-run Chinook salmon (Satterthwaite et al. 2018). Therefore, climate-induced changes in ocean prey distributions that limit access to coastal prey may disproportionately affect spring-run Chinook salmon that rely on marine resources to a greater degree in order to mature.

11A.1.5. Fall-Run/Late Fall–Run Chinook Salmon—Central Valley ESU

11A.1.5.1. Legal Status

The Central Valley fall- and late fall–run Chinook salmon (*Oncorhynchus tshawytscha*) 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 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 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 is not listed under CESA. Fall- and late fall–run Chinook salmon is designated as a California species of special concern (SSC) (Moyle et al. 1995).

11A.1.5.2. Life History and General Ecology

Adult fall-run Chinook salmon migrate through the Delta and into Central Valley rivers from June through December. Adult late fall–run Chinook salmon migrate through the Delta and into the Sacramento River from October through April. Adult Central Valley fall-run 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.

Most fall-run Chinook salmon fry rear in fresh water from December through June, with outmigration as smolts occurring primarily from January through June. In general, fall-run Chinook salmon fry abundance in the Delta increases following high winter flows. Smolts that arrive in the estuary after rearing upstream migrate quickly through the Delta and Suisun and San Pablo Bays. A small number of juvenile fall-run Chinook salmon spend over a year in fresh water and outmigrate as yearling smolts the following November through April. Late fall–run fry rear in fresh water from April through the following April and outmigrate as smolts from October through February (Snider and Titus 2000). Juvenile Chinook salmon were found to spend about 40 days migrating through the Delta to the mouth of San Francisco Bay (MacFarlane and Norton 2002).

For late fall–run Chinook salmon generally, peak spawning time is typically from October to November, but can continue through December and into January. Juveniles typically emerge from the gravel in December through March and rear in fresh water for 1 to 7 months (Moyle et al. 2015:543–552). Fall- and late fall–run Chinook salmon generally outmigrate as age-0 fish, although some (8.3% in 2011) late fall–run Chinook salmon juveniles outmigrate in their second year. Outmigration is generally from April to June for late fall–run and November to May for fall-run Chinook salmon. During the most recent year for which there are records (2011), the peak outmigration for fall-run was in late December and the late fall–run peak outmigration was from mid-April to mid-May (Schraml et al. 2018).

Juvenile fall-run and late fall–run Chinook salmon migrating through the Delta toward the Pacific Ocean 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. Movement of juvenile Chinook salmon in the estuarine environment is driven by the interaction between tidally influenced saltwater intrusion through San Francisco Bay and freshwater outflow from the Sacramento and San Joaquin Rivers (Healey 1991).

The fall-run Chinook salmon has an ocean-maturing type of life history adapted for spawning in lowland reaches of big rivers, including the mainstem Sacramento River. The late fall–run Chinook salmon has a stream-maturing type of life history (Moyle 2002). Similar to spring-run, adult late fall–run Chinook salmon typically hold in the river for 1 to 3 months before spawning, while fall-run Chinook salmon generally spawn shortly after entering fresh water. Fall-run Chinook salmon migrate upstream past RBDD on the Sacramento River between July and December, typically spawning in upstream reaches from October through March. Late fall–run Chinook salmon migrate upstream past RBDD from August to March and spawn from January to April (National Marine Fisheries Service 2009; Tehama-Colusa Canal Authority 2008). The majority of young fall-run Chinook salmon migrate to the ocean during the first few months following emergence, although some may remain in fresh water and migrate as yearlings. Late fall–run Chinook salmon juveniles typically enter the ocean after 7 to 13 months of rearing in fresh water, at 150- to 170-mm in fork length, considerably larger and older than fall-run Chinook salmon (Moyle 2002). The primary spawning area used by fall-run and late fall–run Chinook salmon in the Sacramento River is the area from Keswick Dam downstream to RBDD. Spawning densities for all of the Chinook salmon runs are highest in this reach, but fall-run Chinook salmon generally spawn farther downstream in the reach than the other Chinook salmon runs (Gard 2013).

Based on carcass surveys and juvenile outmigration trapping, fall-run Chinook salmon typically spawn in Clear Creek from late September through early December, and peak outmigration of juveniles occurs in January and February (Earley et al. 2013). Beginning in 1995, restoration actions in Clear Creek have had an effect on fall-run Chinook salmon populations. The actions have contributed to a near fourfold increase in escapement of fall-run Chinook salmon to Clear Creek (population estimates average 1,749 from 1967 to 1991 and 7,333 from 1992 to 2017) (Clear Creek Technical Team 2018).

Feather River fall-run Chinook salmon are partially hybridized with Feather River spring-run Chinook salmon, but they largely maintain separate fall and spring upstream adult migrations. Fall-run adults return to the Feather River as sexually mature fish and spawn from September into December. The fall-run spawning period begins after the spring-run spawning period, but the spawning periods overlap considerably, leading to superimposition of spring-run redds by subsequently spawning fall-run adults. For this reason, a separation weir has been proposed to physically separate Central Valley spring-run and fall-run Chinook salmon in the river. Suitable water temperatures for Chinook salmon spawning in the Feather River are 42°F (5.5°C) to 58°F (14.4°C). Incubation may extend through March with suitable incubation temperatures between 48°F (8.9°C) and 58°F (14.4°C) (California Department of Water Resources 2007). Studies have confirmed that juvenile rearing and probably some adult spawning are associated with secondary channels within the Feather River low-flow channel. The lower velocities, smaller substrate size, and greater amount of cover (compared to the main river channel) likely make these side channels more suitable for juvenile Chinook salmon rearing. Currently, this type of habitat comprises less than 1% of the available habitat in the low-flow channel (California Department of Water Resources 2007). Juvenile Chinook salmon in the Feather River have been reported to outmigrate as young-of-the-year (YOY) (Seesholtz et al. 2004) and most appear to migrate out of the Feather River within days of emergence (National Marine Fisheries Service 2016). Juvenile outmigration from the Feather River is generally from mid-November through June, with peak outmigration occurring from January through March (National Marine Fisheries Service 2016).

The American River historically supported fall-run and perhaps late fall–run Chinook salmon (Williams 2001). Both natural-origin and hatchery-produced Chinook salmon spawn in the lower American River. An analysis by Palmer-Zwahlen et al. (2018) found that constant fractional marking results from 2013 show that approximately 86% of the fall-run Chinook salmon spawners returning to Nimbus Hatchery were hatchery-origin. Further, 71% of fall-run Chinook salmon recorded at the Hatchery Weir and 65% of carcasses were identified as hatchery fish. Adult fall-run Chinook salmon enter the lower American River from about mid-September through January, with peak migration from approximately mid-October through December (Williams 2001). Spawning in the American River occurs from about mid-October through early February, with peak spawning from mid-October through December. Chinook salmon spawning occurs within an 18-mile (29 km) stretch from Paradise Beach to Nimbus Dam; however, most spawning occurs in the uppermost 3 miles (4.8 km) (California Department of Fish and Game 2012a). Chinook salmon egg and alevin incubation occurs in the lower American River from about mid-October through April. This period varies widely from year to year, although most incubation occurs from about mid-October through January. Chinook salmon juveniles rear in the American River from about January to May (Snider and Titus 1995, 2002). Most Chinook Salmon outmigrate from the lower American River as fry between December and July; outmigration peaks February to March (Snider and Titus 2002; Pacific States Marine Fisheries Commission 2014).

In the Stanislaus River, data collected by private fishery consultants, nonprofit organizations, and CDFW demonstrate that the majority of fall-run Chinook salmon adults migrate upstream from late September through December with peak migration from late October through early November. Most Chinook salmon spawning occurs between Riverbank (RM 33, RKM 53.1) and Goodwin Dam (RM 58.4, RKM 94) (Reclamation 2012). Based on redd surveys conducted by FISHBIO, peak spawning typically occurs in November with roughly 7% of spawning occurring prior to November 1, and 2% prior to October 15. The few redds created during late September and early October are typically in the reach just below Goodwin Dam. By late October, the amount of spawning in downstream locations increases as water temperatures decrease, and the median redd location is typically around Knights Ferry (State Water Resources Control Board 2015). In 2010, over 20% of the fall-run Chinook salmon observed passing the Stanislaus River weir had adipose fin clips, indicating the presence of a coded wire tag in their snout. Since there is no hatchery on the Stanislaus River and no hatchery releases into this tributary have occurred since 2006, it is apparent that straying from other rivers is occurring (FISHBIO Environmental 2010). Rotary screw trap data indicate that about 99% of salmon juveniles migrate out of the Stanislaus River from January through May (Stanislaus River Fish Group 2004). Fry migration generally occurs from January through March, followed by smolt migration from April through May (Reclamation 2012). Watry et al. (2012) found that in both 2010 and 2011, peak passage during the pre-smolt period generally corresponded with flow pulses. Zeug et al. (2014) examined 14 years of rotary screw trap data on the lower Stanislaus River and found a strong positive response in survival, the proportion of pre-smolt migrants and the size of smolts when cumulative flow and flow variance were greater. From the data, they concluded that periods of high discharge in combination with high discharge variance are important for successful outmigration as well as migrant size and the maintenance of diverse migration strategies.

General life stage timing for Central Valley fall-run and late fall–run Chinook salmon is summarized in Tables 11A-6 and 11A-7.

Table 11A-6. Temporal Occurrence of Central Valley Fall-Run Chinook Salmon by Life Stage

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

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 2001.

[5] Snider and Titus 2000.

Table 11A-7. Temporal Occurrence of Central Valley Late Fall–Run Chinook Salmon by Life Stage.

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

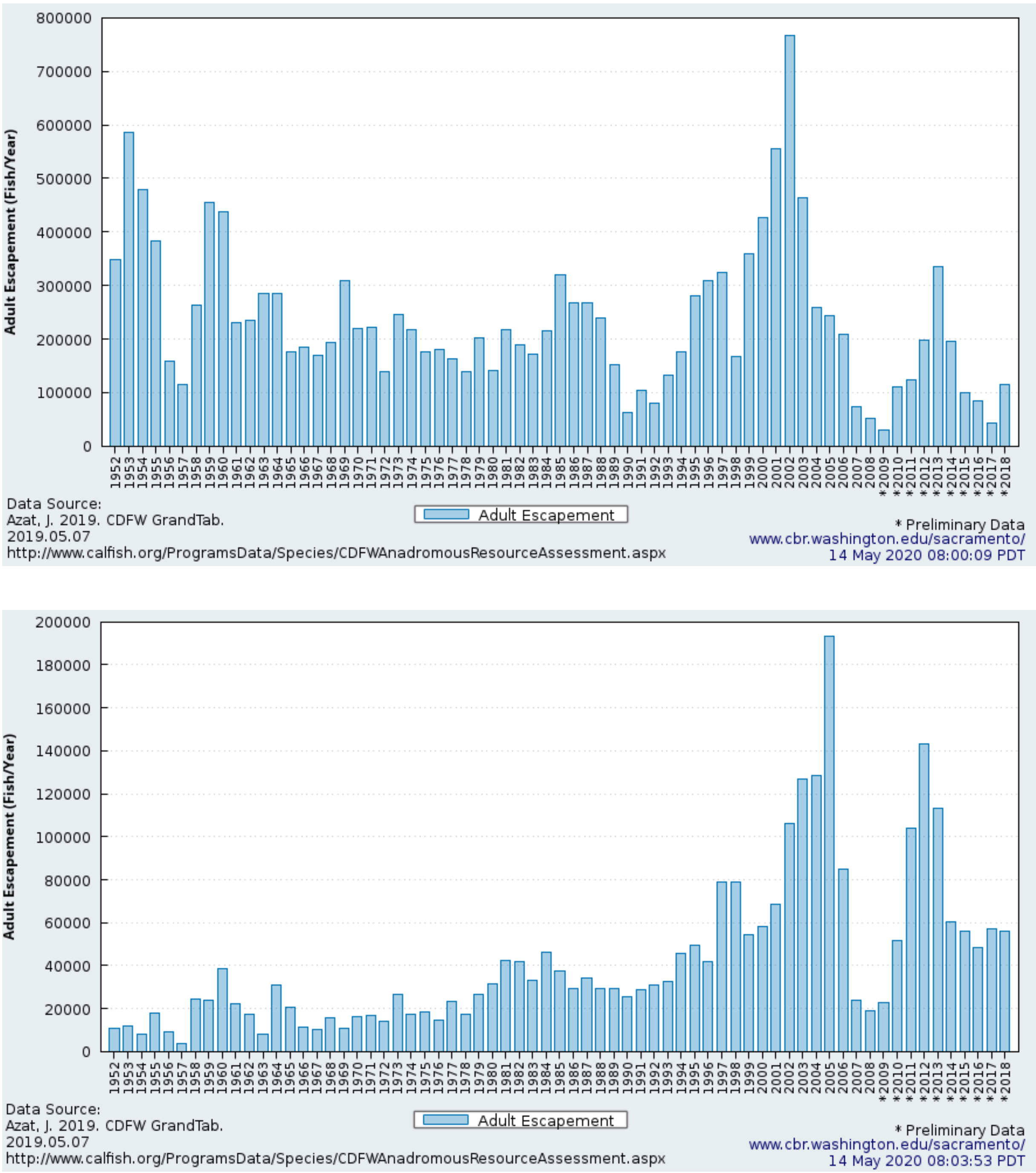
Relative Abundance: = High; = Medium; = Low

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 2001.
[5] Snider and Titus 2000.

11A.1.5.3. Distribution and Abundance

Annual fall-run and late fall–run Chinook salmon escapement to the Sacramento River and its tributaries has generally been lower in the last decade than historically, following peaks in the late 1990s to early 2000s (California Department of Fish and Wildlife 2018a) (Figures 11A-12 and 11A-13). Hatchery fall-run escapement was relatively consistent at approximately 50,000–60,000 fish during 2014–2018 (Figure 11A-12), with hatchery escapement of late fall–run in recent years estimated to be greater than in-river numbers (Figure 11A-13). Studies have suggested that hatchery-produced Chinook salmon may contribute large (approximately 90%) proportions of Chinook salmon to the mixed-stock fishery along the central California coast (Barnett-Johnson et al. 2007). Sturrock et al. (2019) found that transport distance of hatchery-origin juvenile Chinook salmon to release sites had increased over time (particularly during droughts) and was strongly associated with straying rate (averaging 0–9% compared to 7–89% for salmon released on site versus in the bay upstream of Golden Gate Bridge, respectively), increasing the effects of hatchery releases on natural spawners. The authors suggested that decreasing variation in release location and timing could reduce spatiotemporal buffering, narrowing ocean arrival timings and increasing risk of mismatch with peak prey production. The percentage of hatchery-origin fish released downstream of the Delta has been variable over time. For example, from the mid-1980s to 2012, the proportion of hatchery fall-run Chinook salmon juveniles released downstream of the Delta by state and federal hatcheries varied from around

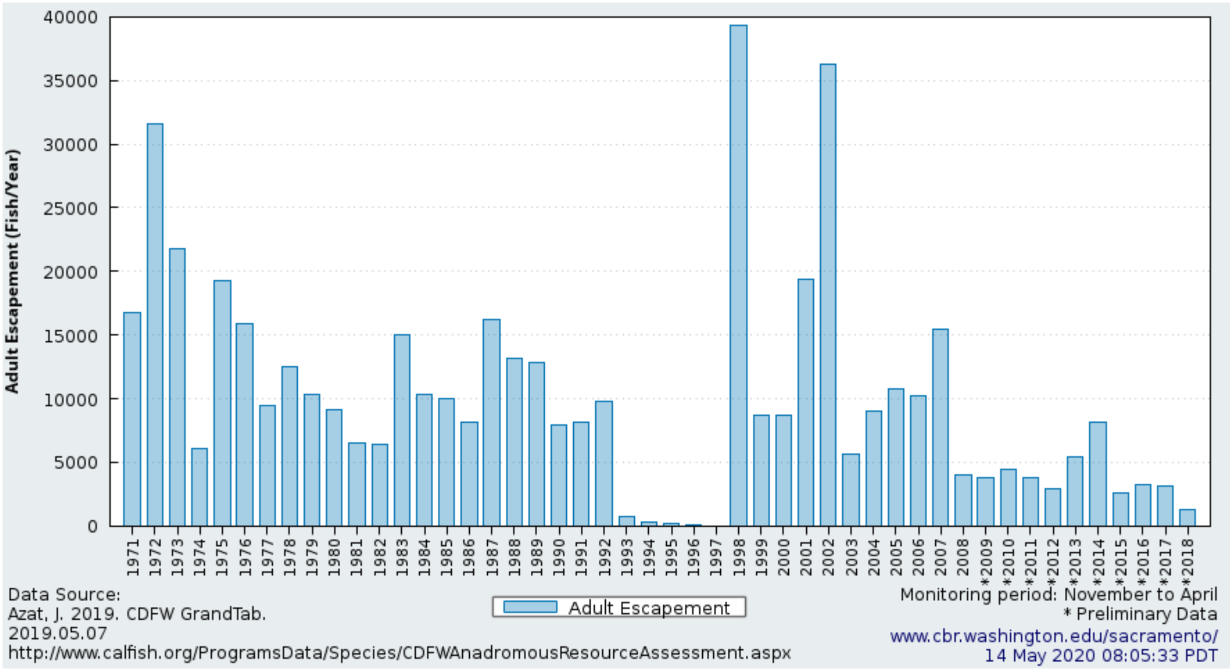
20% to 60% (Huber and Carlson 2015). Similarly, from 2013 to 2017, the percentage of juvenile fall-run and spring-run Chinook salmon released by state Central Valley hatcheries downstream of the Delta varied between 24% (2016) and 60% (2013) (California Department of Fish and Wildlife 2018c).

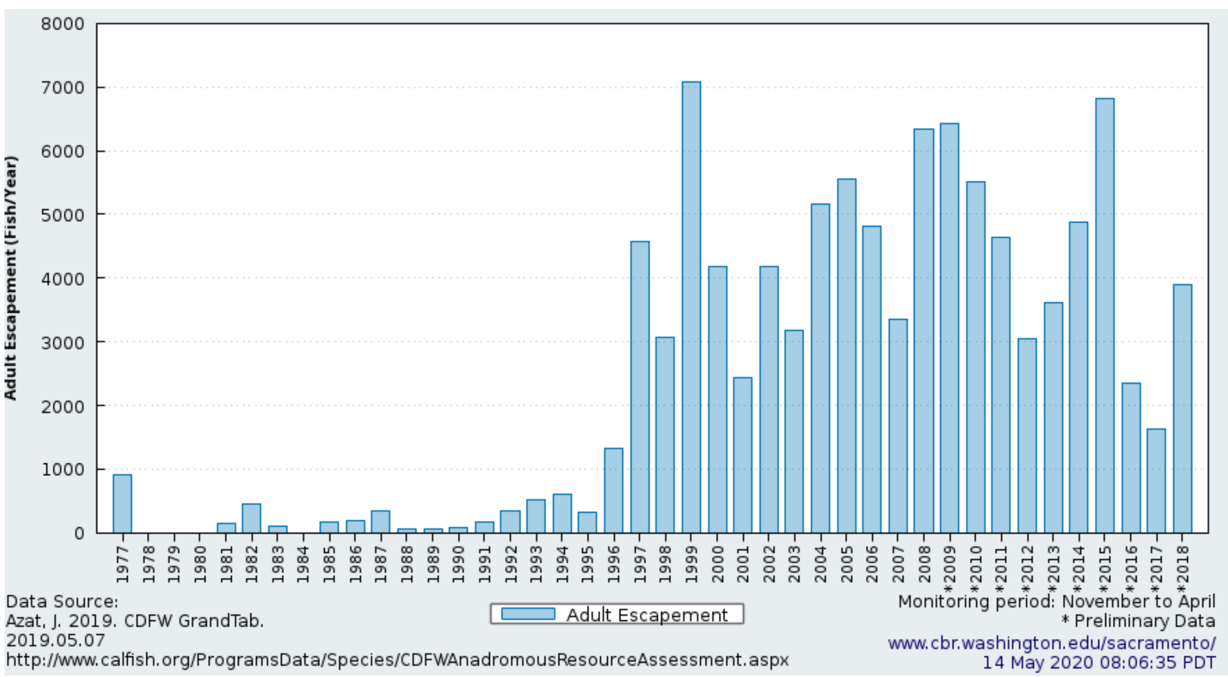


Source: Columbia Basin Research, University of Washington 2020.

Note: Vertical axis scale differs between upper and lower panel.

Figure 11A-12. Fall-Run Chinook Salmon Adult In-River (Upper) and Hatchery (Lower) Annual Escapement in the Central Valley, 1970–2018





Source: Columbia Basin Research, University of Washington 2020.
Note: Vertical axis scale differs between upper and lower panel.

Figure 11A-13. Late Fall–Run Chinook Salmon Adult In-River (Upper) and Hatchery (Lower) Annual Escapement in the Central Valley, 1970–2018

Attachment 1 provides graphical summaries of juvenile fall-run and late fall-run Chinook salmon monitoring, sampling and salvage timing in the Central Valley, as produced by the Central Valley Prediction Assessment of Salmon database (SacPAS).

11A.1.5.4. Stressors

Factors affecting fall-run and late fall–run Chinook salmon are generally similar to those discussed above for winter-run and spring-run Chinook salmon. Recent life cycle modeling for fall-run suggested that among the processes examined, the most influential were temperature experienced during egg incubation, freshwater flow during juvenile outmigration, and environmentally mediated predation during early marine residence (Friedman et al. 2019).[4] Michel (2019) found a statistically significant positive correlation between Sacramento River flow and hatchery-origin fall-run and late fall–run Chinook salmon smolt to adult return ratio, which was higher than the correlation with indices of marine productivity.

Central Valley fall-run and late fall–run Chinook salmon pass through the Delta as adults migrating upstream and juveniles outmigrating downstream. Adult fall-run and late fall–run Chinook salmon migrating through the Delta must navigate the many channels and avoid direct sources of mortality and minimize exposure to sources of nonlethal stress. Additionally, outmigrating juveniles are subject to predation and entrainment in the project export facilities and smaller diversions.

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; Buchanan et al. 2013). Juvenile salmon migrating from the San Joaquin River generally experience greater mortality than fish outmigrating from the Sacramento River. In years when spring flows are reduced and water temperatures are increased, mortality is typically higher in both rivers. Closing the DCC gates and installation of the Head of Old River Fish Control Gate to reduce the movement of juvenile salmon into the south Delta from the Sacramento and San Joaquin Rivers, respectively, may contribute to improved survival of outmigrating juvenile Chinook salmon from these watersheds.

Although not directly comparable to these previous coded wire tag studies in the San Joaquin River, Buchanan et al. (2013, 2015) found that survival of acoustically tagged hatchery-origin (Feather River) juvenile Chinook salmon was either not statistically different between routes (2009) or was higher through the south Delta via the Old River route than via the San Joaquin River (2010). Additionally, most fish in the Old River that survived to the end of the Delta had been salvaged from the federal water export facility on the Old River and trucked around the remainder of the Delta (Buchanan et al. 2013; San Joaquin River Group Authority 2013). Buchanan et al. (2013) indicated that the differences in their results compared to past coded wire tag studies may reflect that an alternative nonphysical barrier was being used during their investigation to examine its ability to keep fish out of the Old River instead of the Head of Old River Fish Control Gate, which is a physical barrier that reduces not only the number of fish, but also the majority of flows, from entering the Old River. Nonphysical barriers may deprive smolts routed to the San Joaquin River of the increased flows needed for improved survival and may have created habitat for increased predation at the site (Buchanan et al. 2013).

---

[4] The most influential environmental processes were represented in the model by daily temperature at RBDD October 1–December 1; median February flow at Colusa; and an annual index of predation by common murre at Southeast Farallon Island.

Mesick (2001) surmised that when water exports are high relative to San Joaquin River flows, little, if any, San Joaquin River water reaches San Francisco Bay, where it may be needed to help attract the salmon back to the Stanislaus River. During mid-October from 1987 through 1989, when export rates exceeded 400% of Vernalis flows, Mesick (2001) found that straying rates ranged between 11% and 17%. In contrast, straying rates were estimated to be less than 3% when Delta export rates were less than about 300% of San Joaquin River flow at Vernalis during mid-October. Marston et al. (2012) provided statistical relationships between straying rate and flow and exports, concluding that the results indicate that flow is the primary factor but that empirical data indicate that little if any pulse flow leaves the Delta when south Delta exports are elevated; they hypothesized that exports in combination with pulse flows may explain straying. Peterson et al. (2017) studied environmental factors and management actions influencing upstream migration patterns of adult fall-run Chinook in the Stanislaus River. They found that the Head of Old River rock barrier had positive and consistent influences on daily counts in the years it was installed and that managed pulse flows resulted in immediate increases in daily passages, but the response was brief and represented a small portion of the total run.

One of the limiting factors for juvenile fall-run Chinook salmon from the Stanislaus River and elsewhere in the San Joaquin River Basin appears to be the high rates of mortality for juveniles migrating through dredged channels in the Delta, particularly the Stockton Deep Water Ship Channel (Newcomb and Pierce 2010). Pickard et al. (1982) reported that the survival of juvenile fish in the ship channel is highest during flood flows or when a barrier is placed at the Head of Old River that more than doubles the flow in the ship channel. As noted in the account for spring-run Chinook salmon, the CAMT SST work suggests that high correlations between inflows and exports make it difficult to evaluate their effects on salmon survival independently using statistical methods. The Stanislaus River Fish Group (SRFG) (2004) noted that escapement is also directly correlated with springtime flows, when each brood migrates downstream as smolts. However, the cause of the mortality in the ship channel has not been studied. Buchanan and Skalski (2020) found through-Delta survival of acoustically tagged fall-run Chinook salmon smolts was positively associated with Old River flow in the strongly tidal interior Delta but not with higher San Joaquin River flow either entering the Delta from upstream or in the Delta near the riverine/tidal interface. Survival in the upstream, more riverine region of the Delta was positively associated with San Joaquin River flow measured at the riverine/tidal interface and average net flow in the interior Delta, which the authors suggested provided evidence of different mechanisms driving survival in the upstream versus downstream reaches of the Delta (Buchanan and Skalski 2020). A large portion of juvenile fall-run Chinook salmon surviving through the Delta from the San Joaquin River Basin move through the CVP salvage facility (Buchanan et al. 2018).

Dredging for gravel and gold, regulated flows, and the diking of floodplains for agriculture have substantially limited the availability of spawning and rearing habitat for fall-run Chinook salmon in the Stanislaus River. Reclamation has conducted spawning gravel augmentation to improve spawning and rearing habitats in the Stanislaus River reach between Goodwin Dam and Knights Ferry in most years since 1999. The dredged areas also contain an abundance of large predatory fish, although SRFG concluded that there is uncertainty about whether predation is a substantial source of mortality for juvenile salmon. SRFG (2004) also concluded that water diversions for urban and agricultural use in all three San Joaquin River tributaries, which reduce flows and potentially result in unsuitably warm water temperatures during spring and fall, affecting fall-run

Chinook salmon juvenile rearing and adult and juvenile migration in the lower San Joaquin River and Delta.

In the Delta, tidal and floodplain habitat areas provide important rearing habitat for foraging juvenile salmonids, including fall-run Chinook salmon. Studies have shown that juvenile salmon may spend 2 to 3 months rearing in these habitat areas, and habitat losses resulting from land reclamation and levee construction are considered to be major stressors (Williams 2010). The channeled, leveed, and riprapped river reaches and sloughs common in 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.

11A.1.6. Steelhead—California Central Valley DPS

11A.1.6.1. Legal Status

The California Central Valley (CCV) steelhead (*Oncorhynchus mykiss irideus*) ESU was listed as a threatened species under 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 Bay-Delta (63 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 DPS, which is also listed as threatened under the ESA. On June 14, 2004, NMFS proposed that all west coast steelhead be reclassified from ESUs to DPSs and proposed to retain CCV 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 CCV 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 CCV 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.

CCV steelhead is not listed under CESA but is designated as a California SSC.

11A.1.6.2. Life History and General Ecology

Upstream migration of CCV steelhead begins with estuarine entry from the ocean as early as July and continues through February or March in most years (McEwan and Jackson 1996; National Marine Fisheries Service 2009a). Populations of steelhead occur primarily within the watersheds of the Sacramento River Basin, although not exclusively. Steelhead can spawn more than once, with postspawn adults (typically females) potentially moving back downstream through the Delta after completion of spawning in their natal streams.

Upstream migrating adult steelhead enter the Sacramento River and San Joaquin River Basins through their respective mainstem river channels. Steelhead entering the Mokelumne River system (including Dry Creek and the Cosumnes River) and the Calaveras River system to spawn are likely to move up the mainstem San Joaquin River channel before branching off into the channels of their natal rivers, although some may detour through the south Delta waterways and enter the San Joaquin River through the Head of Old River.

Steelhead entering the San Joaquin River Basin appear to have a later spawning run than those entering the Sacramento River, with adults entering the system starting in late October through December, indicating that migration up through the Delta may begin a few weeks earlier. During fall, warm water temperatures in the south Delta waterways and water quality impairment because of low dissolved oxygen at Stockton have been suggested as potential barriers to upstream migration (National Marine Fisheries Service 2009a). Reduced water temperatures, as well as rainfall runoff and flood control release flows, provide the stimulus to adult steelhead holding in the Delta to move upriver toward their spawning reaches in the San Joaquin River tributaries. Adult steelhead may continue entering the San Joaquin River Basin through winter.

Juvenile steelhead can be found in all waterways of the Delta, but particularly in the main channels leading from their natal river systems (National Marine Fisheries Service 2009a). Juvenile steelhead are recovered in trawls from October through July at Chipps Island and at Mossdale. Chipps Island catch data indicate there is a difference in the outmigration timing between wild and hatchery-reared steelhead smolts from the Sacramento and eastside tributaries. Hatchery fish are typically recovered at Chipps Island from January through March, with a peak in February and March corresponding to the schedule of hatchery releases of steelhead smolts from the Central Valley hatcheries (Nobriga and Cadrett 2001; Reclamation 2008). The timing of wild (unmarked) steelhead outmigration is more spread out and based on salvage records at the CVP and SWP fish collection facilities, outmigration occurs over approximately 6 months with the highest levels of recovery in February through June (Aasen 2011, 2012). Steelhead are salvaged annually at the project export facilities (e.g., 4,631 fish were salvaged in 2010, and 1,648 in 2011) (Aasen 2011, 2012).

Outmigrating steelhead smolts enter the Delta primarily from the Sacramento or San Joaquin Rivers. Mokelumne River steelhead smolts can either follow the north or south branches of the Mokelumne River through the central Delta before entering the San Joaquin River, although some fish may enter farther upstream if they diverge from the south branch of the Mokelumne River into Little Potato Slough. Calaveras River steelhead smolts enter the San Joaquin River downstream of the Port of Stockton. Although steelhead have been routinely documented by CDFW in trawls at Mossdale since 1988 (San Joaquin River Group Authority 2011), it is unknown whether successful outmigration occurs outside the seasonal installation of the barrier at the Head of Old River (between April 15 and May 15 in most years). Prior to the installation of the Head of Old River Fish Control Gate, steelhead smolts exiting the San Joaquin River Basin could follow one of two routes to the ocean, either staying in the mainstem San Joaquin River through the central Delta or entering the Head of Old River and migrating through the south Delta and its associated network of channels and waterways.

CCV steelhead use the San Francisco and San Pablo Bays as a migration corridor to and from the ocean. The juveniles move quickly through the bays on their way to the ocean, preying on a variety of macroinvertebrates and small fish.

Steelhead are broadly divided into two life history types, summer-run steelhead and winter-run steelhead, based on their state of sexual maturity at the time of river entry. Only winter-run steelhead are currently found in Central Valley rivers and streams. Historically, CCV steelhead were distributed from the upper Sacramento and Pit River systems (upper Sacramento, McCloud, Pit, and Fall Rivers) south to the Kings River (and possibly Kern River system in wet years) (McEwan 2001). Presently, CCV steelhead are found in the Sacramento River downstream of Keswick Dam, in major tributary rivers and creeks in the Sacramento River watershed, and in major tributaries of the San Joaquin River (Stanislaus, Tuolumne, Merced Rivers) and Delta (Mokelumne and Calaveras River). The populations in the Feather and American Rivers are supported primarily by the Feather River and Nimbus Fish Hatcheries. Other major steelhead populations in the Sacramento River watershed are found in Battle, Mill, Deer, Clear, and Butte Creeks.

Adult steelhead migrate upstream past the Fremont Weir between August and March, but primarily from August through October, and they migrate upstream past RBDD during all months of the year, but primarily during September and October (National Marine Fisheries Service 2009a). The primary spawning area used by steelhead in the Sacramento River is the area from Keswick Dam downstream to RBDD. Unlike Pacific salmon, steelhead may live to spawn more than once and generally rear in freshwater streams for 2 to 4 years before outmigrating to the ocean. Both spawning areas and migratory corridors are used by juvenile steelhead for rearing prior to outmigration. The Sacramento River functions primarily as a migration channel, although some rearing habitat remains in areas with setback levees (primarily upstream of Colusa) and flood bypasses (e.g., Yolo Bypass) (National Marine Fisheries Service 2009a).

11A.1.6.3. Distribution and Abundance

Recent steelhead monitoring data are scarce for the upper portion of the Sacramento River system. Hallock (1989) reported that steelhead had declined drastically in the Sacramento River upstream of the Feather River confluence. In the 1950s, the average estimated spawning population size upstream of the Feather River confluence was 20,540 fish (McEwan and Jackson 1996). In 1991–1992, the annual run size for the total Sacramento River system was likely fewer than 10,000 adult fish (McEwan and Jackson 1996). From 1967 to 1993, the estimated number of steelhead passing the Red Bluff Pumping Plant ranged from a low of 470 to a high of 19,615 (California Hatchery Scientific Review Group 2012). Steelhead escapement surveys at Red Bluff ended in 1993.

Both steelhead and resident (non-anadromous) rainbow trout (*Oncorhynchus mykiss*) occur in Clear Creek. Adult CCV steelhead populations in Clear Creek have been relatively stable between 2003 and 2011, with redd counts ranging from 42 to 409, with an average of 176 (Giovanetti et al. 2013; Provins and Chamberlain 2019). Adult Central Valley steelhead spawn in Clear Creek from early December to mid-March. Steelhead rear in Clear Creek year-round, and outmigration can occur in any month, although peak outmigration in 2011 was from February to June (Schraml et al. 2018).

CCV steelhead adults migrate into the Feather River between July and March, and redd construction occurs from late December to March, peaking in late January (Federal Energy Regulatory Commission 2007; McEwan 2001). Spawning in the Feather River primarily occurs within the low-flow channel between the Fish Barrier Dam and the Thermalito Afterbay outlet, although a small amount of spawning occurs downstream of the Thermalito Afterbay outlet (Federal Energy Regulatory Commission 2007). Nearly half of all observed redds are constructed in the uppermost mile of the low-flow channel (Federal Energy Regulatory Commission 2007). Fry begin to outmigrate in February, soon after emerging, with the majority outmigrating between March and mid-April. Most juveniles outmigrate by September, but a small portion of juveniles that do not outmigrate rear in the river for up to 1 year, most often in secondary channels of the low-flow channel (Federal Energy Regulatory Commission 2007).

Although some spawning by steelhead in the American River occurs naturally (Hannon and Deason 2008), the population is supported primarily by the Nimbus Fish Hatchery. The total estimated steelhead return to the river (spawning naturally and in the hatchery) has ranged from 946 to 3,426 fish, averaging 2,184 fish per year from 2002 to 2010 (California Hatchery Scientific Review Group 2012). Steelhead spawning surveys have shown approximately 300 steelhead spawning in the river each year (Hannon and Deason 2008). Lindley et al. (2007) classifies the listed (i.e., naturally spawning) population of American River steelhead at a high risk of extinction because it is reportedly mostly composed of winter-run steelhead originating from Nimbus Fish Hatchery; possibly up to 90% of spawners are of hatchery origin (Hannon and Deason 2008). NMFS considers the American River population to be important to the survival and recovery of the species (National Marine Fisheries Service 2009a).

Steelhead from the American River (collected from both the Nimbus Fish Hatchery and the American River) are genetically more similar to Eel River and Mad River steelhead than other Central Valley steelhead stocks because individuals from these rivers were used as broodstock for Nimbus Fish Hatchery (Nielsen et al. 2005; California Hatchery Scientific Review Group 2012). American River steelhead exhibit a slightly later upstream migration period than other Central Valley steelhead (Lee and Chilton 2007).

Adult steelhead migrate up the American River from October through April with a peak occurring from December through March (Surface Water Resources 2001). Adult steelhead have been caught in the Nimbus Fish Hatchery trap as early as the first week of October. Spawning typically occurs in the lower American River between late December and early April, with the peak occurring in late February to early March (Hannon and Deason 2008). Spawning occurs between Nimbus Dam and Paradise Beach, although approximately 90% of spawning occurs upstream of the Watt Avenue Bridge (Hannon and Deason 2008). Embryo incubation occurs shortly after spawning in late December and generally extends through May, although incubation can occur into June in some years (Surface Water Resources 2001). Although steelhead embryo and alevin mortality from high flows in the American River has not been documented, flows high enough to mobilize spawning gravels and scour or entomb redds have been recorded during the spawning and embryo incubation periods (National Marine Fisheries Service 2009a). Juvenile *O. mykiss* are present year-round throughout the lower American River, with rearing generally upstream of spawning areas. Juveniles can rear in the lower American River for a year or more before outmigrating as smolts from January through June (Snider and Titus 2000; Surface Water Resources 2001), although it is rare to find individuals older than YOY fry and parr (Snider and Titus 2002; Pacific States Marine Fisheries Commission 2014). Peak juvenile steelhead outmigration occurs from March through May (McEwan and Jackson 1996; Surface Water Resources 2001; Pacific States Marine Fisheries Commission 2014). Juvenile steelhead rear in the lower American River from Nimbus Dam to Paradise Beach. During summer months, juveniles occur in most major riffle areas, with the highest densities near the higher density spawning areas (Reclamation 2008). The number of juveniles in the American River decreases throughout summer (Reclamation 2008). Juveniles experience water temperature-related stress during summer and early fall (Lower American River Task Force 2002; Water Forum 2005; National Marine Fisheries Service 2014) despite laboratory studies indicating that American River steelhead may be more tolerant of high temperatures than steelhead from other rivers (Myrick and Cech 2004).

CCV steelhead were thought to be extirpated from the San Joaquin River system (National Marine Fisheries Service 2009a). However, monitoring has detected small self-sustaining (i.e., of natural origin, not of hatchery origin) populations of steelhead in the Stanislaus River and other streams previously thought to be devoid of steelhead (Stanislaus River Fish Group 2003; McEwan 2001). There is a catch-and-release steelhead fishery in the lower Stanislaus River between January 1 and October 15. Surveys of *O. mykiss* (resident rainbow trout and the anadromous steelhead) abundance and distribution conducted annually since 2009 have documented a relatively stable population. River-wide abundance estimates from 2009 to 2014 have averaged just over 20,220 (all life stages combined) and have never been estimated to be less than about 14,000 (2009). The highest densities and abundances of *O. mykiss* are consistently found in Goodwin Canyon. Key factors that may contribute to higher than average abundances in the Stanislaus River (relative to other San Joaquin River tributaries) include high gradient reaches that are typically associated with fast-water habitats, particularly in Goodwin Canyon (State Water Resources Control Board 2015).

Historically, the distribution of steelhead extended into the headwaters of the Stanislaus River (Yoshiyama et al. 1996). Steelhead currently can migrate more than 58 miles (93.3 km) up the Stanislaus River to the base of Goodwin Dam. In the Stanislaus River, there are few data regarding the migration patterns of adult steelhead since adults generally migrate during periods when river flows and turbidity are high, making fish difficult to observe with standard adult monitoring techniques. Stanislaus River weir data indicate that steelhead migrate upstream, through the south Delta and lower San Joaquin River, between September and March (Reclamation 2014). High Delta export rates relative to San Joaquin River flows at Vernalis, when adults are migrating through the Delta (presumably December through May), may result in adults straying to the Sacramento River Basin.

It is believed that steelhead spawn primarily between December and March in the Stanislaus River. Although few steelhead spawning surveys have been conducted in the Stanislaus River, spawning *O. mykiss* were documented between Goodwin Dam and Horseshoe Bar in a 2014 spawning survey (Reclamation and California Department of Water Resources 2015). The spawning adults require holding and feeding habitat with cover adjacent to suitable spawning habitat. These habitat features are relatively rare in the lower Stanislaus River because of in-river gravel mining and the scouring of gravel from riffles in Goodwin Canyon.

Juvenile steelhead rear in the Stanislaus River for at least 1 year, and usually 2 years, before migrating to the ocean. As a result, flow, water temperature, and dissolved oxygen concentration in the reach between Goodwin Dam and the Orange Blossom Bridge (their primary rearing habitat) are critical during summer (Reclamation 2012).

Small numbers of CCV steelhead smolts have been captured in rotary screw traps at Caswell State Park and near Oakdale (FISHBIO Environmental 2007; Watry et al. 2007, 2012), and data indicate that steelhead outmigrate primarily from February through May. Rotary screw traps are generally not considered efficient at catching fish as large as steelhead smolts, and the number captured is too small to estimate capture efficiency, so no steelhead smolt outmigration population estimate has been calculated. The capture of these fish in downstream migrant traps and the advanced smolting characteristics exhibited by many of the fish indicate that some steelhead/rainbow trout juveniles might outmigrate to the ocean in spring. However, it is not known whether the parents of these fish were anadromous or fluvial (i.e., migrate within fresh water). Resident populations of steelhead/rainbow trout in large streams are typically fluvial, and migratory juveniles look much like smolts.

Steelhead were historically present in the San Joaquin River, though data on their population levels are lacking (McEwan 2001). The current steelhead population in the San Joaquin River is substantially reduced compared with historical levels, although resident rainbow trout occur throughout the major San Joaquin River tributaries. Additionally, small populations of steelhead persist in the lower San Joaquin River and tributaries (e.g., Stanislaus, Tuolumne, and possibly Merced Rivers) (Zimmerman et al. 2009; McEwan 2001). Steelhead/rainbow trout of anadromous parentage occur at low numbers in all three major San Joaquin River tributaries. These tributaries have a higher percentage of resident rainbow trout compared to the Sacramento River and its tributaries (Zimmerman et al. 2009). Presence of steelhead smolts from the San Joaquin River Basin is estimated annually by CDFW based on the Mossdale Trawl (San Joaquin River Group Authority 2011). The sampling trawls capture steelhead smolts, although usually in small numbers. One steelhead smolt was captured and returned to the river during the 2009 sampling period (San Joaquin River Group Authority 2010), and three steelhead were captured and returned in both 2010 and 2011 (Speegle et al. 2013).

General life stage timing for CCV steelhead is summarized in Tables 11A-8 and 11A-9.

Table 11A-8. Temporal Occurrence of Central Valley Steelhead by Life Stage

Relative Abundance	High (▼)								Medium (☒)						Low (#)					None (-)					
Migration Life Stage: (a) Adult	Month																							
Location	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
[1]Sacramento R. at Fremont Weir	#	#	#	#	#	-	-	-	-	-	-	#	#	#	#	☒	▼	▼	▼	☒	#	#	#	#
[2]Sacramento R. at Red Bluff Diversion Dam	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	☒	☒	▼	☒	#	#	#	#
[3]San Joaquin River	▼	▼	☒	☒	#	#	-	-	-	-	-	-	#	#	#	#	☒	☒	☒	☒	☒	☒	▼	▼
Migration Life Stage: (b) Juvenile	Month																							
Location	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
[1,2]Sacramento R. near Fremont Weir	#	#	#	#	☒	☒	☒	☒	☒	☒	☒	☒	#	#	#	#	#	#	☒	☒	☒	☒	#	#
[4]Sacramento R. at Knights Landing	▼	▼	▼	▼	☒	☒	☒	☒	#	#	#	#	-	-	-	-	-	-	-	-	#	#	#	#
[5]Chipps Island (clipped)	☒	☒	▼	▼	☒	☒	#	#	#	#	-	-	-	-	-	-	-	-	-	-	-	-	#	#
[5]Chipps Island (unclipped)	☒	☒	☒	☒	▼	▼	▼	▼	▼	▼	☒	☒	#	#	-	-	-	-	-	-	-	#	#	#
[6]San Joaquin R. at Mossdale	-	-	#	#	☒	☒	▼	▼	▼	▼	#	#							#	#	-	-	-	-

Sources: [1] Hallock et al. (1957); [2]McEwan (2001); [3]California Department of Fish and Game (2007); [4]NMFS analysis of 1998-2018 CDFW data; [5]NMFS analysis of 1998-2018 USFWS data; [6]NMFS analysis of 2003-2018 USFWS data.

Source: National Marine Fisheries Service 2019:100.

Table 11A-9. Temporal Occurrence of Central Valley Steelhead by Life Stage in the Delta

Relative Abundance	High (▼)			Medium (☒)			Low (#)			None (-)	
Life Stage	Month										
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult [1]	☒	☒	☒	☒	▼	-	#	☒	▼	☒	☒	☒
Juvenile [2]	#	☒	☒	▼	▼	#	#	-	#	-	-	#
Salvaged [3]	☒	▼	▼	☒	#	#	-	-	-	-	#	#

1Adult presence was determined using information in Moyle (2002), Hallock et al. (1961), and California Department of Fish and Wildlife (2015b).
2Juvenile presence in the Delta was determined using Delta Juvenile Fish Monitoring Program data.
3Months in which salvage of wild juvenile steelhead at State and Federal pumping plants occurred; values in cells are salvage data reported by the facilities (He and Stuart 2016).

Source: National Marine Fisheries Service 2019:101).

Attachment 1 provides graphical summaries of juvenile steelhead monitoring, sampling and salvage timing in the Central Valley, as produced by the Central Valley Prediction Assessment of Salmon database (SacPAS).

11A.1.7. Steelhead—Central California Coast DPS

11A.1.7.1. Distribution, Life History, and Habitat Requirements

Central California Coast steelhead (*Oncorhynchus mykiss irideus*) DPS are winter-run steelhead and therefore are at or near sexual maturity when they enter fresh water during late fall and winter. They typically enter San Francisco Bay in early winter, although they have been seen in the bay as early as August (Goals Project 2000). Central California coast steelhead from San Francisco and San Pablo Bays spawn in tributaries of the bays, including the Guadalupe and Napa Rivers and Sonoma Creek. They spawn from late December through April. Juvenile steelhead typically rear in fresh water for a longer time period than other salmonids, typically ranging from 1 to 3 years. Throughout their range, steelhead typically remain at sea for one to four growing seasons before returning to fresh water to spawn.

Migrating adult steelhead require deep holding pools with cover such as underwater ledges and caverns. The juveniles are primarily drift feeders and may forage in open water of estuarine subtidal and riverine tidal wetland habitats. The estuarine diet of juvenile steelhead includes emergent aquatic insects, aquatic insect larvae, snails, amphipods, opossum shrimp (mysids), and small fish.

Central California coast steelhead spawn in several drainages of San Francisco and San Pablo Bays, including the Guadalupe River, Coyote Creek, San Francisquito Creek, Sonoma Creek, and the Napa River (Leidy et al. 2005). Historically, most streams with suitable habitat within the San Francisco Estuary supported central California coast steelhead populations. Current runs are estimated at fewer than 10,000 fish in San Francisco Bay tributaries (Goals Project 2000).

11A.1.8. Green Sturgeon—Southern DPS

11A.1.8.1. Legal Status

The North American green sturgeon (*Acipenser medirostris*) population is composed of two 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 designated as a Species of Concern (69 FR 19975). Only the Southern DPS is found in the Plan Area.

After a status review was completed in 2002 (Adams et al. 2002), 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 ESA (National Marine Fisheries Service 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 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 on July 2, 2010 (75 FR 30714).

11A.1.8.2. Life History and General Ecology

Green sturgeon reach maturity around 14 to 16 years of age and can live to be 70 years old, returning to their natal rivers every 3 to 5 years for spawning (Van Eenennaam et al. 2005). Adult green sturgeon move through the Delta from February through April, arriving at holding and spawning locations the upper Sacramento River between April and June (Heublein 2006; Kelly et al. 2007). Following their initial spawning run upriver, adults may hold for a few weeks to months in the upper river before moving back downstream in fall (Vogel 2008; Heublein et al. 2009), or they may migrate immediately back downstream through the Delta. Radio-tagged adult green sturgeon have been tracked moving downstream past Knights Landing during summer and fall, typically in association with pulse flows in the river (Heublein et al. 2009), similar to behavior exhibited by adult green sturgeon on the Rogue River and Klamath River systems (Erickson et al. 2002; Benson et al. 2007).

Similar to other estuaries along the West Coast of North America, adult and subadult green sturgeon frequently congregate in the San Francisco Estuary during summer and fall (Lindley et al. 2008). Specifically, adults and subadults may reside for extended periods in the central Delta as well as in Suisun and San Pablo Bays, presumably for feeding, because bays and estuaries are preferred feeding habitat rich in benthic invertebrates (e.g., amphipods, bivalves, and insect larvae). In part because of their bottom-oriented feeding habits, sturgeon are at risk of harmful accumulations of toxic pollutants in their tissues, especially pesticides such as pyrethroids and heavy metals such as selenium and mercury (Israel and Klimley 2008; Stewart et al. 2004). Subadult and adult green sturgeon occupy a diversity of depths within bays and estuaries for feeding and migration. Tagged adults and subadults within the San Francisco Estuary and Delta occupy waters over shallow depths of less than 33 feet (10 m), either swimming near the surface or foraging along the bottom, although recent studies suggested adults tend to be benthically oriented in the San Francisco Estuary and Delta (Chapman et al. 2019). Juvenile green sturgeon are largely oriented at or near the bottom (Thomas et al. 2019).

Green sturgeon larval distribution is estimated to extend at least 62 miles downstream from spawning habitats on the Sacramento and Feather Rivers in high-flow years. This estimated downstream distribution corresponds with the Colusa area on the Sacramento River (RM 157) and the confluence of the Sacramento and Feather Rivers near Verona (RM 80) for larvae originating in the Sacramento River and Feather River, respectively (Heublein et al. 2017a:14). Juveniles are believed to use the Delta for rearing for the first 1 to 3 years of their lives before moving out to the ocean and are likely to be found in the main channels of the Delta and the larger interconnecting sloughs and waterways, especially within the central Delta and Suisun Bay and Suisun Marsh. Project operations at the DCC have the potential to reroute green sturgeon as they outmigrate through the lower Sacramento River to the Delta (Israel and Klimley 2008; Vogel 2011). When the DCC is open, there is no passage delay for adults, but juveniles could be diverted from the Sacramento River into the interior Delta. This has been shown to reduce the survival of juvenile Chinook salmon (Brandes and McLain 2001; Newman and Brandes 2010; Perry et al. 2012), but it is unknown whether it has similar effects on green sturgeon.

The Sacramento River provides habitat for green sturgeon spawning, adult holding, foraging, and juvenile rearing. Sturgeon spawn in deep pools (averaging about 28 feet or 8.5 m deep) (National Marine Fisheries Service 2018). Suitable spawning temperatures and spawning substrate exist for green sturgeon in the Sacramento River upstream and downstream of RBDD (Reclamation 2008). Although the upstream extent of historical green sturgeon spawning in the Sacramento River is unknown, the observed distribution of sturgeon eggs, larvae, and juveniles indicates that spawning occurs from Hamilton City to as far upstream as the Inks Creek confluence and possibly up to the Cow Creek confluence (Brown 2007; Poytress et al. 2013). Adult green sturgeon that migrate upstream in April, May, and June are completely blocked by the Anderson-Cottonwood Irrigation District (ACID) diversion dam (National Marine Fisheries Service 2009), rendering approximately 3 miles of spawning habitat upstream of the diversion dam inaccessible. Based on the distribution of sturgeon eggs, larvae, and juveniles in the Sacramento River, CDFW (2002) indicated that green sturgeon spawn in late spring and early summer, although they periodically spawn in late summer and fall (as late as October) (Heublein et al. 2009, 2017b; National Marine Fisheries Service 2018). Green sturgeon eggs are believed generally to hatch about a week after fertilization (Heublein et al. 2017b). The number of green sturgeon accessing the upper Sacramento River appears to have increased following the decommissioning of RBDD (Steel et al. 2019).

Green sturgeon from the Sacramento River are genetically distinct from their northern counterparts, indicating a spawning fidelity to their natal rivers (Israel et al. 2004), even though individuals can range widely (Lindley et al. 2008). Larval green sturgeon have been regularly captured during their dispersal stage at about 2 weeks of age (24 to 34 mm fork length) in rotary screw traps at RBDD (California Department of Fish and Game 2002) and at about 3 weeks old when captured at the Glenn-Colusa Irrigation District (GCID) intake (Van Eenennaam et al. 2001). Young green sturgeon appear to rear for the first 1 to 2 months in the Sacramento River between Keswick Dam and Hamilton City (California Department of Fish and Game 2002).

Southern DPS North American green sturgeon are thought to have historically spawned in the Sacramento, Feather, and San Joaquin Rivers (Adams et al. 2007). Adults enter San Francisco Bay around late winter through early spring and generally migrate to spawning areas from late February through April. Spawning mainly occurs April through late July, with some occurring in late summer and early fall (Heublein et al. 2017a). A significant portion of the spawning habitat was lost with the construction of Oroville Dam (Federal Energy Regulatory Commission 2007; Yoshiyama et al. 2001; Schick et al. 2005). While regular occurrence of green sturgeon has been verified in the Sacramento River, only intermittent observations of spawning, at the Thermalito Afterbay outlet, have been reported in the lower Feather River (Beamesderfer et al. 2007; Seesholtz and Manuel 2012). After hatching, green sturgeon larvae possess limited swimming ability and generally seek refuge in low-velocity and complex habitats, such as large cobble substrate (Kynard et al. 2005). While little is known about green sturgeon rearing, it is likely that juveniles rear near spawning habitat for a few months or more before migrating to the Delta (Heublein et al. 2017b:15).

Green sturgeon is also present in the San Joaquin River, but at considerably lower numbers than white sturgeon (*Acipenser transmontanus*). Between 2007 and 2012, anglers reported catching six green sturgeon in the San Joaquin River (Jackson and Van Eenennaam 2013). In 2017, environmental DNA testing confirmed the identity of a green sturgeon observed in the Stanislaus River at Knights Ferry. Although the reported presence of green sturgeon in the San Joaquin River coincides with the spawning migration period of green sturgeon within the Sacramento River, no evidence of spawning has been detected (Jackson and Van Eenennaam 2013).

General life stage timing for southern DPS green sturgeon is summarized in Tables 11A-10 and 11A-11.

Table 11A-10. Temporal Occurrence of Southern Distinct Population Segment Green Sturgeon by Life Stage

Relative Abundance	High (▼)									Medium (⊠)							Low (#)					None (-)			
Life-Stage: (a) Adult-sexually mature[1]	Month																							
Location	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Sac River (river mile 332.5-451)	#	#	#	#	⊠	⊠	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	⊠	⊠	⊠
Sac River (<river mile 332.5)	#	#	#	⊠	⊠	⊠	⊠	⊠	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
Sac-SJ-SF Estuary	#	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	#	#
(b) Larva	Month																							
Location	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Sac River (<river mile 332.5)	-	-	-	-	-	#	⊠	⊠	▼	▼	▼	▼	▼	▼	⊠	⊠	⊠	⊠	#	#	-	-	-	-
(c) Juvenile (≤5 months old)	Month																							
Location	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Sac River (<river mile 332.5)	-	-	-	-	-	-	-	#	⊠	⊠	⊠	⊠	▼	▼	▼	▼	▼	▼	▼	⊠	⊠	⊠	⊠	⊠
(d) Juvenile (≤5 months old)	Month																							
Sac River (<river mile 391)	⊠	⊠	⊠	⊠	#	#	#	#	#	#	#	⊠	⊠	⊠	⊠	▼	▼	▼	▼	▼	▼	▼	▼	#
(e) Sub-Adults and Non-spawning adults	Month																							
Location	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Sac-SJ-SF Estuary	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	⊠	⊠
Pacific Coast	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠
Coastal Bays & Estuaries	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	▼	▼	▼	▼	▼	▼	▼			▼	▼ ▼	▼	▼ ⊠	⊠

[1] *Sexually mature adults (≥4.8 feet TL females, ≥ 3.9 feet TL males including pre- and post- spawning individuals)*

Sources: (a) (Heublein et al. 2009); (DuBois and Danos 2018; Klimley et al. 2015a; Mora et al. 2018; Poytress et al. 2015); (b) (Heublein et al. 2017; Poytress et al. 2015); (c) (Heublein et al. 2017; Poytress et al. 2015); (d) (California Department of Fish and Game 2002; Heublein et al. 2017; Poytress et al. 2015; Radtke 1966); (e) (DuBois and Danos 2018; Erickson and Webb 2007; Huff et al. 2011; Lindley et al. 2011; Lindley et al. 2008; Moser and Lindley 2007). Outside of Sac-SJ-SF estuary (e.g. Columbia R., Grays Harbor, Willapa Bay).

Source: National Marine Fisheries Service 2019:113–114.

Table 11A-11. Temporal Occurrence of Southern Distinct Population Segment Green Sturgeon by Life Stage in the Delta

Relative Abundance	High (▼)	Medium (⊠)	Low (#)	None (-)

Life Stage	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adult [1]	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠
Juvenile [2]	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠	⊠
Salvaged [3]	#	#	#	#	#	-	⊠	▼	#	#	#	#

[1]*Adult presence was determined to be year round according to information in (California Department of Fish and Game 2008; California Department of Fish and Game 2009; California Department of Fish and Game 2010a; California Department of Fish and Game 2011; California Department of Fish and Game 2012; California Department of Fish and Wildlife 2013a; California Department of Fish and Wildlife 2014a; Lindley et al. 2008; Moyle 2002).*

[2]*Juvenile presence in the Delta was determined to be year round by using information in (USFWS Delta Juvenile Fish Monitoring Program data), (Moyle et al. 1995; Radtke 1966).*

Source: National Marine Fisheries Service 2019:115.

11A.1.8.3. Distribution and Abundance

The current population status is unknown (Beamesderfer et al. 2007; Adams et al. 2007). A genetic analysis of green sturgeon larvae captured in the Sacramento River resulted in an estimate of the number of adult spawning pairs upstream of RBDD ranging from 32 to 124 between 2002 and 2006 (Israel 2006). Using results from acoustic telemetry and dual-frequency identification sonar (DIDSON) studies to locate green sturgeon in the Sacramento River to derive an adult spawner abundance estimate of 2,106 fish (95% confidence interval = 1,246–2,966), Mora et al. (2018) applied a conceptual demographic structure to the adult population estimate and generated a subadult sDPS green sturgeon population estimate of 11,055 (95% confidence interval = 6,540–15,571), together with an estimate of 4,387 juveniles (95% confidence interval = 2,595–6,179). It should be noted that the estimate does not include spawning adults in the lower Feather or Yuba Rivers (National Marine Fisheries Service 2019), with spawning confirmed in the Feather River (Seesholtz et al. 2015). Mora et al. (2018) cautioned that their juvenile and subadult green sturgeon estimates are less reliable than their adult estimates because the former were based on the ratios from a modeling study; the percentage of juvenile sturgeon is particularly uncertain because so little is known about this life stage. Additionally, the modeling study upon which the juvenile and subadult estimates are based requires four assumptions that Mora et al. (2018) admitted are rarely met: (1) constant recruitment, (2) population equilibrium, (3) stable size and age structure, and (4) a lack of density dependence. Mora et al. (2018) suggested, however, that their study provided a rough estimate of total abundance that is suitable for assessing the impacts of take, such as that observed in coastal trawl fisheries and at large water diversions.

Juvenile green sturgeon and white sturgeon are periodically (although rarely) collected from the lower San Joaquin River at south Delta water diversion facilities and other sites (National Marine Fisheries Service 2009; Aasen 2011, 2012). Green sturgeon are salvaged from the south Delta diversion facilities and are generally juveniles greater than 10 months but less than 3 years old (Reclamation 2008). NMFS (2005) suggested that the high percentage of San Joaquin River flows contributing to the TFCF could mean that some entrained green sturgeon originated in the

San Joaquin River Basin. Anglers have reported catching a few green sturgeon in recent years in the San Joaquin River (California Department of Fish and Game 2012b).

11A.1.8.4. Stressors

In part because of their bottom-oriented feeding habits, sturgeon are at risk of harmful accumulations of toxic pollutants in their tissues, especially pesticides such as pyrethroids and heavy metals such as selenium and mercury (Israel and Klimley 2008; Stewart et al. 2004).

NMFS (2009) noted that, similar to winter-run Chinook salmon, the restriction of spawning habitat for green sturgeon to only one reach of the Sacramento River increases the vulnerability of this spawning population to catastrophic events, which is one of the primary reasons that the Southern DPS of green sturgeon was federally listed as a threatened species in 2006. However, there is evidence that green sturgeon may also spawn in the Feather River, although perhaps irregularly (Seesholtz et al. 2015).

11A.1.9. White Sturgeon

11A.1.9.1. Status, Distribution, Life History, and Habitat Requirements

The population status of white sturgeon in the Sacramento River is unclear. Overall, limited information on trends in adult and juvenile abundance in the Delta population suggests that numbers are declining (Reis-Santos et al. 2008). Statistical analysis has demonstrated a positive relationship between Delta outflow and recruitment of white sturgeon year classes (Kohlhorst et al. 1991).

White sturgeon are generally similar to green sturgeon in terms of their biology and life history. Like green sturgeon and other sturgeon species, white sturgeon are late-maturing and infrequent spawners, which makes them vulnerable to overexploitation and other sources of adult mortality. White sturgeon are believed to be most abundant within the San Francisco Estuary and Delta region (Moyle 2002). Both nonspawning adults and juveniles can be found throughout the Delta year-round (Radtke 1966; Kohlhorst et al. 1991; Moyle 2002; California Department of Water Resources et al. 2013). When not undergoing spawning or ocean migrations, adults and subadults are usually most abundant in brackish portions of the San Francisco Estuary and Delta (Kohlhorst et al. 1991). White sturgeon is not presently listed under the ESA or CESA but is a California SSC (Moyle et al. 2015:102–117). Overall, information on trends in adults and juveniles suggests that numbers are declining (Moyle 2002; National Marine Fisheries Service 2009a).

Central Valley white sturgeon are most abundant within the San Francisco Estuary and Delta, but the population spawns mainly in the Sacramento River (Moyle 2002). White sturgeon larvae rear primarily in the Sacramento River and the Delta (Moyle 2002; Israel et al. 2008). White sturgeon are found in the Sacramento River primarily downstream of RBDD (Tehama-Colusa Canal Authority 2008), with most spawning between Knights Landing and Colusa (Schaffter 1997).

The Central Valley population of white sturgeon spawns mainly in the Sacramento and Feather Rivers, with occasional spawning in the San Joaquin River (Moyle 2002; Jackson 2013). Most spawning in the Sacramento River occurs in April and May between Knights Landing and Colusa (Kohlhorst 1976). Spawning-stage adults generally move into the lower reaches of rivers during winter prior to spawning and migrate upstream in response to higher flows to spawn from February to early June (McCabe and Tracy 1994; Schaffter 1997).

After absorbing yolk sacs and initiating feeding, YOY white sturgeon make an active downstream migration that disperses them widely to rearing habitat throughout the lower Sacramento River and the Delta (McCabe and Tracy 1994; Israel et al. 2008). White sturgeon larvae have been observed to be flushed farther downstream in the Delta and Suisun Bay in high outflow years but are restricted to more interior locations in low outflow years (Stevens and Miller 1970). White sturgeon larvae are periodically collected in various locations throughout the Delta in general larval fish monitoring (e.g., 20-mm Townet survey) in late winter and spring and in salvage at federal and state Delta pumping facilities, so that larval distribution generally is suggested to range from downriver of spawning habitats (primarily in the Sacramento and San Joaquin Rivers) to the approximate downstream extent of the Delta at Chipps Island (Heublein et al. 2017a). From 1995 through 2019, white sturgeon larvae were collected in the 20-mm Townet survey in 89% of wet, 67% of above normal, and 40% of below normal water year types (Table 11A-12). No white sturgeon larvae were collected in any critical or dry water years (California Department of Fish and Wildlife 2020), consistent with previous observations from Stevens and Miller (1970).

Table 11A-12. Annual Number of White Sturgeon Larvae Collected in the 20-mm Survey, 1995–2019

Year	Water Year Type	Number of White Sturgeon Larvae Collected
1995	W	4
1996	W	1
1997	W	0
1998	W	81
1999	W	7
2000	AN	16
2001	D	0
2002	D	0
2003	AN	2
2004	BN	0
2005	AN	0
2006	W	15
2007	D	0
2008	C	0
2009	D	0
2010	BN	0
2011	W	8
2012	BN	0
2013	D	0
2014	C	0

Year	Water Year Type	Number of White Sturgeon Larvae Collected
2015	C	0
2016	BN	137
2017	W	73
2018	BN	6
2019	W	34

Source: California Department of Fish and Wildlife 2020.

Salinity tolerance increases with increasing age and size (McEnroe and Cech 1985), allowing white sturgeon to access a broader range of habitat in the San Francisco Estuary (Israel et al. 2008). During dry years, white sturgeon have been observed following brackish waters farther upstream, while the opposite occurs in wet years (Kohlhorst et al. 1991). Adult white sturgeon tend to concentrate in deeper areas and tidal channels with soft bottoms, especially during low tides, and typically move into intertidal or shallow subtidal areas to feed during high tides (Moyle 2002). These shallow water habitats provide opportunities for feeding on benthic organisms, such as opossum shrimp (mysids), amphipods, the invasive overbite clam (*Potamocorbula amurensis*), and small fishes (Israel et al. 2008; Kogut 2008). White sturgeon also have been found in tidal habitats of medium sized tributary streams to the San Francisco Estuary, such as Coyote Creek and Guadalupe River in the South Bay and Napa and Petaluma Rivers and Sonoma Creek in the north bay (Leidy 2007).

Numerous factors likely affect the white sturgeon population in the Delta, similar to those for green sturgeon. Survival during early life history stages may be adversely affected by insufficient flows, lack of rearing habitat, predation, warm water temperatures, decreased dissolved oxygen, chemical toxicants in the water, and entrainment at diversions (Cech et al. 1984; Israel et al. 2008). Historical habitats, including shallow intertidal feeding habitats, have been lost in the Delta because of channelization. Overexploitation by recreational fishing and poaching also likely has been an important factor adversely affecting numbers of adult sturgeon (Moyle 2002), although new regulations were implemented in 2007 by CDFW to reduce harvest. The relatively high current levels of exploitation (annually nearly 14%) will likely continue to decrease the population size in the future (albeit with considerable uncertainty); maintaining a stable population would likely require low levels of exploitation (<3%) (Blackburn et al. 2019). Like green sturgeon, there have historically been substantial passage problems for white sturgeon such as the Fremont Weir (Sommer et al. 2014). Positive correlations exist between white sturgeon year class strength indices and Delta outflow (Fish 2010). Vessel strikes are a source of injury and mortality to white sturgeon in the San Francisco Estuary and Delta, although the proportion of fish affected is not known (Hildebrand et al. 2016; Demetras et al. 2020).

White sturgeon are known to use the lower Feather River primarily for spawning, embryo development, and early rearing. Limited quantitative information is available on the status of white sturgeon in the lower Feather River, but the spawning population was most likely much larger prior to construction of Oroville Dam in 1961 (Israel et al. 2008). Sixteen white sturgeon were recorded from creel surveys and sightings during 2006, and more were captured by anglers in 2007 (Israel et al. 2008). Numerous factors likely limit the success of the white sturgeon population in the lower Feather River, but loss of historical habitat, alteration of temperatures and flows caused by the Oroville Project, and recreational fishing and poaching are expected to be among the most important factors. General information on white sturgeon life history traits is provided in the section above on the Sacramento River area.

Small numbers of white sturgeon inhabit the American River, as evidenced by white sturgeon report cards submitted to CDFW by anglers in recent years (e.g., DuBois and Harris 2015, 2016; DuBois and Danos 2017, 2018). These individuals were caught in fall, winter, and spring months, the majority of which were caught in winter. Very little other information about use of the American River by white sturgeon is available.

Little is known about white sturgeon populations inhabiting the San Joaquin River. Spawning-stage adults generally move into the lower reaches of rivers during winter prior to spawning, then migrate upstream to spawn in response to higher flows (Schaffter 1997; McCabe and Tracy 1994). Based on tag returns from white sturgeon tagged in the Delta and recovered by anglers, Kohlhorst et al. (1991) estimated that over 10 times as many white sturgeon spawn in the Sacramento River as in the San Joaquin River. CDFW fisheries catch information for the San Joaquin River obtained from fishery report cards (California Department of Fish and Game 2008, 2009b, 2010, 2011, 2012b; California Department of Fish and Wildlife 2013, 2014a) documented that anglers upstream of State Route 140 annually caught between 8 and 25 mature white sturgeon between 2007 and 2013. Below State Route 140 downstream to Stockton, anglers annually caught between 2 and 35 mature white sturgeon over the same time period. Most of the white sturgeon caught were released.

White sturgeon spawning in the San Joaquin River was documented for the first time in 2011 and confirmed in 2012. Viable white sturgeon eggs were collected in 2011 at one sampling location downstream of Laird Park (Gruber et al. 2012) and in 2012 at four sampling locations generally between Laird Park and the Stanislaus River confluence (Jackson and Van Eenennaam 2013). Although the majority of sturgeon likely spawn in the Sacramento River, the results of these surveys confirm that white sturgeon do spawn in the San Joaquin River in both wet- and dry-year conditions and may be an important source of production for the white sturgeon population in the Sacramento–San Joaquin River system.

11A.1.10. Pacific Lamprey

11A.1.10.1. Status, Distribution, Life History, and Habitat Requirements

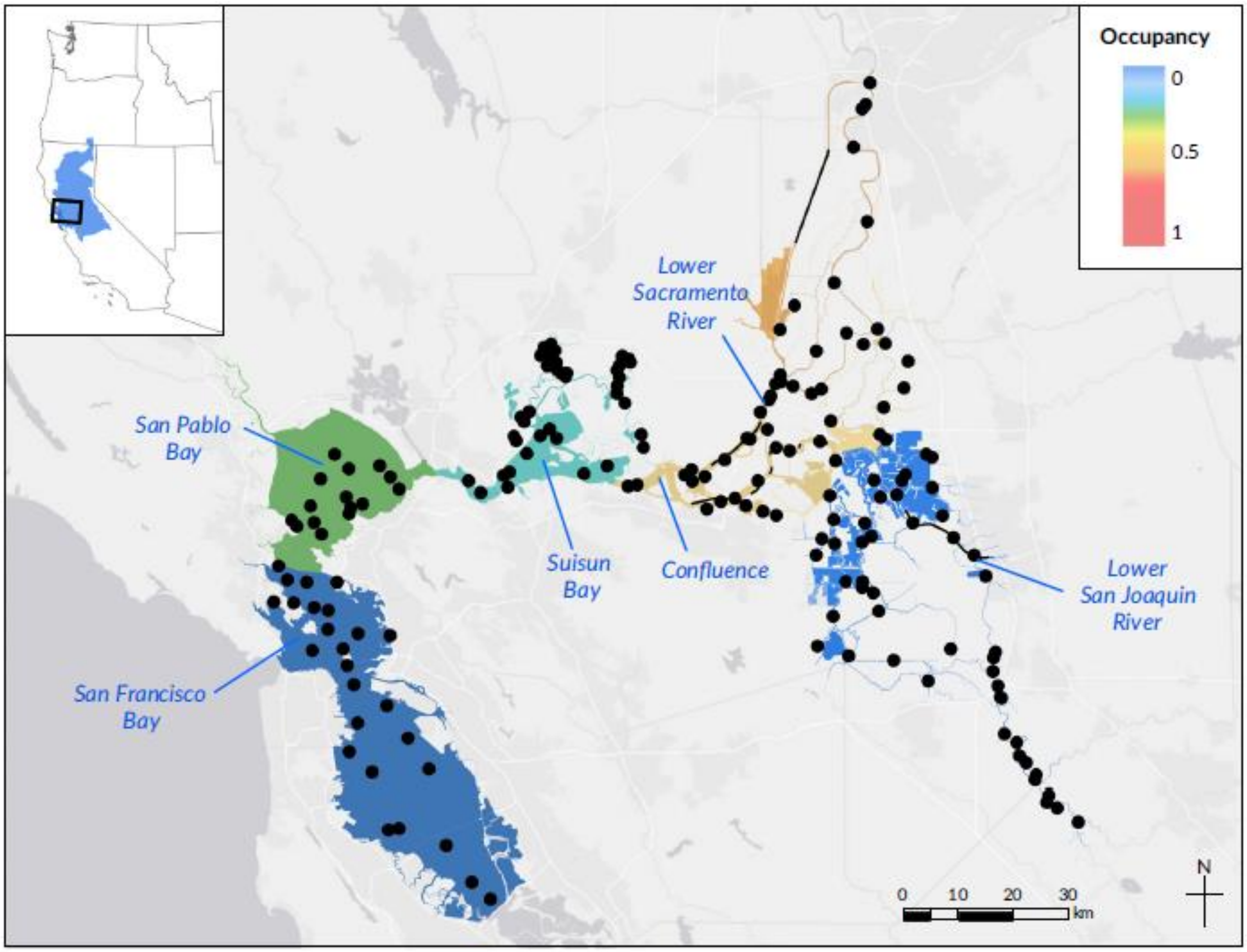
Pacific lamprey (*Entosphenus tridentatus*) is a widely distributed species that uses the Delta for upstream migration as adults, for downstream migration as juveniles, and for rearing as ammocoetes (the larval stage of lamprey) (Hanni et al. 2006; Moyle et al. 2009). Pacific lamprey is present in the north, central, and south Delta, and ammocoetes are present year-round in all of the regions (California Department of Water Resources et al. 2013). Limited information on the status of Pacific lamprey in the Delta exists, but the number of lamprey inhabiting the Delta is likely greatly suppressed compared with historical levels, as suggested by the loss of access to historical habitat and apparent population declines throughout California and the Sacramento and San Joaquin River Basins (Moyle et al. 2009). Pacific lamprey is designated as a California SSC (Moyle et al. 2015).

Limited data indicate most adult Pacific lamprey migrate though the Delta en route to upstream holding and spawning grounds in the early spring through early summer (Hanni et al. 2006). As documented in other large river systems, it is likely that some adult migration through the Delta occurs from late fall and winter through summer and possibly over an even broader period (Robinson and Bayer 2005; Hanni et al. 2006; Moyle et al. 2009; Clemens et al. 2012; Lampman 2011). Data from the FMWT survey in the lower Sacramento and San Joaquin Rivers and Suisun Bay suggest that peak outmigration of Pacific lamprey through the Delta coincides with high-flow events from fall through spring (Hanni et al. 2006). Some outmigration likely occurs year-round, as observed at sites farther upstream (Hanni et al. 2006) and in other river systems (Moyle 2002). Some Pacific lamprey ammocoetes likely spend part of their extended (5 to 7 years) freshwater residence rearing in the Delta, particularly in the upstream, freshwater portions (California Department of Water Resources et al. 2013).

Pacific lamprey adults enter the Sacramento River from the Delta primarily during about March through June and hold in the river for about a year prior to spawning (Moyle et al. 2015). Spawning occurs in gravel redds in the upper river from March through July. The eggs and pro-larvae incubate for about 1 to 1.5 months. After the larvae (ammocoetes) emerge, they drift downstream and burrow into fine sediments primarily in off-channel habitats, where they rear (Schultz et al. 2014; Moyle et al. 2015). After 5 or more years, the ammocoetes metamorphose to the macropthalmia (juvenile) stage and migrate downstream to the Delta and ocean. Migration downstream is closely associated with rainfall events, with most migrants sampled in the upper Sacramento River being collected on the day of a rainfall event or the following 2 days (Goodman et al. 2015).

River flow potentially affects survival of Pacific lamprey eggs and larvae, and the migratory habitat of the juveniles and adults. Pacific lamprey build their spawning redds in shallow water (about 0.5 to 3.5 feet or 0.15 to 1 m) (Gunckel et al. 2009; Schultz et al. 2014; Moyle et al. 2015), so reductions in water level can dewater the redds. The larvae select habitats, often off-channel, with fine sediments, low flow velocity, and shallow depths (approximately 1 ft or 0.3 m), so they are vulnerable to stranding by reductions in water level.

In the San Francisco Estuary and Delta, occupancy of habitat by lamprey (including Pacific lamprey, western river lamprey [*Lampetra ayresii*], and Kern brook lamprey [*Lampetra hubbsi*] combined) was found to be greatest in the north and central Delta, with zero to low occupancy in the south Delta, San Joaquin River, and San Francisco Bay (Figure 11A-14). Predicted occupancy of habitat declines with increasing temperature; for example, in the lower Sacramento River, occupancy probability ranges from nearly 1 at very low temperatures (below 10°C [50.0°F]) to below 0.25 at temperatures around 25°C (77.0°F) (Goertler et al. 2019).



Source: Goertler et al. 2019.
Note: Data examined were for 2006–2016. Filled black circles are sampling sites.

Figure 11A-14. Mean Modeled Lamprey Occupancy Estimates Mapped by Region with Sites used in the Single-Season Lamprey Occupancy Model

There are no data on Pacific lamprey spawning specific to Clear Creek, but they are assumed to occur throughout the accessible portion of Clear Creek downstream of Whiskeytown Dam. Pacific lamprey are inferred to spawn and rear in Clear Creek because ammocoetes have been routinely collected in the screw trap at RM 1.7 (RKM 2.7). Lamprey life cycles in Clear Creek are assumed to follow those elsewhere in California. Pacific lamprey inhabit accessible reaches of the lower Feather River (California Department of Water Resources 2003). Little information is available on factors limiting Pacific lamprey populations in the lower Feather River, but they are likely affected by many of the same factors as salmon and steelhead because of parallels in their life cycles. Hannon and Deason (2008) have documented Pacific lamprey spawning in the nearby American River between early January and late May, with peak spawning typically occurring in early April. Pacific lamprey ammocoetes rear in the lower Feather River or American River for all or part of their 5- to 7-year freshwater residence.

Limited information on Pacific lamprey status in the Stanislaus River exists, but the species has experienced loss of access to historical habitat and apparent population declines throughout

California and the Sacramento and San Joaquin River Basins (Moyle et al. 2009). Pacific lamprey ammocoetes are expected to rear in the Stanislaus River for all or part of their 5- to 7-year freshwater residence. Data from rotary screw trapping in the nearby Mokelumne and Tuolumne Rivers suggest that outmigration of Pacific lamprey generally occurs from early winter through early summer (Hanni et al. 2006). Catches of juvenile Pacific lampreys in trawl surveys of the mainstem San Joaquin River, near the mouth of the Stanislaus River at Mossdale, occurred during winter and spring. Significant numbers of lampreys of unknown species and unspecified life stage have been captured during rotary screw trapping on the Stanislaus River at Oakdale (FISHBIO Environmental 2007) and Caswell (Watry et al. 2007).

Pacific lamprey are an anadromous species that is important to local tribes and supports a subsistence fishery on the lower Trinity River. Adult Pacific lamprey may begin their upstream migration during all months of the year, but peak upstream migration typically occurs from December through June (Larson and Belchik 1998; Petersen Lewis 2009). After entering fresh water, Pacific lamprey hold through summer and most of the winter before reaching sexual maturity. Pacific lamprey undergo a secondary migration in the late winter or early spring from holding areas to spawning grounds; spawning occurs during the spring (Robinson and Bayer 2005; Clemens et al. 2012; Lampman 2011). Therefore, adult Pacific lamprey can be found in the Trinity River throughout the year. Ammocoetes rear within fine substrates in depositional areas and remain in the Trinity River and tributaries for up to 7 years before outmigrating to the ocean (Moyle 2002; Reclamation and Trinity County 2006). Limited data are available on the distribution and abundance of Pacific lamprey in the Trinity River. They are expected to have a distribution similar to anadromous salmonids that use the mainstem Trinity River and accessible reaches of larger tributaries. Pacific lamprey abundance in the Trinity River is believed to be declining based on information from Tribal fishermen who catch lamprey in the lower Klamath River (Petersen Lewis 2009). Parallels in the lifecycle of Pacific lamprey make them susceptible to many of the same factors as salmon and steelhead. Reduced access to historical spawning and rearing habitats in the Trinity River above Lewiston Dam, degraded spawning and rearing habitat resulting from operations of dams and water diversions, impacts from historic mining practices, and predation by nonnative invasive species (e.g., brown trout) have likely contributed to adverse effects on the Trinity River Pacific lamprey population.

11A.1.11. Western River Lamprey

11A.1.11.1. Status, Distribution, Life History, and Habitat Requirements

The river lamprey is not listed under ESA or CESA. On January 27, 2003, a broad group of West Coast conservation organizations petitioned the 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 FR 77158).

River lamprey are found in large coastal streams from just north of Juneau, Alaska, to the San Francisco Bay (Vladykov and Follett 1958, Wydoski and Whitney 1979). The Sacramento and San Joaquin River Basins are at the southern edge of their range (Moyle et al. 2009). River lamprey seem to be primarily associated with the lower portions of certain large river systems, and most records for California are from the lower Sacramento–San Joaquin system, especially the Stanislaus and Tuolumne Rivers (Moyle et al. 1995; Moyle 2002). In the Sacramento River, they have been documented upstream to RBDD (Hanni et al. 2006; Moyle et al. 2009). River lamprey have also been collected in the Feather and American Rivers and Mill and Cache Creeks (Vladykov and Follett 1958; Hanni et al. 2006; Moyle et al. 2009). Quantitative data on populations are extremely limited, but loss and degradation of historical habitats suggest populations may have declined. The river lamprey is considered a California Species of Special Concern (Moyle et al. 2015).

River lamprey life history is poorly known, especially in California (Moyle et al. 2015). The adults migrate from the ocean to spawning areas during the fall and late winter (Beamish 1980). Spawning is believed to occur February through May in small tributary streams (Moyle 2002). The redds are built at the upstream end of small riffles (Moyle 2002). After the larvae (ammocoetes) emerge, they drift downstream and burrow into sediments in pools or side channels where they rear. After several years, the larvae metamorphose in late July and the juveniles (macropthalmia) migrate downstream in the following year from May to July (Moyle 2002).

River flow potentially affects survival of river lamprey eggs and larvae, and migratory habitat of the juveniles and adults. River lamprey build their spawning redds in shallow water (Moyle et al. 2015), so reductions in water level can dewater the redds. Assuming river lamprey larvae habitat requirements are similar to those of Pacific lamprey, the larvae select habitats that are often off-channel, with low flow velocity and shallow depths; therefore, they are vulnerable to stranding by reductions in water level.

River lamprey have been collected in the Feather River, but there is little information about their use of the Feather River (Vladykov and Follett 1958; Hanni et al. 2006; Moyle et al. 2009). Spawning is generally in spring, at least in other locations (Beamish 1980), with adult-sized river lamprey collected in the Feather River from mid-November to early May (Hanni et al. 2006). There are no monitoring programs that target river lamprey. Quantitative data on populations are limited, but loss and degradation of historical habitats suggest populations may have declined. River lamprey are inconspicuous, often overlooked, and ammocoetes can be difficult to distinguish from ammocoetes of the co-occurring Pacific lamprey. Hanni et al. (2006) summarized distribution data and did not include specific information for the American River or Stanislaus River. It is possible that the species occurs in these areas based on available habitat. River lamprey have been collected in the San Joaquin River at Mossdale, suggesting spawning somewhere in the San Joaquin River Basin.

11A.1.12. Sacramento Hitch

11A.1.12.1. Status, Distribution, Life History, and Habitat Requirements

Sacramento hitch (*Lavinia exilicauda exilicauda*) is a California SSC (Moyle et al. 2015). The species historically occurred in low-elevation streams throughout the Sacramento and San Joaquin Valleys and in the Delta, but are now extirpated from the San Joaquin River and tributaries between Friant Dam and the Merced River (Brown 2000, as cited by Moyle et al. 2015; California Department of Fish and Game 2007, as cited in Moyle et al. 2015). Within the San Francisco Estuary and Delta vicinity, there are historical records (from before the water development of the 1950s) for Sacramento hitch in Coyote Creek and Alameda Creek. However, the species may have been introduced to Arroyo Valle through water transfers from the Central

Valley. Furthermore, it is unknown if populations in these streams are reproducing or are sustained from reservoir or historical stream populations (Leidy 2007). The species occurs in some urban streams and may tolerate highly altered habitats. Sacramento hitch face continued threats from population fragmentation (e.g., dams), agriculture (e.g., flow alteration and pollution), estuary alteration, and nonnative species. The species appears to be in long-term decline and mainly consists of scattered, small populations over a broad area. However, there is only moderate concern for overall species extinction in part due to its fairly secure establishment in some areas (Moyle et al. 2015).

Moyle et al. (2015:2) summarized habitat and distribution: Spawning takes place mainly in riffles of streams tributary to lakes, river, and sloughs after flows increase in response to spring rains, but spawning requirements are in need of further documentation. Moyle et al. (2015:2) indicate that YOY hitch spend the next two months after hatching shoaling in shallow water or staying close to aquatic plants before moving out into more open water at around 50-mm fork length. The species is distributed in the Sacramento River Basin and in some north Delta locations, but no longer in the San Joaquin River Basin (Moyle et al. 2015:2–3).

11A.1.13. Sacramento Splittail

11A.1.13.1. Status, Distribution, Life History, and Habitat Requirements

The Sacramento splittail (*Pogonichthys macrolepidotus*) was listed as threatened under ESA on February 8, 1999 (64 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 USFWS for re-evaluation of their original listing decision. Upon further evaluation, Sacramento 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 Sacramento splittail from the ESA. However, on October 7, 2010, the USFWS found that listing of Sacramento splittail was not warranted (75 FR 62070). The Sacramento splittail is designated as a California SSC by the CDFW.

Sacramento splittail are found primarily in marshes, turbid sloughs, and slow-moving river reaches throughout the Delta subregion (Sommer et al. 1997, 2008). Sacramento splittail are most abundant in moderately shallow, brackish tidal sloughs and adjacent open-water areas, but they also can be found in freshwater areas with tidal or riverine flow (Moyle et al. 2004).

Adult Sacramento splittail typically migrate upstream from brackish areas in January and February and spawn in fresh water, particularly on inundated floodplains when they are available, in March and April (Sommer et al. 1997; Moyle et al. 2004; Sommer et al. 2008). A substantial amount of Sacramento splittail spawning occurs in the Yolo and Sutter Bypasses and the Cosumnes River area of the Delta (Moyle et al. 2004). Spawning also can occur in the San Joaquin River during high-flow events (Sommer et al. 1997, 2008). However, not all adults migrate significant distances to spawn, as evidenced by spawning in the Napa and Petaluma Rivers (Feyrer et al. 2005).

Although juvenile Sacramento splittail are known to rear in upstream areas for a year or more (Baxter 1999), most move to the Delta after only a few weeks or months of rearing in floodplain habitats along the rivers (Feyrer et al. 2006). Juveniles move downstream into the Delta from April to August (Meng and Moyle 1995; Feyrer et al. 2005). Juvenile size at outmigration downstream from the Yolo Bypass was found to generally be around 30–40-mm fork length (Feyrer et al. 2006). Sacramento splittail recruitment is largely limited by extent and period of inundation of floodplain spawning habitats, with abundance observed to spike following wet years and dip after dry years (Moyle et al. 2004). However, the 5- to 7-year life span buffers the adult population abundance (Sommer et al. 1997; Moyle et al. 2004). Other factors that may adversely affect the splittail population in the Delta include entrainment, predation, changed estuarine hydraulics, nonnative species (Moyle et al. 2004), pollutants (Greenfield et al. 2008), and limited food.

Historically, Sacramento splittail were widespread in the Sacramento River from Redding to the Delta (Rutter 1908, as cited in Moyle et al. 2004). This distribution has become somewhat reduced in recent years (Sommer et al. 1997, 2007). During drier years there is evidence that spawning occurs farther upstream (Feyrer et al. 2005). Adult Sacramento splittail migrate upstream in the lower Sacramento River to above the mouth of the Feather River and into the Sutter and Yolo Bypasses (Sommer et al. 1997; Feyrer et al. 2005; Sommer et al. 2007). Each year, mainly during the spring spawning season, a small number of individuals have been documented at the Red Bluff Pumping Plant and the entrance to the GCID intake (Moyle et al. 2004).

As previously noted, nonreproductive adult Sacramento splittail are most abundant in moderately shallow, brackish areas in the Delta and Suisun Bay, but can also be found in freshwater areas with tidal or riverine flow (Moyle et al. 2004). Adults typically migrate upstream from brackish areas in January and February and spawn in fresh water on inundated floodplains in March and April (Moyle et al. 2004; Sommer et al. 2007). In the Sacramento drainage, the most important spawning areas appear to be the Yolo and Sutter Bypasses, in years that they are inundated. However, some spawning occurs almost every year along inundated river edges and backwaters created by small increases in flow. Sacramento splittail spawn in the Sacramento River from Colusa to Knights Landing in most years (Feyrer et al. 2005).

Most juvenile Sacramento splittail move from upstream areas downstream into the Delta from April through August (Meng and Moyle 1995; Sommer et al. 2007). The production of YOY Sacramento splittail is largely influenced by extent and duration of inundation of floodplain spawning habitats, with abundance spiking following wet years and declining after dry years (Sommer et al. 1997; Moyle et al. 2004; Feyrer et al. 2006). Other factors that may affect the Sacramento splittail adult population include pumping at the CVP and SWP south Delta export facilities, flood control operations and infrastructure, entrainment by irrigation diversions, recreational fishing, changed estuarine hydraulics, pollutants, and nonnative species (Moyle et al. 2004; Sommer et al. 2007).

Sacramento splittail enter the lower Feather River primarily in wet years. On the lower Feather River, February through May is believed to encompass the period of Sacramento splittail spawning, egg incubation, and initial rearing (Sommer et al. 2008, California Department of Water Resources 2004). Sacramento splittail use shallow flooded vegetation for spawning. Most spawning in the Feather River is thought to occur downstream of the Yuba River confluence (Federal Energy Regulatory Commission 2007). The primary factor that likely limits the lower Feather River population of Sacramento splittail is availability of spawning and rearing habitats as related to inundation of floodplains (Moyle et al. 2004; California Department of Water Resources 2004).

Sacramento splittail likely spawn in the lower reaches of the American River, particularly in wetter conditions (Moyle et al. 2004). Mature individuals begin a gradual upstream migration toward spawning areas between late November and late January (Moyle et al. 2004). Spawning typically occurs between late February and early July (Wang 2010). Although juvenile Sacramento splittail can rear in upstream areas for a year or more (Baxter 1999), most move downstream after only a few weeks of rearing (Reclamation 2008a). Most juveniles move downstream into the Delta from April to August (Meng and Moyle 1995).

In wet years Sacramento splittail have been found in the San Joaquin River as far upstream as Salt Slough (Baxter 1999, 2000; Brown and Moyle 1993; Saiki 1984). Historically, Sacramento splittail were widespread in the San Joaquin River and found upstream to Tulare and Buena Vista Lakes, where they were harvested by native peoples (Moyle et al. 2004). Spawning typically takes place on inundated floodplains from February through June, with peak spawning in March and April. Today, Sacramento splittail likely ascend the San Joaquin River to Salt Slough during wet years (Baxter 1999). During dry years, Sacramento splittail are uncommon in the San Joaquin River and occur only downstream of the Tuolumne River (Moyle et al. 2004). Most spawning takes place in the flood bypasses, along the lower reaches of the Sacramento and San Joaquin Rivers and major tributaries, and lower Cosumnes River and similar areas in the western Delta.

11A.1.14. Hardhead

11A.1.14.1. Status, Distribution, Life History, and Habitat Requirements

Hardhead (*Mylopharodon conocephalus*) is a California SSC (Moyle et al. 2015). The species is found throughout the Sacramento–San Joaquin River Basin and are fairly common in the Sacramento River and the lower reaches of the American and Feather Rivers. In other parts of their range, populations have declined or have become increasingly isolated (Moyle 2002). Hardhead also inhabit reservoirs and are abundant in a few impoundments where water level fluctuations prevent black bass from reproducing in large numbers (Moyle 2002). Hardhead tend to be absent from areas that have been highly altered (Moyle et al. 1995) or that are dominated by introduced fish species, especially centrarchids (species of the black bass and sunfish) (Moyle et al. 1995). Hardhead are omnivorous, with a diet consisting mostly of benthic invertebrates and aquatic plants, but also including drifting insects. In reservoirs, hardhead also prey on zooplankton (Moyle et al. 1995).

Hardhead spawn mainly in April and May, but some may spawn as late as August in the foothill regions of the upper San Joaquin River (Wang 2010). They migrate upstream and into tributary streams as far as 45 miles (72.4 km) to spawning sites. Spawning behavior has not been documented, but it is assumed to be similar to that of the pikeminnow, which deposit their eggs over gravel-bottomed riffles, runs, and at the head of pools (Moyle et al. 1995). Spawning substrates may also include sand and decomposed granite (Wang 2010).

Hardhead larvae and juveniles likely inhabit stream margins with abundant cover and move into deeper habitats as they grow larger. Adults occupy the deepest part of pools. Juvenile and adult hardhead are present in the Sacramento River year-round. They tend to prefer water temperatures near 67°F (19.4°C) (Thompson et al. 2012), but have been captured at RBDD, where water temperatures are generally much cooler (Tucker et al. 1998).

Hardhead are present in very low abundance in the San Francisco Estuary and Delta, as reflected by electrofishing in the 1980s and 2000s (Brown and Michniuk 2007) and very few individuals being collected at the SWP/CVP south Delta fish salvage facilities (California Department of Water Resources 2020:4-62).

In 2004 and 2005, hardhead were found at only 2 of 31 sampling locations upstream of Whiskeytown Dam (both in the mainstem Clear Creek) (Wulff et al. 2012). Hardhead are also found in Whiskeytown Reservoir (National Park Service 1999).

Hardhead are fairly common year-round in the lower reaches of the American River (Moyle 2002). Although migratory behavior of hardhead in the American River individuals is unknown, individuals from other large rivers, such as the Sacramento River, migrate into tributary streams during April and May. Hardhead typically spawn between April and May (Moyle 2002). Although hardhead early life history is largely unknown, young individuals likely remain along stream edges with dense cover and move into deeper water as they grow, which allows migrants to move back downstream in the current (Moyle 2002).

In the San Joaquin drainage, hardhead are present throughout tributary streams, but are largely absent from the mainstem San Joaquin River as a result of periodic desiccation during the dry season. Hardhead are widely distributed in foothill streams and may be found in a few reservoirs such as Redinger and Kerkhoff Reservoirs upstream of Millerton Reservoir on the San Joaquin River.

11A.1.15. Central California Roach

11A.1.15.1. Status, Distribution, Life History, and Habitat Requirements

The Sacramento–San Joaquin Roach (*Lavinia symmetricus symmetricus*), a California SSC, is part of the California Roach complex, which consists of various subspecies (Moyle 2002). Central California roach is a small (usually less than 10-cm total length), stout-bodied minnow that occurs in tributaries to the Sacramento and San Joaquin Rivers and tributaries to San Francisco Bay. Their historic distribution in the upper Sacramento River Basin is poorly understood, but their upstream range limit is thought to have been Pit River Falls (Moyle et al. 2015).

Central California roach are found in small, high gradient, often intermittent tributaries but appear to be poorly adapted to lakes and reservoirs. Where dams have been constructed on Central Valley streams, Central California roach persist only in small tributaries to the resultant reservoirs (Moyle et al. 2015). Their absence from reservoirs is likely due both to habitat alteration and to the presence of introduced predatory fish species. Central California roach is a California SSC (Moyle et al. 2015). They primarily inhabit small streams, but may occur in backwaters with dense riparian cover along the mainstem rivers (Baumsteiger and Moyle 2019).

Central California roach frequent a wide variety of habitats, which are often isolated by downstream barriers. They are adaptable fish and tolerate relatively high water temperatures and low oxygen levels (Moyle et al. 2016). They spawn from March through early July, usually when water temperatures exceed about 61°F or 16.1°C (Moyle 2002). Hatching takes place in 2 to 3 days, and fry remain in crevices until they can actively swim. Roach are omnivores, eating such items as terrestrial insects, filamentous algae, aquatic insect larvae and adults, crustaceans, and detritus.

Central California roach are present in very low abundance in the San Francisco Estuary and Delta, as reflected by electrofishing in the 1980s and 2000s (Brown and Michniuk 2007) and none being collected at the SWP/CVP south Delta fish salvage facilities (California Department of Water Resources 2020:4-62).

In 2004 and 2005, Central California roach were found in 3 of 11 surveyed streams upstream of Whiskeytown Dam. They were confined to Clear Creek and its tributary Cline Gulch upstream of the Carr Powerhouse and Grizzly Gulch upstream of Whiskeytown Reservoir. They were also found in Paige-Boulder Creek, a tributary of Clear Creek downstream of Whiskeytown Dam. Where found, Central California roach may be locally abundant, second in abundance only to riffle sculpin and, in some locations, Sacramento sucker (Wulff et al. 2012).

11A.1.16. Sacramento Perch

11A.1.16.1. Status, Distribution, Life History, and Habitat Requirements

Sacramento perch (*Archoplites interruptus*) is the only species of the family Centrarchidae (i.e., sunfishes) that naturally occurs west of the Rocky Mountains (Moyle 2002). The native range of Sacramento perch includes the Central Valley, Pajaro and Salinas Rivers, tributaries to the San Francisco Estuary (e.g., Alameda Creek), and Clear Lake (in Lake County) (Crain and Moyle 2011). Sacramento perch is extinct in its native range (Moyle et al. 2015:1).

Sacramento perch are often associated with beds of rooted, submerged, and emergent vegetation and other submerged objects. Sacramento perch are able to tolerate a wide range of physicochemical water conditions. This tolerance is thought to be an adaptation to fluctuating environmental conditions resulting from floods and droughts. Thus, Sacramento perch do well in highly alkaline water (McCarraher and Gregory 1970; Moyle 1976). Most populations today are established in warm, turbid, moderately alkaline reservoirs or farm ponds. Spawning occurs during spring and early summer when water temperatures are about 18°C to 29°C (64.4°F to 84.2°F), and usually begins by the end of March, continuing through early August (McCarraher and Gregory 1970).

Sacramento perch were apparently largely gone from the Delta by the time of the major fish surveys of the 1950s and 1960s (Moyle 2002). Because Sacramento perch are tolerant of a wide range of conditions, they would still likely be abundant throughout their native range in the absence of introduced centrarchids, especially crappie and sunfishes, which successfully compete with Sacramento perch (Moyle 2002) and may prey on their embryos and larvae (Moyle 2002). Interspecific competition for food and space may be the single most important cause of the Sacramento perch decline (Moyle 2002).

Only two Sacramento perch have been reportedly salvaged at the SWP and CVP fish salvage facilities between 1959 and 2005, while only two have been reportedly caught during Delta fisheries surveys during the same period (Bay Delta and Tributaries Project 2010). However, these salvage numbers represent only the actual number of Sacramento perch counted, not the actual number of Sacramento perch salvaged.

11A.1.17. Starry Flounder

11A.1.17.1. Status, Distribution, Life History, and Habitat Requirements

Starry flounder (*Platichthys stellatus*) is a species for which essential fish habitat (EFH for Pacific Groundfish) exists in the San Francisco Estuary and Delta. The overall extent of Pacific Groundfish EFH includes all water and substrate in depths that are less than or equal to 11,483 feet (3,500 meters) to the mean high-water level or the upriver extent of saltwater intrusion (upstream area and landward where waters have salinities less than 0.5 ppt), known spawning habitat and thermal refugia, complex channels and floodplains and areas containing estuarine and marine SAV.

Starry flounder is a flatfish that belongs to the family Pleuronectidae (Moyle 2002). Starry flounder range from north of the Bering Strait south to Los Angeles Harbor. Older juveniles and adults are found from 75 miles (120.7 km) upstream to the outer continental shelf at 375 m (1230 ft) depth, but most adults are found at less than 150 m (492 ft) depth. Most juvenile fish are found in shallow, fresh to brackish water, and shift to salinities of 10–15 ppt as they mature, but appear to remain within estuaries through at least their second year (Baxter et al. 1999; Moyle 2002). During the late fall and winter, mature starry flounder probably migrate to shallow coastal waters to spawn (Orcutt 1950). Adults primarily inhabit coastal marine waters (Orcutt 1950; Haertel and Osterberg 1967; Bottom et. al. 1984; Hieb and Baxter 1993). Distribution of age-0 juveniles within the San Francisco Estuary and Delta is primarily in Suisun Bay and San Pablo Bay, with lower abundance in the west Delta (Baxter 1999:410). Starry flounder older than age 1 (age-1+ fish) occur principally in San Pablo Bay, Suisun Bay, and Central Bay (Baxter et al. 1999:411–412).

In general, abundance indices from the past decade suggest a decline relative to several decades ago, consistent with declines in commercial and recreational catch (ICF International 2016a:5.E-12 and 5.E-13). Starry flounder are found on different substrates including gravel, clean shifting sand, hard stable sand, and mud substrata, but fishermen report the largest catches over soft sand. Prey from mud (sternapsid worms) and sand (*Siliqua patula* clams) habitats have been observed in the stomach of a single individual, suggesting fish move freely from one habitat type to another (Orcutt 1950). Starry flounder also consume crabs, shrimps, worms, clams and clam siphons, other small mollusks, small fishes, nemertean worms, and brittle stars (Hart 1973). Starry flounder can tolerate a wide range of salinities. In the Sacramento and San Joaquin Rivers, starry flounder have been observed in salinities of 0.02–0.06 ppt (i.e., essentially fresh water) (Orcutt 1950), and have been collected 75 miles (120.7 km) upstream in the Columbia River. Age-0 and age-1+ starry flounder are a common species in estuarine habitats along the West Coast (see Orcutt 1950; Sopher 1974; Pearson 1989; Emmett et al. 1991; Baxter et al. 1999; Kimmerer 2002). Spawning occurs primarily during the winter months of December and January (Orcutt 1950). Starry flounder reach approximately 110 mm in length by the end of their first year. By the time they reach age 2 many fish have migrated to ocean habitats adjacent to their natal estuaries. Starry flounder become reproductively mature at age 2 for males and age 3 for females, which equates to approximately 28 cm in males and approximately 35 cm in females. Adults may move seasonally into shallow coastal waters to spawn, perhaps in proximity to estuaries to take advantage of estuarine circulation which would advect fertilized eggs near the bottom into nursery areas.

Hieb and Baxter (1993) established specific habitat criteria for starry flounder YOY (<70 mm) in the San Francisco Estuary: 90% were collected from intertidal and subtidal habitats <7 m in depth, and with accompanying salinities of <22%. The exclusivity of fresh and brackish water rearing habitat in age-0 and age-1 starry flounder coupled with the relationship between freshwater outflow and abundance makes a strong case for estuarine dependence (Emmett et al. 1991; Hieb and Baxter 1993). However, spawning in coastal areas and variation in abundance during high outflow years suggest that coastal ocean conditions as well as high outflow work in conjunction to determine year class abundance (Hieb and Baxter 1993). There is a significant correlation between Delta outflow (X2) and indices of starry flounder abundance in the San Francisco Estuary and Delta, although the mechanism underlying the correlation does not appear to be related to extent of habitat and may be related to enhanced transport to estuarine rearing grounds by increased residual circulation with increased outflow (Kimmerer et al. 2009). It is unknown the extent to which this potential enhanced transport and apparent greater abundance in the San Francisco Estuary and Delta with greater outflow may contribute to overall coastwide starry flounder abundance (Grimaldo 2018:13-14).

11A.1.18. Northern Anchovy

11A.1.18.1. Status, Distribution, Life History, and Habitat Requirements

Northern anchovy (*Engraulis mordax*) is a species for which EFH exists in the San Francisco Estuary and Delta and is one of the species managed under the Coastal Pelagic Species Fishery Management Plan (FMP). The overall extent of Coastal Pelagic EFH is based on a thermal range bordered by the geographic area where the managed coastal pelagic species in the FMP occur at any life stage, where these species have occurred historically during periods of similar environmental conditions, or where environmental conditions do not preclude colonization by these species. Species diversity and abundance declines on an upstream gradient as determined by the tolerance of individual species for low and variable salinity conditions.

Northern anchovy is distributed along the West Coast from British Columbia to Baja, California (Miller and Lea 1972). The central subpopulation, which is present in the project area, ranges from approximately San Francisco, California, to Punta Baja, Baja California. Members of the central population move north during the summer and south during the winter (Haugen et al. 1969). Northern anchovy is an important forage fish for other resident and migratory species in the San Francisco Estuary and Delta, including salmon, jacksmelt (*Atherinopsis califoniensis*), and striped bass (Baxter et al. 1999:167). It supports a moderate commercial fishery for live bait (Smith and Kato 1979). The annual abundance of northern anchovy is highly variable between years. Surveys have shown that the greatest densities occur in Central, San Pablo, and South Bays, and only in late summer were they collected in appreciable numbers in Suisun Bay (Baxter et al. 1999).

Northern anchovy is a small fish typically found in schools near the surface of the water. They are short-lived, rarely living past 4 years of age. A portion of the population reaches maturity at the end of their first year, about 50% by the end of their second year, and all are mature by their third or fourth year (Clark and Phillips 1952). Female anchovy are batch spawners, spawning 20,000 to 30,000 eggs a year in two or three events (Baxter 1967). Spawning can occur during every month of the year and is temperature dependent, increasing in late winter and early spring and peaking from February to April. They spawn in nearshore areas across their entire range, in the upper 50 meters of the water column. Spawning in the bay occurs at higher temperatures and lower salinities than spawning in coastal areas (McCrae 1994; Bergen and Jacobson 2001). Both northern anchovy eggs and larvae are found near the surface, and eggs need 2 to 4 days to hatch, depending on water temperatures. The San Francisco Bay is a very productive nursery area because of high abundance of food for both larvae and adults, advective losses are lower than in adjacent coastal waters, and the bay is warmer, with varying salinity allowing for eggs and larvae throughout the year (Reclamation 2008). Anchovies feed diurnally either by filter feeding or biting, depending on the size of the food. Juvenile and adult anchovy feed at a higher trophic level than larvae, selectively feeding on larger zooplankton (mysids), fish eggs, and fish larvae and have been observed to eat small fish at times, even their own species (Baxter 1967).

Larvae eat phytoplankton and dinoflagellates, while larger larvae pick up copepods and other zooplankton. Larger female anchovies can consume up to 4%–5% of their total body weight per day. Competitors with the anchovy for food include sardines and other schooling planktivores, such as jacksmelt and topsmelt (*Atherinops affinis*). These species are also potential predators of young anchovy life stages (Goals Project 2000).

Factors affecting anchovy production are mostly natural influences, such as ocean temperature (California Department of Fish and Game 2001). Offshore within the California Current, temperature, upwelling, and stable stratification of the water column are believed to work together to produce conditions that are favorable to anchovy larvae (Lasker 1975). Investigation of the correlations between Delta outflow (X2) and indices of abundance and habitat did not find statistically significant relationships (Kimmerer et al. 2009). The distribution of northern anchovy shifted toward higher salinity when *Potamocorbula* invaded in the mid- to late 1980s, reducing summer abundance by >90% in the low-salinity region of the San Francisco Estuary and Delta (Kimmerer 2006).

11A.1.19. Striped Bass

11A.1.19.1. Status, Distribution, Life History, and Habitat Requirements

Striped bass is a recreationally important anadromous species introduced into the Sacramento and San Joaquin River Basins between 1879 and 1882 (Moyle 2002). Despite their nonnative status and piscivorous feeding habits, striped bass are considered important because they are a major game fish in the Delta. Striped bass use the Delta as a migratory route and for rearing and seasonal foraging. Striped bass spend the majority of their lives in salt water, returning to fresh water to spawn. When not migrating for spawning, adult striped bass in the San Francisco Estuary and Delta are found in San Pablo Bay, San Francisco Bay, and the Pacific Ocean (Moyle 2002). Adult striped bass spend about 6 to 9 months of the year in San Francisco and San Pablo Bays (Hassler 1988). Striped bass also use deeper areas of many of the larger channels in the Delta, in addition to large embayments such as Suisun Bay.

Spawning occurs in spring, primarily in the Sacramento River between Sacramento and Colusa and in the San Joaquin River between Antioch and Venice Island (Farley 1966). Eggs are free-floating and negatively buoyant and hatch as they drift downstream, with larvae occurring in shallow and open waters of the lower reaches of the Sacramento and San Joaquin Rivers, the Delta, Suisun Bay, Montezuma Slough, and Carquinez Strait. According to Hassler (1988), the distribution of larvae in the estuary depends on river flow. In low-flow years, all striped bass eggs and larvae are found in the Delta, while in high-flow years, the majority of eggs and larvae are transported downstream into Suisun Bay.

YOY striped bass distribute themselves in accordance with the estuarine salinity gradient (Kimmerer 2002; Feyrer et al. 2007), indicating that salinity is a major factor affecting their habitat use and geographic distributions. Kimmerer (2002) found that distributions of fish species, including striped bass, substantially overlapped with the low-salinity zone. Older striped bass are increasingly flexible about their distribution relative to salinity (Moyle 2002). Statistically significant correlations between indices of age-0 abundance or survival in the San Francisco Estuary and Delta have been found with Delta outflow (X2) (e.g., Kimmerer et al. 2009; Mac Nally et al. 2010), with evidence for greater extent of habitat as the mechanism (Kimmerer et al. 2009). However, subsequent density-dependent survival after the first summer dampens the effects of flow on subsequent recruitment (Kimmerer et al. 2000).

The entrainment of striped bass has been observed at the south Delta export facilities, including Clifton Court Forebay (Stevens et al. 1985; Bowen et al. 1998; Aasen 2012). In water year 2011, salvage of striped bass at export facilities (approximately 550,000 fish) continued a generally low trend observed since the mid-1990s. Prior to 1995, annual striped bass salvage was generally above 1 million fish (Aasen 2012). DWR et al. (2013) reported that striped bass longer than 24 mm were effectively screened at TFCF and bypassed the pumps. However, planktonic eggs, larvae, and juveniles smaller than 24 mm in length received no protection from entrainment. Although the percentage entrainment of YOY juveniles during June through September at the south Delta export facilities was estimated to be appreciable (median of 33%, maximum of 99%), any population-level effect may have been obscured by variability in total mortality and possibly salvage operations success, or the density-dependent effect during and after this life stage (Kimmerer et al. 2000, 2001).

Striped bass, primarily YOY, are one of the pelagic fish of the upper estuary that have shown substantial variability in their populations, with evidence of long-term declines (Kimmerer et al. 2000; Sommer et al. 2007). A substantial proportion of the variability in abundance index patterns has been associated with variation of outflow in the estuary (Jassby et al. 1995; Kimmerer et al. 2001; Loboschefsky et al. 2012), although this is disputed by some stakeholders (Bourez 2011). However, surveys showed that population levels for YOY striped bass began to decline sharply around 1987 and 2002 (Thomson et al. 2010), despite relatively moderate hydrology, which typically supports at least modest fish production (Sommer et al. 2007). Moyle (2002) cites causes of decline in striped bass to include climatic factors, entrainment at project export facilities in the south Delta, other diversions, pollutants, reduced estuarine productivity, invasions by alien species, and human exploitation. Kimmerer et al. (2000, 2001) attribute the decline in juvenile YOY striped bass to declining carrying capacity, likely related to food limitation. Loboschefsky et al. (2012) showed that there had been no long-term decline for age-1 and older striped bass as of 2004.

Striped bass occur in the lower Feather River and have been reported to occur in the Thermalito Forebay (Federal Energy Regulatory Commission 2007). Striped bass are a popular sport fish in the lower Feather River during periods when they migrate upstream to spawn. Little is known about striped bass use of the Feather River, although acoustically tagged striped bass released in the Feather River spent more time in the river than acoustically striped bass released in the Sacramento River (Sabal et al. 2019). These acoustically tagged striped bass generally seemed to follow seasonal prey sources, with the most time spent in the San Francisco and San Pablo Bays during the summer, and greatest detections in Delta in the winter, with an overall variability to behavior that may have allowed persistence since the original introduction of the species (Sabal et al. 2019).

Striped bass are year-round inhabitants of the American River from the confluence with the Sacramento River to Nimbus Dam, with highest densities during summer (Surface Water Resources 2001; Moyle 2002). Although specific spawning locations in the American River are not well understood, the river is believed to serve as a nursery area for YOY and subadult striped bass (Surface Water Resources 2001). They provide a locally important sportfishing resource.

Striped bass occur in the Stanislaus River, and they support a sport fishery when adult fish migrate upstream to spawn. Striped bass have been observed at Lovers Leap and at Knights Ferry from May through the end of June. These adult fish were observed in all habitats (U.S. Fish and Wildlife Service 2002; Kennedy and Cannon 2005). The distribution of striped bass in the Stanislaus River is thought to be limited to downstream of the historic Knights Ferry Bridge because of a set of falls about 3 feet (0.91 m) tall in the area (U.S. Fish and Wildlife Service 2002b). Ainsley et al. (2013) reported that striped bass were collected in May at two locations on the mainstem San Joaquin River between the Head of Old River and the mouth of the Stanislaus River.

11A.1.20. American Shad

11A.1.20.1. Status, Distribution, Life History, and Habitat Requirements

American shad is a recreationally important anadromous species introduced into the Sacramento and San Joaquin River Basins in the 1870s (Moyle 2002). American shad spend most of their adult life at sea and may make extensive migrations along the coast. American shad become sexually mature while in the ocean and migrate through the Delta to spawning areas in the Sacramento, Feather, American, and Yuba Rivers. Some spawning also takes place in the lower San Joaquin, Mokelumne, and Stanislaus Rivers (U.S. Fish and Wildlife Service 1995). The spawning migration may begin as early as February, but most adults migrate into the Delta in March and early April (Skinner 1962). Migrating adults generally take 2 to 3 months to pass through the Delta (Painter et al. 1979). They enter the Feather River annually in spring to spawn and are present in the lower Feather River from May through mid-December during the adult immigration, spawning, and outmigration periods of their life cycle (California Department of Water Resources 2003). Adult American shad migrate into the lower American River to spawn during the late spring, typically during April through early July (California Department of Fish and Game 1986). American shad migrate up the Stanislaus River to spawn in the late spring and support a sport fishery during that period. American shad have been observed on occasion from June through July at Lovers Leap (U.S. Fish and Wildlife Service 2002; Kennedy and Cannon 2005). American shad were found primarily in the faster habitats and were observed in schools of 20 or more (U.S. Fish and Wildlife Service 2002). Little is known about American shad in the San Joaquin River. They may spawn in the San Joaquin River system, but their abundance is unknown. Sport fishing for American shad occurs seasonally in the San Joaquin River. A unique, successfully reproducing landlocked population of American shad exists in Millerton Lake.

Water temperature is an important factor influencing the timing of spawning. American shad are reported to spawn at water temperatures ranging from approximately 46°F (7.8°C) to 79°F (26.1°C) (U.S. Fish and Wildlife Service 1967), although optimal spawning temperatures are reported to range from about 60°F (15.5°C) to 70°F (21.1°C) (Bell 1986; California Department of Fish and Game 1980; Leggett and Whitney 1972; Painter et al. 1979; Leidy 1984). Spawning takes place mostly in the main channels of rivers, and generally about 70% of the spawning run is made up of first-time spawners (Moyle 2002).

Shad have remarkable abilities to navigate and to detect minor changes in their environment (Leggett 1973). Although homing is generally assumed in the Sacramento River and its tributaries, there is some evidence that numbers of first-time spawning fish are proportional to flows of each river at the time the shad arrive. When suitable spawning conditions are found, American shad school and broadcast their eggs throughout the water column. The optimal temperature for egg development is reported to occur at 62°F (16.7°C). At this temperature, eggs hatch in 5 to 8 days; at temperatures near 75°F (23.9°C), eggs would hatch in 3 days (MacKenzie et al. 1985). Egg incubation and hatching, therefore, are coincident with the spawning period.

Fertilized eggs are slightly negatively buoyant, are not adhesive, and drift in the current. Newly hatched larvae are found downstream of spawning areas and can be rapidly transported downstream by river currents because of their small size. Juvenile American shad rear in the Sacramento River from Colusa to Sacramento, the lower Feather River below the Yuba River, and the Sacramento River portion of the Delta (Stevens et al. 1987). As previously noted, rearing also takes place in the Mokelumne River near the DCC. Based on density, juvenile rearing in the American and Yuba Rivers appears less than other areas (Stevens et al. 1987). Overall, in contrast to striped bass, an appreciable portion of the American shad population appears to rear upstream of the Delta based on density in seine catches (Stevens et al. 1987). Some juvenile shad may rear in the Delta for up to a year before outmigrating to the ocean (U.S. Fish and Wildlife Service 1995). Outmigration from the Delta begins in late June and continues through November (Painter et al. 1979).

Juvenile American shad are frequently encountered in the Delta during the FMWT survey and in fish salvage monitoring at the south Delta SWP and CVP fish facilities (California Department of Water Resources et al. 2013). American shad use of the Delta has been observed to vary with salinity (e.g., X2) and outflows (Kimmerer 2002). Statistically significant negative correlations exist between X2 and indices of abundance in the San Francisco Estuary and Delta, with the mechanism potentially being related to the extent of available habitat (Kimmerer et al. 2009).

American shad are entrained at the TFCF (Bowen et al. 1998) and in the Clifton Court Forebay, mostly during May through December when young American shad migrate downstream. The American shad population in the Sacramento and San Joaquin River Basins has declined since the late 1970s, most likely because of increased diversion of water from rivers and the Delta, combined with changing ocean conditions, and possibly pesticides (Moyle 2002). Salvage of

American shad at project export facilities in water year 2011 represented nearly 659,000 fish (Aasen 2012), with similar but slightly lower salvage in 2010 (545,125 fish) (Aasen 2011).

11A.1.21. Threadfin Shad

11A.1.21.1. Status, Distribution, Life History, and Habitat Requirements

Threadfin shad (*Dorosoma petenense*) were intentionally introduced to provide forage for game fish. Threadfin shad were planted by CDFW in reservoirs throughout California, with the Sacramento and San Joaquin River Basins planted in 1959. From these transplants, they have become established in the Sacramento–San Joaquin River system and the Delta. Threadfin shad live mainly in fresh water and become progressively less abundant as salinity increases. Juveniles form dense schools and, in estuaries, are found in water of all salinities, although they are most abundant in fresh water. Threadfin shad are fast-growing but short-lived; few live longer than 2 years. Spawning takes place in California in April through August, peaking in June and July when water temperatures exceed 20°C (68°F), although spawning has been observed at 14°C to 18°C (57.2°F to 64.4°F). The embryos hatch in 3 to 6 days and larvae immediately assume a planktonic existence.

As noted by Baxter et al. (2010:75), threadfin shad is widely distributed but is most commonly encountered and most abundant in the southeastern Delta, especially the San Joaquin River near and just downstream of Stockton, where suitable abiotic habitat coincides with high prey abundance (Feyrer et al. 2009); these regions also have a relatively high density of SAV, which provides important spawning and larval rearing habitat (Grimaldo et al. 2004). Baxter et al. (2010) also noted that historical surveys by Turner (1966) found relatively high abundance in the northeast Delta in dead-end sloughs.

Threadfin shad are susceptible to entrainment in water diversions and the species is salvaged at the SWP and CVP south Delta fish salvage facilities in higher abundance than any other fish species. Herbold et al. (2005) estimated annual salvage from approximately 1.5 million to about 10 million during 1994–2005. Some evidence for correlations with abundance indices has been found for water clarity, indices of predator and prey abundance, and south Delta exports (Mac Nally et al. 2010; Thomson et al. 2010).

11A.1.22. Black Bass

11A.1.22.1. Largemouth Bass

Status, Distribution, Life History, and Habitat Requirements

Largemouth bass is a nonnative species to California. They were introduced in California in 1891 (Dill and Cordone 1997; Moyle 2002) and have since been introduced to suitable waters, including streams and reservoirs, throughout the state. Like striped bass, largemouth bass have become an important sport fishery in the Delta.

Largemouth bass first spawn during their second or third spring at about 17.8 cm in length. Spawning is limited to fresh water (Moyle 2002). The males begin building nests when the water temperature reaches about 60°F (15.5°C). Spawning takes place from April through June, at temperatures up to 75°F (23.9°C). Nests are shallow pits in depths of 3 to 7 feet (0.91 to 2.1 m) and are often built next to submerged objects. Females lay their eggs in one or more nests. The eggs hatch in 2 to 5 days and sac fry usually spend 5 to 8 days in or near the nest (Moyle 1976). For the first month or two after hatching, fry feed mainly on zooplankton. YOY bass stay close to shore in schools that swim in the open water. By the time they reach about 2 inches in length, the juveniles feed largely on aquatic insects and fish fry, including other largemouth bass, and after they reach 10 to 12.5 cm, they prey primarily on fish and crayfish. Largemouth bass are thought to be a major predator of juvenile Chinook salmon and other native fish species in the Delta (Nobriga and Feyrer 2007). In addition to the Delta, they occur in lower riverine habitats such as in the Feather River and American River. Their growth rate is highly variable, depending on genetic background, food availability, inter- and intra-specific competition, temperature regimes, and other environmental factors. Maximum size for the species is approximately 30 inches total length and the maximum age is 16 years (Moyle 1976).

Largemouth bass prefer warm, quiet waters with aquatic vegetation and low turbidity. They are known to tolerate dissolved oxygen levels as low as 1 milligram of oxygen per liter (mg/L) (Lee et al. 1980; Moyle 2002). The species thrives in areas with high levels of infestation by nonnative aquatic plants (Brown and Michniuk 2007). Recent studies suggest juvenile and larger largemouth bass abundance is positively correlated with water temperature, whereas juvenile largemouth bass abundance is greatest at intermediate levels of SAV but larger fish are widespread even in areas with limited SAV (Conrad et al. 2016). A study in the San Joaquin River between the Head of Old River and Stockton in 2015–2016 found a mean of 333 largemouth bass per kilometer, which were estimated to consume 3 to 5 fall-run Chinook salmon per day per kilometer during the peak of the salmon outmigration period, compared to up to 24 salmon consumed per day per kilometer by striped bass (Michel et al. 2018).

11A.1.22.2. Smallmouth Bass

Status, Distribution, Life History, and Habitat Requirements

Smallmouth bass (*Micropterus dolomieu*) are most common in large, clear lakes and cool, clear streams with large amounts of cover. In streams they prefer complex habitat with a variety of pools, riffles, runs, rocky bottoms, and overhanging trees, while lake populations concentrate in narrow bays along shores where rocky shelves project under water. Optimal water temperature differs with age, as adults tend to stay in areas that are 25°C to 27°C (77.0°F to 80.6°F), while younger fish prefer areas which are 29°C to 31°C (84.2°F to 87.8°F), reflecting their more shallow water environment. Regardless of age, however, temperatures greater than 35°C (95.0°F) are metabolically stressful, and temperatures over 38°C (100.4 °F) are lethal. Smallmouth bass are also restricted in their habitat choice by the amount of dissolved oxygen in the water. Although they can survive in areas with 1 to 3 milligrams of oxygen per liter, they require at least 6 mg/L for normal growth rates (University of California, Agriculture and Natural Resources 2019a). Juveniles and populations in crowded lakes may school, but this is rare and the majority are solitary hunters that stalk around some kinds of submerged debris. This localizes populations to such a degree that several reproductively independent groups can exist within a single lake. Foraging occurs throughout the day but is most intense in the evening and the early morning. Crustaceans and aquatic insects make up the majority of a smallmouth bass's diet until it reaches 3 to 5 cm TL, at which point crayfish and fish become more important. By the time an individual reaches 10 to 15 cm TL, these larger food items dominate the diet. Smallmouth bass are opportunistic, however, and insects, amphibians, and small mammals are not uncommon sources of food (University of California, Agriculture and Natural Resources 2019a).

Smallmouth bass reach maturity in their third or fourth spring, at which point they move into shallower water. Spawning begins in May and can continue into June or July. Males construct nests 30 to 60 cm (1 to 2 ft) in diameter, preferably in rubble, gravel, or sand 1 meter (3.3 ft) deep with submerged logs, boulders, and other submerged objects acting as cover. This is only the optimal environment, however, and nests can be found on a variety of substrates varying in depth from 0.5 to 5 meters (1.6 to 16.4 ft). These nests may be built close together, but they are not colonial and males defend the nests against other males as vigorously as they would against predators. Spawning is initiated by a female repeatedly swimming by a nest, changing colors, and keeping her head down in a mating posture. Eventually the pair circle the nest, with the male nipping at the female and the female occasionally rubbing her abdomen on the nest floor. The pair then settle into the nest and release their eggs and milt simultaneously. Smallmouth bass are mostly monogamous, but the larger fish spawn earlier in the season and may have the opportunity to spawn again. Each female may release 2,000 to 21,000 eggs into her nest. The males guard the embryos and fan water over them to provide more oxygen. After hatching, it takes 1 to 2 weeks before fry become free swimming, and the male still guards them for another 1 to 4 weeks after that until they are too active to be herded. At 2 to 3 cm TL, the young disperse to shallow water where high mortality rates are suffered because of predation and high stream flows. Those that survive generally grow to between 6 cm and 18 cm in their first year, and between 25 cm and 41 cm in their fourth, while stream populations grow at a decidedly slower rate. The largest individual on record weighed 4.1 kilograms (University of California, Agriculture and Natural Resources 2019a). All life stages of smallmouth bass can occur in the freshwater regions of the Delta.

11A.1.22.3. Spotted Bass

Status, Distribution, Life History, and Habitat Requirements

Spotted bass (*Micropterus punctulatus*) are most common in moderately sized, clear, low-gradient rivers and reservoirs. In streams they spend most of their time hiding in pools, avoiding riffles or backwaters with heavy plant growth. Reservoir populations stay along steep rocky banks toward the upstream end of the reservoir. During the summer they can be found in temperatures between 24°C and 31°C (75.2°F and 87.8°F), and despite a low tolerance for brackish water, they have been found in salinities up to 10 ppt. Juveniles can easily be seen schooling in shallow areas close to shore, but adults are more solitary and spend most of their time 1 meter to 4 meters deep or even farther down when temperatures equalize in winter. Like most fish, the spotted bass's diet expands as a fish gets older. Fry eat mostly zooplankton and small insects, and then move on to crustaceans and larger aquatic insects as juveniles. Individuals between 75 mm and 150 mm feed on aquatic insects, fish, crayfish, and terrestrial insects, eventually preferring crayfish (University of California, Agriculture and Natural Resources 2019b).

Maturity is reached in the second or third year and spawning occurs when temperatures reach 15°C to 18°C (59°F to 64.4°F), continuing until temperatures reach 22°C to 23°C (71.6°F to 73.4 °F) in early June. Males move to shallow water in March and early April, where they construct nests 40 to 80 cm in diameter. Lake nests are built in areas 0.5 to 4.5 meters deep with large rocks and rubble or gravel, while nearly any area with low current can be used in rivers. These nests may be built close together, but spotted bass are not colonial and males defend the nests as vigorously against other males as they would against predators. Spawning is initiated by a female repeatedly swimming by a male's nest, changing colors, and keeping her head down in a mating posture. Eventually the pair circles the nest, with the male nipping at the female and the female occasionally rubbing her abdomen on the nest floor. The pair then settle into the nest and release their eggs and milt simultaneously. Spotted bass are mostly monogamous, but some males may have more than one nest. Each female lays 2,000 to 14,000 eggs per nest. The male tends to and defends the nest for up to 4 weeks until the fry disperse at 30 millimeters total length (mm TL). Growth varies with habitat. Warmwater reservoirs support the highest growth, and cold streams support the slowest. On average, however, individuals reach 65 to 170 mm TL in their first year and 245 to 435 mm TL in their fourth. Few live longer than 4 or 5 years, and the largest recorded individual for California was 450 mm TL (University of California, Agriculture and Natural Resources 2019b). All life stages of spotted bass can occur in the freshwater regions of the Delta.

11A.1.23. California Bay Shrimp

11A.1.23.1. Status, Distribution, Life History, and Habitat Requirements

A summary of California bay shrimp (*Crangon franciscorum*) was provided by Baxter et al. (1999:78–79), upon which this account is largely based. Bay shrimp include several species of *Crangon*, primarily *C. franciscorum*. They are fished commercially by trawlers in the San Francisco Estuary and Delta and sold as bait to sport anglers. From 1980 to 1995, the fishery annually landed between 100,000 and 200,000 pounds, although landings were considerably greater (2–3 million pounds) in the 1920s and 1930s, when bay shrimp were sold for human consumption. The fishery was concentrated in South Bay in the late 1980s to early 1990s probably because of lower salinity water from sewage treatment plant discharges. There appears to have been a general decline in landings in the past two decades, with only one year above 100,000 pounds and most years since 2005 having 60,000 pounds or less in landings (ICF International 2016b:4–295).

Bay shrimp migrate seasonally in response to salinity, temperature, and maturity or life stage: for example, *C. franciscorum* larvae hatch in winter/early spring in Central Bay or the Gulf of the Farallones, with post-larvae and juveniles migrating upstream to rear in lower salinity, warmer areas such as San Pablo and Suisun Bays during the summer, before migrating downstream in fall/winter to complete the life cycle. Diet is variable by location and size and may consist of mysid shrimps, amphipods, bivalves, and copepods, for example. Bay shrimp are preyed upon by many fish in the estuary, including striped bass, staghorn sculpin, and green and white sturgeon, as well as other taxa such as harbor seals and diving ducks. The overall distribution is broad: for example, the dominant species *C. franciscorum* ranges from southeast Alaska to San Diego, California.

As with some other species in the San Francisco Estuary and Delta, there is a statistically significant negative correlation between abundance index and X2, which does not appear to be related to extent of habitat and may be related to enhanced transport to estuarine rearing grounds by increased residual circulation with increased outflow (Kimmerer et al. 2009).

11A.1.24. Southern Resident Killer Whale

11A.1.24.1. Status, Distribution, Life History, and Habitat Requirements

This species account was adapted from the DWR (2020) Final EIR for Long-Term Operation of the SWP. Southern resident killer whales (*Orcinus orca*) are found primarily in the coastal waters offshore of British Columbia and Washington and Oregon in summer and fall (National Marine Fisheries Service 2008). During winter, southern resident killer whales are sometimes found off the coast of central California and more frequently off the Washington coast (Hilborn et al. 2012).

The 2005 listing (70 FR 69903) of southern resident killer whale DPS as endangered lists several factors that may be limiting the recovery of killer whales, including the quantity and quality of prey, accumulation of toxic contaminants, and sound and vessel disturbance. The *Recovery Plan for Southern Resident Killer Whales* (National Marine Fisheries Service 2008) posits that reduced prey availability forces whales to spend more time foraging, which may lead to reduced reproductive rates and higher mortality rates. Reduced food availability may lead to mobilization of fat stores, which can release stored contaminants and adversely affect reproduction or immune function (National Marine Fisheries Service 2008).

The Independent Science Panel reported that southern resident killer whales depend on Chinook salmon as a critical food resource (Independent Science Panel and ESSA Technologies 2012). Hanson et al. (2010) analyzed tissues from predation events and feces to confirm that Chinook salmon were the most frequent prey item for the southern resident killer whale in two regions of the whale's summer range off the coast of British Columbia and Washington State, representing more than 90% of the diet in July and August. Samples indicated that when southern resident killer whales are in inland waters from May through September, they consume Chinook salmon stocks that originate from regions that include the Fraser River, Puget Sound, the Central British Columbia Coast, West and East Vancouver Island, and California's Central Valley (Hanson et al. 2010).

Significant changes in food availability for southern resident killer whale have occurred over the past 150 years, largely due to human impacts on prey species. Salmon abundance has been reduced over the entire range of southern resident killer whale, from British Columbia to California. NMFS (2008) indicates that wild salmon have declined primarily due to degraded aquatic ecosystems, overharvesting, and production of fish in hatcheries. NMFS (2008) supports restoration efforts, including habitat, harvest, and hatchery management considerations, and continued use of existing NMFS authorities under the ESA and Magnuson-Stevens Fishery Conservation and Management Act to ensure an adequate prey base.

Central Valley streams produce Chinook salmon that contribute to the diet of southern resident killer whale. The number of Central Valley Chinook salmon that annually enter the ocean and survive to a size susceptible to predation by southern resident killer whale is not known. NMFS (2019:131) reviewed available information from sources such as fishery harvest, escapement data, and diet studies for Chinook salmon stocks on the West Coast and concluded that Central Valley Chinook salmon constitute a sizeable percentage of Chinook salmon that would be expected to be encountered by southern resident killer whale in coastal waters off California and Oregon, and at least a small portion of Chinook salmon in the ocean as far north as British

Columbia. As summarized by NMFS (2019:132–133), a recent report evaluated 30 stocks of West Coast Chinook salmon for recovery priority to increase southern resident killer whales' prey base, based on each stock's contribution to diet, degree of spatiotemporal overlap, and whether it would be consumed during times of killer whale reduced body condition or diversified diet. Central Valley stocks ranked 13 (spring-run Chinook salmon), 16 (fall and late fall–run Chinook salmon), and 21 (winter-run Chinook salmon) (National Marine Fisheries and Washington Department of Fish and Wildlife 2018:7-8).

11A.2 Special-Status Aquatic Species Table

Table 11A-13. Special-Status Aquatic Species Identified as Having the Potential to Occur in the Study Area

Common Name	Scientific Name	Status[a] Federal/State	Range and General Habitat Description	Potential for Occurrence
Delta Smelt	*Hypomesus transpacificus*	T/E	San Pablo Bay, Napa River, Suisun Bay, Suisun Marsh, Delta, Sacramento River, San Joaquin River, and Mokelumne River. Prefer salinities less than 6 parts-per-thousand	High
Longfin Smelt	*Spirinchus thaleichthys*	C/T	Coastal Pacific Ocean, San Francisco Bay, Coyote and Alviso Sloughs, San Pablo Bay, Napa River, Suisun Bay, Suisun Marsh, Delta, Sacramento River, and San Joaquin River. Peak spawning occurs when water temperatures are between 5°C and 11°C (41°F and 51.8°F) and centered in brackish water	High
Winter Run-Chinook Salmon – Sacramento River ESU	*Oncorhynchus tshawytscha*	E/E	Pacific Ocean, San Francisco Bay, Suisun Bay, Suisun Marsh, Delta, and the mainstems and tributaries of the Sacramento and San Joaquin River Basins. Spawn on gravel substrate and rear in stream margins, off-channel areas, and floodplains	High
Spring-Run Chinook Salmon – Central Valley ESU	*Oncorhynchus tshawytscha*	T/T	Pacific Ocean, San Francisco Bay, Suisun Bay, Suisun Marsh, Delta, and the mainstems and tributaries of the Sacramento and San Joaquin River Basins. Spawn on gravel substrate and rear in stream margins, off-channel areas, and floodplains	High
Fall-Run/Late Fall-Run Chinook Salmon – Central Valley ESU	*Oncorhynchus tshawytscha*	SC/SSC	Pacific Ocean, San Francisco Bay, Suisun Bay, Suisun Marsh, Delta, and the mainstems and tributaries of the Sacramento and San Joaquin River Basins. Spawn on gravel substrate and rear in stream margins, off-channel areas, and floodplains	High
Steelhead – Central Valley DPS	*Oncorhynchus mykiss irideus*	T/SSC	Pacific Ocean, San Francisco Bay, Suisun Bay, Suisun Marsh, and Delta, and the mainstems and tributaries of the Sacramento and San Joaquin River Basins. Reduced temperatures and increased flow stimulate spawning runs	High

Common Name	Scientific Name	Status[a] Federal/State	Range and General Habitat Description	Potential for Occurrence
Steelhead – Central California Coast DPS	*Oncorhynchus mykiss irideus*	T/–	Pacific Ocean, San Francisco and San Pablo Bays, including Guadalupe River, Coyote Creek, San Francisquito Creek, Sonoma Creek, and Napa River. Adults require deep holding pools with cover and juveniles forage in riverine tidal wetlands and open water of estuarine subtidal areas	High
Green Sturgeon – Southern DPS	*Acipenser medirostris*	T/SSC	Pacific Ocean, San Francisco Bay, Suisun Bay, Suisun Marsh, and Delta, and in Sacramento, Feather, and San Joaquin Rivers. Spawning takes place in deep pools and rearing occurs in main channels and larger interconnecting sloughs and waterways	High
White Sturgeon	*Acipenser transmontanus*	–/SSC	Pacific Ocean, San Francisco Bay and tributaries (Coyote and Sonoma Creeks, and in Guadalupe, Napa, and Petaluma Rivers), Suisun Bay, Suisun Marsh, Delta, and in Sacramento, Feather, and San Joaquin Rivers. Deeper pools and tidal channels with soft bottoms	High
Pacific Lamprey	*Entosphenus tridentatus*	SC/SSC	San Francisco Bay and its tributaries, Suisun Bay, Suisun Marsh, Delta, and in Sacramento, San Joaquin, Feather, Stanislaus, Mokelumne, Tuolumne, and Trinity Rivers. Build spawning redds in shallow water (about 0.5 to 3.5 feet).	High
Western River Lamprey	*Lampetra ayresii*	–/SSC	Sacramento, San Joaquin, Stanislaus, Tuolumne, Feather, America Rivers, and in Mill and Cache Creek. Spawn in gravel redds and rear in fine sediments in off-channel habitats.	High
Kern Brook Lamprey	*Lampetra hubbsi*	–/SSC	Lower San Joaquin River below Millerton Reservoir	High
Sacramento Hitch	*Lavinia exilicauda exilicauda*	–/SSC	Low-elevation streams throughout the Sacramento River Basin and in the north Delta. Spawn in riffles of streams tributary to lakes, river, and sloughs and rear in shallow water or close to aquatic plants	High

Common Name	Scientific Name	Status[a] Federal/State	Range and General Habitat Description	Potential for Occurrence
Sacramento Splittail	*Pogonichthys macrolepidotus*	–/SSC	Suisun Bay, Suisun Marsh, Delta, and in Sacramento, Feather, America, San Joaquin, and Cosumnes Rivers. Moderately shallow, brackish tidal sloughs and adjacent open-water areas, freshwater areas with tidal or riverine flow.	High
Hardhead	*Mylopharodon conocephalus*	–/SSC	Sacramento and San Joaquin River Basins including American and Feather Rivers, and rarely in Delta and San Francisco Estuary. Spawn in gravel-bottomed riffles, runs and at the head of pools and rear in stream margins with abundant cover	High
Central California Roach	*Lavinia symmetricus symmetricus*	–/SSC	Tributaries to the Sacramento and San Joaquin Rivers and tributaries to San Francisco Bay. Small streams and backwaters of mainstem rivers with dense riparian cover	High
Sacramento Perch	*Archoplites interruptus*	–/SSC	Native range includes the Central Valley, Pajaro and Salinas Rivers, tributaries to the San Francisco Estuary, and Clear Lake. Associated with beds of rooted, submerged, and emergent vegetation and other submerged objects.	High
Starry Flounder	*Platichthys stellatus*	–/–	Coastal Pacific Ocean, San Francisco Bay, San Pablo Bay, Suisun Bay, Sacramento River, and San Joaquin River. Found on different substrates including soft sand, gravel, clean shifting sand, hard stable sand, and mud substrata	High
Northern Anchovy	*Engraulis mordax*	–/–	Pacific Ocean, San Francisco Bay, San Pablo Bay, Suisun Bay. Spawn in the upper 50 meters of water column in nearshore areas	High
Striped Bass	*Morone saxatilis*	–/–	Pacific Ocean, San Francisco Bay, San Pablo Bay, Suisun Bay, Suisun Marsh, Delta, Sacramento River, San Joaquin River, Feather River, American River, and Stanislaus River. Occupy moderately shallow areas down to deeper areas of channels.	High
American Shad	*Alosa sapidissima*	–/–	Pacific Ocean, San Francisco Bay, San Pablo Bay, Suisun Bay, Suisun Marsh, Delta, and Sacramento, Feather, American, Yuba, lower San Joaquin, Mokelumne, and Stanislaus Rivers. Spawn in main channels of rivers and rear upstream of Delta	High

Common Name	Scientific Name	Status[a] Federal/State	Range and General Habitat Description	Potential for Occurrence
Threadfin Shad	*Dorosoma petenense*	–/–	Suisun Bay, Suisun Marsh, Delta, and throughout the Sacramento and San Joaquin River Basins. Spawn and rear in areas with submerged aquatic vegetation	High
Largemouth Bass	*Micropterus salmoides*	–/–	Delta and lower river habitats of Feather and American Rivers. Warm, quiet waters with aquatic vegetation and low turbidity.	High
Smallmouth Bass	*Micropterus dolomieu*	–/–	Freshwater regions of the Delta and in large, clear lakes and cool, clear streams with large amounts of cover. Spawn in rubble, gravel, or sand 1 meter deep with submerged logs, boulders and other objects acting as cover.	High
Spotted Bass	*Micropterus punctulatus*	–/–	Freshwater regions of the Delta and in moderately sized, clear, low-gradient rivers and reservoirs. Juveniles school in areas close to shore and adults are solitary and stay at depths between 1 and 4 meters.	High
California Bay Shrimp	*Crangon franciscorum*	–/–	Coastal Pacific Ocean, San Francisco Bay, San Pablo Bay, and Suisun Bay. Rear in lower salinity, warmer areas during summer	High
Southern Resident Killer Whale	*Orcinus orca*	E/–	Coastal Pacific Ocean. Consume Chinook salmon from central California	High

Table source: California Department of Fish and Wildlife 2020, Moyle et al. 2015

[a] Status Explanations:l

Federal:

– = not listed under the federal Endangered Species Act

E = listed as endangered under the federal Endangered Species Act

T = listed as threatened under the federal Endangered Species Act

C = candidate for listing under the federal Endangered Species Act

SC = Species of Concern as identified by National Marine Fisheries Service or U.S. Fish and Wildlife Service

State:

– = not listed under the California Endangered Species Act

E = listed as endangered under the California Endangered Species Act

T = listed as threatened under the California Endangered Species Act

C = candidate for listing under the California Endangered Species Act

SSC = California species of special concern

11A.3 References Cited

Aasen, G. 2011. Fish Salvage at the State Water Project's and Central Valley Project's Fish Facilities during the 2010 Water Year. *IEP Newsletter*. Vol. 24, Number 1, Spring.

Aasen, G. 2012. Fish Salvage at the State Water Project's and Central Valley Project's Fish Facilities during the 2011 Water Year. *IEP Newsletter.* Vol. 25, Number 1, Fall/Winter.

Adams, P. B., C. B. Grimes, J. E. Hightower, S. T. Lindley, and M. L. Moser. 2002. Status Review for North American Green Sturgeon, *Acipenser medirostris*.

Adams, P. B., C. B. Grimes, J. E. Hightower, S. T. Lindley, M. L. Moser, and M. J. Parsley. 2007. Population Status of North American Green Sturgeon, *Acipenser medirostris*. *Environmental Biology of Fishes* 79:339–356.

Ahearn, D. S., J. H. Viers, J. F. Mount, and R. A. Dahlgren. 2006. Priming the Productivity Pump: Flood Pulse Driven Trends in Suspended Algal Biomass Distribution Across a Restored Floodplain. *Freshwater Biology* 51:1417–1433.

Ainsley, S., J. Pombo, T. Wright, and E. Loury. 2013. *Pilot Study: The Feasibility of Using Fyke Traps in the Lower San Joaquin River to Capture Adult Striped Bass.* FISHBIO, Oakdale, CA. July.

Anderson, J. 2018. Using River Temperature to Optimize Fish Incubation Metabolism and Survival: A Case for Mechanistic Models. *Researchgate* Preprint. 10.1101/257154.

Azat, J. 2012. *Grandtab 2012.04.23: California Central Valley Chinook Population Database Report*. California Department of Fish and Game, Sacramento, CA.

Baerwald, M. R., B. M. Schreier, G. Schumer, and B. May. 2012. Detection of Threatened Delta Smelt in the Gut Contents of the Invasive Mississippi Silverside in the San Francisco Estuary using TaqMan Assays. *Transactions of the American Fisheries Society* 141(6):1600–1607.

Barnett-Johnson, R., C. B. Grimes, C. F. Royer, and C. J. Donohoe. 2007. Identifying the Contribution of Wild and Hatchery Chinook Salmon (*Oncorhynchus tshawytscha*) to the Ocean Fishery Using Otolith Microstructure as Natural Tags. *Canadian Journal of Fisheries and Aquatic Sciences* 64(12):1683–1692.

Baumsteiger, J., and P. B. Moyle. 2019. A Reappraisal of the California Roach/Hitch (Cypriniformes, Cyprinidae, *Hesperoleucus*/*Lavinia*) Species Complex. *Zootaxa* 4543(2):221–240.

Baxter, J. L. 1967. Summary of Biological Information on the Northern Anchovy *Engraulis mordax* Girard. *California Cooperative Oceanic Fisheries Investigations Reports* 11:110–116.

Baxter, R. D. 1999. Status of Splittail in California. *California Fish and Game* 85:28–30.

Baxter, R., K. Hieb, S. DeLeón, K. Fleming, and J. Orsi. 1999. *Report on the 1980-1995 Fish, Shrimp, and Crab Sampling in the San Francisco Estuary, California*. Interagency Ecological Program for the Sacramento-San Joaquin Estuary, Technical Report 63, California Department of Fish and Game, Stockton, CA, 503 pp.

Baxter, R., R. Breuer, L. Brown, L. Conroy, F. Feyrer, S. Fong, K. Gehrts, L. Grimaldo, B. Herbold, P. Hrodey, A. Mueller-Solger, T. Sommer, and K. Souza. 2010. *Pelagic Organism Decline Work Plan and Synthesis of Results*. Interagency Ecological Program for the San Francisco Estuary.

Beamesderfer, R., M. Simpson, and G. Kopp. 2007. Use of Life History Information in a Population Model for Sacramento Green Sturgeon. *Environmental Biology of Fishes* 79:315–337.

Beamish, R. J. 1980. Adult Biology of the River Lamprey (*Lampetra ayresi*) and the Pacific Lamprey (*Lampetra tridentata*) from the Pacific Coast of Canada. *Canadian Journal of Fish and Aquatic Science* 53:2898–2908.

Bell, M. C. 1986. *Fisheries Handbook of Engineering Requirements and Biological Criteria*. U.S. Army Corps of Engineers, Fish Passage Development and Evaluation Program, Sacramento, CA.

Bennett, W. A. 2005. Critical Assessment of the Delta Smelt Population in the San Francisco Estuary, California. *San Francisco Estuary and Watershed Science* 3(2). Available: https://escholarship.org/uc/item/0725n5vk. Accessed: November 3, 2020.

Bennett, W. A., and J. R. Burau. 2015. Riders on the Storm: Selective Tidal Movements Facilitate the Spawning Migration of Threatened Delta Smelt in the San Francisco Estuary. *Estuaries and Coasts* 38(3):826–835. doi: http://dx.doi.org/10.1007/s12237-014-9877-3.

Bennett, W. A., and P. B. Moyle. 1996. Where Have All The Fishes Gone? Interactive Factors Producing Fish Declines in the Sacramento-San Joaquin Estuary. In *San Francisco Bay: the Ecosystem*, ed. J. T. Hollibaugh, 519–542. American Association for the Advancement of Science, Pacific Division, San Francisco, CA.

Bennett, W. A., W. J. Kimmerer, and J. R. Burau. 2002. Plasticity in Vertical Migration by Native and Exotic Estuarine Fishes in a Dynamic Low-Salinity Zone. *Limnology and Oceanography* 47(5):1496–1507.

Benson, R. L., S. Turo, and B. W. McCovey. 2007. Migration and Movement Patterns of Green Sturgeon (*Acipenser medirostris*) in the Klamath and Trinity Rivers, California, USA. *Environmental Biology of Fishes* 79:269–279.

Bergen, D. R., and L. D. Jacobson. 2001. Northern Anchovy. In *California's Living Marine Resources: A Status Report*, edited by W. S. Leet, C. M. Dewees, R. Klingbeil, and E. J. Larson, 303–305. California Department of Fish and Game. Publication SG01-11.

Bever, A. J., M. L. MacWilliams, B. Herbold, L. R. Brown and F. V. Feyrer. 2016. Linking Hydrodynamic Complexity to Delta Smelt (*Hypomesus transpacificus*) Distribution in the San Francisco Estuary, USA. *San Francisco Estuary and Watershed Science* 14(1). Available: https://escholarship.org/uc/item/2x91q0fr. Accessed: November 3, 2020.

Bever, A. J., M. L. MacWilliams, and D. K. Fullerton. 2018. Influence of an Observed Decadal Decline in Wind Speed on Turbidity in the San Francisco Estuary. *Estuaries and Coasts* 41:1943–1967.

Blackburn, S. E., M. L. Gingras, J. DuBois, Z. J. Jackson, and M. C. Quist. 2019. Population Dynamics and Evaluation of Management Scenarios for White Sturgeon in the Sacramento–San Joaquin River Basin. *North American Journal of Fisheries Management* 39(5):896–912.

Bottom, D. L., K. K. Jones, and M. J. Herring. 1984. *Fishes of the Columbia River Estuary*. Columbia River Estuary Data Development Program. Oregon Department of Fish and Wildlife, Portland, OR.

Boughton, D. A. and A. S. Pike. 2013. Floodplain Rehabilitation as a Hedge against Hydroclimatic Uncertainty in a Migration Corridor of Threatened Steelhead. *Conservation Biology* 27(6):1158–1168.

Bouley, P., and W. J. Kimmerer. 2006. Ecology of a Highly Abundant, Introduced Cyclopoid Copepod in a Temperate Estuary. *Marine Ecology Progress Series* 324:219–228.

Bourez, W. 2011. Subject: Relating Delta Smelt Index to X2 position, Delta Flows, and Water Use. Memorandum from MBK Engineers to the Northern California Water Association. December 15

Bowen, M., S. Siegfried, C. Liston, L. Hess, and C. Karp. 1998. *Fish Collections and Secondary Louver Efficiency at the Tracy Fish Collection Facility, October 1993 to September 1995*. Tracy Fish Collection Facility Studies, Volume 7. Bureau of Reclamation.

Brandes, P. L., and J. S. McLain. 2001. Juvenile Chinook Salmon Abundance, Distribution, and Survival in the Sacramento-San Joaquin Estuary. In *Fish Bulletin 179(2): Contributions to the Biology of the Central Valley Salmonids*, edited by R. L. Brown, 39–136. Sacramento, CA: California Department of Fish and Game.

Brooks, M., E. Fleishman, L. Brown, P. Lehman, I. Werner, N. Scholz, C. Mitchelmore, J. Lovvorn, M. Johnson, D. Schlenk, S. van Drunick, J. Drever, D. Stoms, A. Parker, and R. Dugdale. 2012. Life Histories, Salinity Zones, and Sublethal Contributions of Contaminants to Pelagic Fish Declines Illustrated with a Case Study of San Francisco Estuary, California, USA. *Estuaries and Coasts* 35(2):603–621. doi: http://dx.doi.org/10.1007/s12237-011-9459-6.

Brown, L. R. 2000. Fish Communities and Their Associations with Environmental Variables, Lower San Joaquin River Drainage, California. *Environmental Biology of Fishes* 57(3):251–269.

Brown, K. 2007. Evidence of Spawning by Green Sturgeon, *Acipenser medirostris*, in the Upper Sacramento River, California. *Environmental Biology of Fishes* 79:297–303.

Brown, L. R. and D. Michniuk. 2007. Littoral Fish Assemblages of the Alien dominated Sacramento–San Joaquin Delta, California 1980–1983 and 2001–2003. *Estuaries and Coasts* 30:186–200.

Brown, L. R., and P. B. Moyle. 1993. Distribution, Ecology, and Status of Fishes of the San Joaquin River Drainage, California. *California Fish and Game* 79:96–113.

Brown, L. R., W. A. Bennett, R. W. Wagner, T. Morgan-King, N. Knowles, F. Feyrer, D. H. Schoelhamer, M.T. Stacey, and M. Dettinger. 2013. Implications for future survival of delta smelt from four climate change scenarios for the Sacramento-San Joaquin Delta, California. *Estuaries and Coasts*. DOI 10.1007/s12237-013-9585-4. Available : http://link.springer.com/article/10.1007%2Fs12237-013-9585-4#.

Brown L. R., L. M. Komoroske, R. W. Wagner, T. Morgan–King, J. T. May, R. E. Connon, N. A. Fangue. 2016. Coupled Downscaled Climate Models and Ecophysiological Metrics Forecast Habitat Compression for an Endangered Estuarine Fish: *PLOS ONE* 11(1):e0146724. doi: http://dx.doi.org/10.1371/journal.pone.0146724.

Buchanan, R. A., J. R. Skalski, P. L. Brandes, and A. Fuller. 2013. Route Use and Survival of Juvenile Chinook Salmon through the San Joaquin River Delta. *North American Journal of Fisheries Management* 33(1):216-229.

Buchanan, R., P. Brandes, M. Marshall, J. S. Foott, J. Ingram, D. LaPlante, and J. Israel. 2015. *2012 South Delta Chinook Salmon Survival Study*. Ed: P. Brandes, U.S. Fish and Wildlife Service. 145 p.

Buchanan R. A., P. L. Brandes, and J. R. Skalski. 2018. Survival of Juvenile Fall-Run Chinook Salmon through the San Joaquin River Delta, California, 2010–2015. *North American Journal of Fisheries Management* 38(3):663–679. Available: https://doi.org/10.1002/nafm.10063.

Buchanan, R. A., and J. R. Skalski. 2020. Relating Survival of Fall-Run Chinook Salmon through the San Joaquin Delta to River Flow. *Environmental Biology of Fishes*. doi: https://doi.org/10.1007/s10641-019-00918-y.

California Department of Fish and Game. 1980. *California Trout, Salmon, and Warmwater Fish Production and Costs, 1978–79*. Inland Fisheries Administrative Report No. 80-1. Inland Fisheries.

California Department of Fish and Game. 1986. *Instream Flow Requirements of the Fish and Wildlife Resources of the Lower American River, Sacramento County, California*. California Department of Fish and Game Stream Evaluation Report No. 86-1.

California Department of Fish and Game. 1998. *A Status Review of the Spring-Run Chinook Salmon (Oncorhynchus tshawytscha) in the Sacramento River Drainage*. Candidate Species Status Report 98-01. Fish and Game Commission, Sacramento, CA.

California Department of Fish and Game. 2001. Factors Affecting Anchovy Production Are Mostly Natural Influences, Such as Ocean Temperature.

California Department of Fish and Game. 2002. *California Department of Fish and Game Comments to NMFS Regarding Green Sturgeon Listing*. Available: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/exhibits/nmfs/spprt_docs/nmfs_exh4_dfg_2002.pdf. Accessed: November 3, 2020.

California Department of Fish and Game. 2004. *Sacramento River Winter-run Chinook Salmon. Biennial Report 2002 – 2003*. Prepared for the Fish and Game Commission. June 2004.

California Department of Fish and Game. 2008. *2007 Sturgeon Fishing Report Card: Preliminary Data Report*.

California Department of Fish and Game. 2009a. *A Status Review of the Longfin Smelt (Spirinchus thaleichthys) in California*. Report to the Fish and Game Commission. January 23.

California Department of Fish and Game. 2009b. *2008 Sturgeon Fishing Report Card: Preliminary Data Report*. June 17.

California Department of Fish and Game. 2010. *2009 Sturgeon Fishing Report Card: Preliminary Data Report*. March 29.

California Department of Fish and Game. 2011. *2010 Sturgeon Fishing Report Card: Preliminary Data Report*. April 20.

California Department of Fish and Game. 2012a. *Central Valley Chinook Salmon In-River Escapement Monitoring Plan*. Fisheries Branch Administrative Report Number: 2012-1. January.

California Department of Fish and Game. 2012b. *2011 Sturgeon Fishing Report Card: Preliminary Data Report.* March 23.

California Department of Fish and Wildlife. 2013. *2012 Sturgeon Fishing Report Card: Preliminary Data Report*. July 12.

California Department of Fish and Wildlife. 2014. *2013 Sturgeon Fishing Report Card: Preliminary Data Report*. May 8.

California Department of Fish and Wildlife. 2018a. *Monthly Abundance Indices*. Available: http://www.dfg.ca.gov/delta/data/fmwt/indices.asp.

California Department of Fish and Wildlife. 2018b. *Grand Tab 2018.04.09: California Central Valley Chinook Population Database Report*. Compiled 9 April 2018. Available: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=84381.

California Department of Fish and Wildlife. 2018c. *Historical Anadromous Fish Releases from CDFW Hatcheries*. Available: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=156895. Accessed: June 12, 2020.

California Department of Fish and Wildlife. n.d. *Spring Kodiak Survey: Egg Stages—Classification of Male Delta Smelt According to Mager (1996) and Mager (Personal Communication) and Classification of Female Delta Smelt According to Mager (1996) and Mager (Personal Communication).* Available: https://www.dfg.ca.gov/delta/data/skt/eggstages.asp. Accessed: November 3, 2020.

California Department of Water Resources. 2003. *Fish Distribution in the Feather River downstream of Thermalito diversion dam to the Confluence with the Sacramento River.* SP-F3.2 Task 1 and F21 Task 2. Draft Report. Oroville Facilities Relicensing FERC Project No. 2100.

California Department of Water Resources. 2004. *Relationship Assessment of Fish/Wildlife Management and Recreation*. Final. R-4. Oroville Facilities Relicensing FERC Project No. 2100.

California Department of Water Resources. 2007. *Oroville Facilities Relicensing FERC Project No. 2100 Draft Environmental Impact Report*. May.

California Department of Water Resources, Bureau of Reclamation, U.S. Fish and Wildlife Service, and National Marine Fisheries Service. 2013. *Environmental Impact Report/ Environmental Impact Statement for the Bay Delta Conservation Plan*. Draft. December.

California Department of Water Resources. 2019. *Incidental Take Permit Application for Long-term Operation of the California State Water Project*. December.

California Department of Water Resources. 2020. *Final Environmental Impact Report for Long-term Operation of the California State Water Project*. State Clearinghouse No. 2019049121. March.

California Department of Water Resources and Bureau of Reclamation. 2012. *Yolo Bypass Salmonid Habitat Restoration and Fish Passage Implementation Plan, Long-Term Operation of the Central Valley Project and State Water Project Biological Opinion Reasonable and Prudent Alternative Actions I.6.1 and I.7*. Pages 1–140.

California Department of Water Resources and Bureau of Reclamation. 2017. *Yolo Bypass Salmonid Habitat Restoration and Fish Passage. Draft Environmental Impact Statement/Environmental Impact Report*. December.

California Hatchery Scientific Review Group. 2012. *California Hatchery Review Report.* Prepared for the U.S. Fish and Wildlife Service and Pacific States Marine Fisheries Commission. June.

Carlson, S. M., and W. H. Satterthwaite. 2011. Weakened Portfolio Effect in a Collapsed Salmon Population Complex. *Canadian Journal of Fisheries and Aquatic Sciences* 68(9):1579–589.

Cavallo, B., P. Gaskill, J. Melgo, and S. C. Zeug. 2015. Predicting Juvenile Chinook Salmon Routing in Riverine and Tidal Channels of a Freshwater Estuary. *Environmental Biology of Fishes* 98(6):1571–1582.

Cayan D. R., M. Tyree, M. D. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. D. Bromirski, N. Graham, and R. E. Flick. 2009. *Climate Change Scenarios and Sea Level Rise Estimates for California - 2008 Climate Change Scenarios Assessment - Final Report.* California Energy Commission, PIER Report CEC500-2009-014-F

Cech, J. J., S. J. Mitchell, and T. E. Wragg. 1984. Comparative Growth of Juvenile White Sturgeon and Striped Bass: Effects of Temperature and Hypoxia. *Estuaries* 7:12–18.

Chapman, E. D., E. A. Miller, G. P. Singer, A. R. Hearn, M. J. Thomas, W. N. Brostoff, P. E. LaCivita, and A. P. Klimley. 2019. Spatiotemporal Occurrence of Green Sturgeon at Dredging and Placement Sites in the San Francisco Estuary. *Environmental Biology of Fishes* 102:27–40.

Clark, F. N., and J. B. Phillips 1952. The Northern Anchovy (*Engraulis mordax*) in the California fishery. *California Fish and Game* 38(2):189–207.

Clear Creek Technical Team. 2018. *Annual Report for the Coordinated Long-Term Operations Biological Opinion*.

Clemens, B. J., M. G. Mesa, R. J. Magie, D. A. Young, and C. B. Schreck. 2012. Pre-spawning Migration of Adult Pacific Lamprey, *Entosphenus Tridentatus*, in the Willamette River, Oregon, U.S.A. *Environmental Biology of Fishes* 93:245–254.

Cloern, J. E., Morinaka, N. Brown, R. L., Cayan, D., Dettinger, M. D., Morgan, T. L., Schoellhammer, D. H., Stacey, M. T., van der Wegen, M., Wagner, R. W., and A. D. Jassby. 2011. Projected Evolution of California's San Francisco Bay-Delta-River System in a Century of Climate Change. *PLOS ONE* 6(9):e24465. DOI: 10.371/journal.pone.0024465.

Columbia Basin Research, University of Washington (CBR UW). (2020). SacPAS CDFW GrandTab Adult Escapement. Available: http://www.cbr.washington.edu/sacramento/data/query_adult_grandtab.html Accessed: 13 May, 2020.

Conrad, J. L., A. J. Bibian, K. L. Weinersmith, D. De Carion, M. J. Young, P. Crain, E. L. Hestir, M. J. Santos, and A. Sih. 2016. Novel Species Interactions in a Highly Modified

Estuary: Association of Largemouth Bass with Brazilian Waterweed *Egeria densa*. *Transactions of the American Fisheries Society* 145(2):249–263.

Cordoleani, F., J. Notch, A. S. McHuron, A. J. Ammann, and C. J. Michel. 2018. Movement and Survival of Wild Chinook Salmon Smolts from Butte Creek During Their Out-Migration to the Ocean: Comparison of a Dry Year versus a Wet Year. *Transactions of the American Fisheries Society* 147(1):171–184.

Cordoleani, F., J. Notch, A. S. McHuron, C. J. Michel, and A. J. Ammann. 2019. *Movement and Survival Rates of Butte Creek Spring-Run Chinook Salmon Smolts from the Sutter Bypass to the Golden Gate Bridge in 2015, 2016, and 2017*. NOAA Technical Memorandum NMFS-SWFSC-618. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, CA.

Crain, P. K., and P. B. Moyle. 2011. Biology, History, Status and Conservation of Sacramento Perch, *Archoplites interruptus: A Review*. *San Francisco Estuary and Watershed Science* 9(1). Available: https://escholarship.org/uc/item/8st5g6df. Accessed: November 3, 2020.

Damon, L. J., S. B. Slater, R. D. Baxter, and R. W. Fujimura. 2016. Fecundity and Reproductive Potential of Wild Female Delta Smelt in the Upper San Francisco Estuary, California. *California Fish and Game* 102(4):188–210. Available: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=141865&inline.

del Rosario, R. B., Y. J. Redler, K. Newman, P. L. Brandes, T. Sommer, K. Reece, and R. Vincik. 2013. Migration Patterns of Juvenile Winter-Run-Sized Chinook Salmon (*Oncorhynchus tshawytscha*) through the Sacramento–San Joaquin Delta. *San Francisco Estuary and Watershed Science* 11(1). Available: https://escholarship.org/uc/item/36d88128. Accessed: November 3, 2020.

Demetras, N. J., D. D. Huff, C. J. Michel, J. M. Smith, G. R. Cutter, S. A. Hayes, and S. T. Lindley. 2016. Development of Underwater Recorders to Quantify Predation of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) in a River Environment. *Fishery Bulletin* (114):179–185.

Demetras, N. J., B. A. Helwig, and A. S. McHuron. 2020. Reported Vessel Strike as a Source of Mortality of White Sturgeon in San Francisco Bay. *California Fish and Wildlife* 106(1):59–65.

Dettinger, M. D. 2005. From Climate-Change Spaghetti to Climate-Change Distributions for 21st Century California. *San Francisco Estuary and Watershed Science* 3(1). Available: https://escholarship.org/uc/item/2pg6c039. Accessed: November 3, 2020.

Di Lorenzo, E., K. M. Cobb, J. C. Furtado, N. Schneider, B. T. Anderson, A. Bracco, M. A. Alexander, and D. J. Vimont. 2010. Central Pacific El Nino and Decadal Climate Change in the North Pacific Ocean. *Nature Geoscience*, 3(11):762.

Dill, W. A., and A. J. Cordone. 1997. *Fish Bulletin 178: History and Status of Introduced Fishes in California, 1871–1996*. Sacramento, CA: California Department of Fish and Game, Inland Fisheries Division.

DuBois, J., Harris, M. D. 2015. 2014 Sturgeon Fishing Report Card: preliminary data report. California Department of Fish and Wildlife. Stockton, CA.

DuBois, J., Harris, M. D. 2016. 2015 Sturgeon Fishing Report Card: preliminary data report. California Department of Fish and Wildlife. Stockton, CA.

DuBois, J., Danos, A. 2017. 2016 Sturgeon Fishing Report Card: preliminary data report. California Department of Fish and Wildlife. Stockton, CA.

DuBois, J., Danos, A. 2018. 2017 Sturgeon Fishing Report Card: preliminary data report. California Department of Fish and Wildlife. Stockton, CA.

Dudley, P. N. 2018. A Salmonid Individual-Based Model as a Proposed Decision Support Tool for Management of a Large Regulated River. *Ecosphere* 9(1):e02074.

Dudley, P. N. 2019. Insights from an Individual Based Model of a Fish Population on a Large Regulated River. *Environmental Biology of Fishes* 102(8):1069–1095.

Earley, J. T., D. J. Colby, and M. R. Brown. 2013. *Juvenile Salmonid Monitoring in Sacramento River tributaries, California, from October 2009 through September 2010*. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.

Emmett, R. L., S. L. Stone, S. A. Hinton, and M. E. Monaco. 1991. *Distribution and Abundance of Fishes and Invertebrates in West Coast Estuaries, Volume II: Species Life History Summaries*. ELMR Rep. No. 8. NOOAA/NOS strategic Environmental Assessments division, Rockville, MD, 329 p.

Erickson, D. L., J. A. North, J. E. Hightower, J. Weber, and L. Lauck. 2002. Movement and Habitat Use of Green Sturgeon *Acipenser medirostris* in the Rogue River, Oregon, USA. *Journal of Applied Ichthyology* 18:565–569.

Farley, T. C. 1966. Striped Bass, Roccus Saxatilis, Spawning in the Sacramento–San Joaquin River Systems during 1963 and 1964. In *Fish Bulletin 136: Ecological Studies of the Sacramento–San Joaquin Estuary, Part II—Fishes of the Delta,* edited by J. L. Turner and D. W. Kelley, 28–43. Sacramento, CA: California Department of Fish and Game.

Federal Energy Regulatory Commission. 2007. *Final Environmental Impact Statement for Hydropower License, Oroville Facilities*. FERC Project No. 2100-052, California.

Ferrari, M. C. O., L. Ranåker, K. L. Weinersmith, M. J. Young, A. Sih, and J. L. Conrad. 2014. Effects of Turbidity and an Invasive Waterweed on Predation by Introduced Largemouth Bass. *Environmental Biology of Fishes* 97(1):79–90.

Feyrer, F., B. Herbold, S. A. Matern, and P. B. Moyle. 2003. Dietary Shifts in a Stressed Fish Assemblage: Consequences of a Bivalve Invasion in the San Francisco Estuary. *Environmental Biology of Fishes* 67:277–288.

Feyrer, F., K. Newman, M. Nobriga, and T. Sommer. 2011. Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish. *Estuaries and Coasts* 34:120–128.

Feyrer, F., M. L. Nobriga, and T. R. Sommer. 2007. Multi-Decadal Trends for Three Declining Fish Species: Habitat Patterns and Mechanisms in the San Francisco Estuary, California, USA. *Canadian Journal of Fisheries and Aquatic Sciences* 64:723–734.

Feyrer, F., Portz, D., Odum, D., Newman, K.B., Sommer, T., Contreras, D., Baxter, R., Slater, S.B., Sereno, D. and E. Van Nieuwenhuyse, 2013. SmeltCam: Underwater Video Codend for Trawled Nets with an Application to the Distribution of the Imperiled Delta Smelt. *PLOS ONE*, *8*(7)

Feyrer, R., T. R. Sommer, and R. D. Baxter. 2005. Spatial-Temporal Distribution and Habitat 28 Associations of Age-0 Splittail in the Lower San Francisco Watershed. *Copeia* 2005(1):159–168.

Feyrer, F., T. Sommer, and W. Harrell. 2006. Managing Floodplain Inundation for Native Fish: Production Dynamics of Age-0 Splittail (*Pogonichthys macrolepidotus*) in California's Yolo Bypass. *Hydrobiologia* 573:213–226.

Feyrer, F., T. Sommer, and S. B. Slater. 2009. Old School vs. New School: Status of Threadfin Shad (*Dorosoma petenense*) Five Decades after Its Introduction to the Sacramento–San Joaquin Delta. *San Francisco Estuary and Watershed Science*, 7(1). Available: https://escholarship.org/uc/item/4dt6p4bv.

Finger, A. J., G. Schumer, A. Benjamin, and S. Blankenship. 2017. Evaluation and Interpretation of Genetic Effective Population Size of Delta Smelt from 2011–2014. *San Francisco Estuary and Watershed Science* 15(2).

Fisch, K. M., J. A. Ivy, R. S. Burton, and B. May. 2013. Evaluating the Performance of Captive Breeding Techniques for Conservation Hatcheries: A Case Study of the Delta Smelt Captive Breeding Program. *Journal of Heredity* 104(1):92–104.

Fish, M. A. 2010. A White Sturgeon Year-Class Index for the San Francisco Estuary and Its Relation to Delta Outflow. *IEP Newsletter* 23(2):80–84. Spring.

FISHBIO Environmental, LLC. 2007. *2007 Stanislaus River Data Report*. Final Data.

FISHBIO Environmental, LLC. 2010. *FISHBIO Fall-Run Chinook Salmon Update*. Posted on the FISHBIO blog on December 15, 2010. Available: http://fishbio.com/field-notes/population-dynamics/fishbio-fall-run-chinook-salmon-update-2. Accessed: October 13, 2015.

Fong, S., S. Louie, I. Werner, J. Davis, and R. E. Connon. 2016. Contaminant Effects on California Bay–Delta Species and Human Health. *San Francisco Estuary and Watershed Science* 14(4).

Friedman, W. R., B. T. Martin, B. K. Wells, P. Warzybok, C. J. Michel, E. M. Danner, and S. T. Lindley. 2019. Modeling composite effects of marine and freshwater processes on migratory species. *Ecosphere* 10(7):e02743.

Fry, D. H., Jr. 1961. King Salmon Spawning Stocks of the California Central Valley, 1940–1959. *California Fish and Game* 47(1):55–71.

Gard, M. 2013. *Flow-Habitat Relationships for Juvenile Spring-Run and Fall-Run Chinook Salmon and Steelhead/Rainbow Trout Rearing in Clear Creek between Clear Creek and the Sacramento River*. U.S. Fish and Wildlife Service, Sacramento, CA.

Garwood, R. S. 2017. Historic and Contemporary Distribution of Longfin Smelt (*Spirinchus thaleichthys*) along the California Coast. *California Fish and Game* 103(3):96–117.

Ger, K. A., S. J. Teh, D. V. Baxa, S. Lesmeister, and C. R. Goldman. 2010. The Effects of Dietary *Microcystis aeruginosa* and *microcystin* on the Copepods of the Upper San Francisco Estuary. *Freshwater Biology* 55:1548–1559.

Goals Project. 2000. *Baylands Ecosystem Species and Community Profiles: Life Histories and Environmental Requirements of Key Plants, Fish and Wildlife*. Prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. P.R. Olofson, editor. San Francisco Bay Regional Water Quality Control Board, Oakland, CA.

Goertler, P., K. Jones, J. Cordell, B. Schreier, and T. Sommer. 2018a. Effects of Extreme Hydrologic Regimes on Juvenile Chinook Salmon Prey Resources and Diet Composition in a Large River Floodplain. *Transactions of the American Fisheries Society* 147(2):287–299.

Goertler, P. A. L., T. R. Sommer, W. H. Satterthwaite, and B. M. Schreier. 2018b. Seasonal Floodplain-Tidal Slough Complex Supports Size Variation for Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*). *Ecology of Freshwater Fish* 27:580–593.

Goertler, P. A., A. W. Shakya, A. M. Seesholtz, B. M. Schreier, S. Z. Matica, and K. S. Holley. 2019. Lamprey (*Entosphenus* sp. and *Lampetra* sp.) Estuarine Occupancy Is Regionally Variable and Constrained by Remperature. *Journal of Fish Biolo*gy 96(2):527–532.

Goodman, D. H., S. B. Reid, N. A. Som, and W. R. Poytress. 2015. The Punctuated Seaward Migration of Pacific Lamprey (*Entosphenus tridentatus*): Environmental Cues and Implications for Streamflow Management. *Canadian Journal of Fisheries and Aquatic Sciences* 72(12):1817–1828.

Gould, A. L., and W. J. Kimmerer. 2010. Development, Growth, and Reproduction of the Cyclopoid Copepod *Limnoithona tetraspina* in the Upper San Francisco Estuary. *Marine Ecology Progress Series* 412:163–177.

Greenfield, B. K., S. J. Teh, J. R. M. Ross, J. Hunt, G. H. Zhang, J. A. Davis, G. Ichikawa, D. Crane, S. O. Hung, D. F. Deng, F. C. Teh, and P. G. Green. 2008. Contaminant Concentrations and Histopathological Effects in Sacramento Splittail (*Pogonichthys macrolepidotus*). *Environmental Contamination & Toxicology* 55(2):270–281.

Gregory, R. S., and C. D. Levings. 1998. Turbidity Reduces Predation on Migrating Juvenile Pacific Salmon. *Transactions of the American Fisheries Society* 127(2):275–285.

Grimaldo, L. 2018. Written Testimony of Lenny Grimaldo, Expert Witness for California Department of Water Resources. Exhibit DWR-1222. Part 2 of Hearing in the matter of California Department of Water Resources and United States Bureau of Reclamation Request for a Change in Point of Diversion for California WaterFix Before the California State Water Resources Control Board.

Grimaldo, L. F., R. E. Miller, C. M. Peregrin, and Z. P. Hymanson. 2004. Spatial and Temporal Distribution of Ichthyoplankton in Three Habitat Types of the Sacramento–San Joaquin Delta. Pages 81–96 in F. Feyrer, L. R. Brown, R. L. Brown, and J. J. Orsi, editors. *Early Life History of Fishes in the San Francisco Estuary and Watershed*. Bethesda, MD: American Fisheries Society.

Grimaldo, L., F. Feyrer, J. Burns, and D. Maniscalco. 2017. Sampling Uncharted Waters: Examining Rearing Habitat of Larval Longfin Smelt (*Spirinchus thaleichthys*) in the Upper San Francisco Estuary. *Estuaries and Coasts* 40(6):1771–1784.

Grimaldo, L., J. Burns, R. E. Miller, A. Kalmbach, A. Smith, J. Hassrick, and C. Brennan. 2020. Forage Fish Larvae Distribution and Habitat Use During Contrasting Years of Low and High Freshwater Flow in the San Francisco Estuary. *San Francisco Estuary and Watershed Science* 18(3).

Grimaldo, L. F., T. Sommer, N. Van Ark, G. Jones, E. Holland, P. B. Moyle, P. Smith, and B. Herbold. 2009. Factors Affecting Fish Entrainment into Massive Water Diversions in a Freshwater Tidal Estuary: Can Fish Losses Be Managed? *North American Journal of Fisheries Management* 29(5):1253–1270.

Grossman, G. D. 2016. Predation on Fishes in the Sacramento–San Joaquin Delta: Current Knowledge and Future Directions. *San Francisco Estuary and Watershed Science* 14(2). Available: https://escholarship.org/uc/item/9rw9b5tj. Accessed: November 3, 2020.

Gruber, J. J, Z. J. Jackson, and J.P. Van Eenennaam. 2012. *2011 San Joaquin River Sturgeon Spawning Survey.* First Annual Report. Lodi Fish and Wildlife Office, Anadromous Fish Restoration Program, U.S. Fish and Wildlife Service, Stockton, CA.

Gunckel, S. L., K. K. Jones, and S. E. Jacobs. 2009. Spawning Distribution and Habitat Use of Adult Pacific and Western Brook Lampreys in Smith River, Oregon. In *Biology, Management, and Conservation of Lampreys in North America: American Fisheries Society Symposium 72*, edited by L. R. Brown, S. D. Chase, M. G. Mesa, R. J. Beamish, and P. B. Moyle, 173–189. Bethesda, MD: American Fisheries Society.

Haertel, L., and C. Osterberg. 1967. Ecology of Zooplankton, Benthos and Fishes in the Columbia River Estuary. *Ecology* 48:459–472.

Hallock, R. J. 1989. *Upper Sacramento River Steelhead,* Oncorhynchus mykiss*, 1952–1988*. Report to the U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.

Hallock, R. J., and W. F. Van Woert. 1959. A Survey of Anadromous Fish Losses in Irrigation Diversions from the Sacramento and San Joaquin Rivers. *California Fish and Game* 45(4):227–296.

Hamilton, S. A., and D. D. Murphy. 2018. Analysis of limiting factors across the life cycle of delta smelt (*Hypomesus transpacificus*). *Environmental Management* 62:365–382. Available: https://doi.org/10.1007/s00267-018-1014-9.

Hamilton, S. A., and D. D. Murphy. 2020. Use of Affinity Analysis to Guide Habitat Restoration and Enhancement for the Imperiled Delta Smelt. *Endangered Species Research* 43:103–120.

Hamilton, S., S. Bartell, J. Pierson, and D. Murphy. 2020. Factors controlling calanoid copepod biomass and distribution in the Upper San Francisco Estuary and implications for managing the imperiled delta smelt (*Hypomesus transpacificus*). *Environmental Management* 65:587–601. Available: https://doi.org/10.1007/s00267-020-01267-8.

Hammock, B. G., S. P. Moose, S. S. Solis, E. Goharian, and S. J. Teh. 2019a. Hydrodynamic Modeling Coupled with Long-Term Field Data Provide Evidence for Suppression of Phytoplankton by Invasive Clams and Freshwater Exports in the San Francisco Estuary. *Environmental Management* 63:703–717.

Hammock, B. G., R. Hartman, S. B. Slater, A. Hennessy, and S. J. Teh. 2019b. Tidal Wetlands Associated with Foraging Success of Delta Smelt. *Estuaries and Coasts* 42(3):857–867.

Hance, D. J., R. W. Perry, J. R. Burau, A. Blake, P. Stumpner, X. Wang, and A. Pope. 2020. Combining Models of the Critical Streakline and the Cross-Sectional Distribution of Juvenile Salmon to Predict Fish Routing at River Junctions. *San Francisco Estuary and Watershed Science* 18(1). Available: https://escholarship.org/uc/item/1wr2f87f. Accessed: November 3, 2020.

Hanni, J., B. Poytress, and H. N. Blalock-Herod. 2006. *Spatial and Temporal Distribution Patterns of Pacific and River Lamprey in the Sacramento and San Joaquin Rivers and Delta*. Poster. U.S. Fish and Wildlife Service.

Hannon, J., and B. Deason. 2008. *American River Steelhead Spawning 2001–2007*. Bureau of Reclamation.

Hanson, M. B., R. W. Baird, J. K. B. Ford, J. A. Hempelmann, D. M. Van Doornik, J. R. Candy, C. K. Emmons, G. S. Schorr, B. Gisborne, K. L. Ayres, S. K. Wasser, K. C. Balcomb, K. Balcomb-Bartok, J. G. Sneva, and M. J. Ford. 2010. Species and Stock Identification of

Prey Consumed by Endangered Southern Resident Killer Whales in Their Summer Range. *Endangered Species Research* 11:69–82. Available: https://doi.org/10.3354/esr00263.

Hart, J. L. 1973. *Pacific Fishes of Canada, Bulletin 180*. Ottawa, Canada: Fisheries Resource Board of Canada.

Harvey, B. N., D. P. Jacobson, and M. A. Banks. 2014. Quantifying the Uncertainty of a Juvenile Chinook Salmon Race Identification Method for a Mixed-Race Stock. *North American Journal of Fisheries Management* 34(6):1177–1186.

Hassler, T. J. 1988. *Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest)—Striped Bass*. U.S. Fish and Wildlife Service Biological Report 82(11.82). U.S. Army Corps of Engineers, TR EL-82-4.

Hassrick, J. L., M. J. Henderson, D. D. Huff, W. J. Sydeman, M. C. Sabal, J. A. Harding, A. J. Ammann, E. D. Crandall, E. P. Bjorkstedt, J. C. Garza, and S. A. Hayes. 2016. Early ocean distribution of juvenile Chinook salmon in an upwelling ecosystem. *Fisheries Oceanography* 25(2):133–146.

Haugen, C. W., J. D. Messersmith, and R. H. Wickwire. 1969. Progress Report on Anchovy Tagging off California and Baja California, March 1966 through May 1969. In *Fish Bulletin 147: The Northern Anchovy (Engraulis mordax) and Its Fishery (1965–1968)*, edited by J. D. Messersmith, 75–89. Sacramento, CA: California Department of Fish and Game.

Healey, M. C. 1991. Life History of Chinook Salmon (*Oncorhynchus tshawytscha*). In *Pacific Salmon Life Histories,* edited by C. Groot and L. Margolis. Vancouver, Canada: University of British Columbia Press.

Hennessy, A. 2010. Zooplankton Monitoring, 2009. *Interagency Ecological Program Newsletter* 23(2):15–22.

Herbold, B., C. Armor, R. Baxter, M. Chotkowski, P. Coulston, M. Nobriga, and T. Sommer. 2005. *Historical Patterns in Salvage Data*. CALFED Science Program. Available: http://www.science.calwater.ca.gov/pdf/workshops/POD/CDFG_POD_Historical_Patterns_in_
Salvage_Data.pdf. Accessed: July 12, 2013.

Hestir, E. L., D. H. Schoellhamer, J. Greenberg, T. Morgan-King, and S. L. Ustin. 2016. The Effect of Submerged Aquatic Vegetation Expansion on a Declining Turbidity Trend in the Sacramento–San Joaquin River Delta. *Estuaries and Coasts* 39(4):1100–1112.

Heublein, J. C. 2006. *Migration of Green Sturgeon, Acipenser medirostris in the Sacramento River*. Master's thesis. California State University, San Francisco, CA.

Heublein, J. C., J. T. Kelly, C. E. Crocker, A. P. Klimley, and S. T. Lindley. 2009. Migration of Green Sturgeon, *Acipenser medirostris* in the Sacramento River. *Environmental Biology of Fishes* 84(3): 245–258.

Heublein, J., R. Bellmer, R. D. Chase, P. Doukakis, M. Gingras, D. Hampton, J. A. Israel, Z. J. Jackson, R. C. Johnson, O. P. Langness, S. Luis, E. Mora, M. L. Moser, L. Rohrbach, A. M. Seesholtz, T. Sommer, and J. Stuart. 2017a. *Life History and Current Monitoring Inventory of San Francisco Estuary Sturgeon*. September. NOAA-TM-NMFS-SWFSC-589. National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, CA.

Heublein, J., R. Bellmer, R. D. Chase, P. Doukakis, M. Gingras, D. Hampton, J. A. Israel, Z. J. Jackson, R. C. Johnson, O. P. Langness, S. Luis, E. Mora, M. L. Moser, L. Rohrbach, A. M. Seesholtz, and T. Sommer. 2017b. *Improved Fisheries Management through Life Stage Monitoring: The Case for the Southern Distinct Population Segment of North American Green Sturgeon and the Sacramento–San Joaquin River White Sturgeon*. September. NOAA-TM-NMFS-SWFSC-588. National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, CA.

Hieb, K., and R. Baxter. 1993. Delta Outflow/San Francisco Bay. In *1991 Annual Report, Interagency Ecological Studies Program for the Sacramento–San Joaquin Estuary,* edited by P.L. Herrgesell.

Hilborn, R., S. P. Cox, F. M. D. Gulland, D. G. Hankin, N. T. Hobbs, D. E. Schindler, and A. W. Trites. 2012. *The Effects of Salmon Fisheries on Southern Resident Killer Whales: Final Report of the Independent Science Panel*. November 30. Prepared for National Marine Fisheries Service and Fisheries and Oceans Canada.

Hildebrand, L. R., A. Drauch Schreier, K. Lepla, S. O. McAdam, J. McLellan, M. J. Parsley, V. L. Paragamian, and S. P. Young. 2016. Status of White Sturgeon (*Acipenser transmontanus* Richardson, 1863) throughout the Species Range, Threats to Survival, and Prognosis for the Future. *Journal of Applied Ichthyology* 32(S1):261–312.

Hobbs, J. A., W. A. Bennett, and J. E. Burton. 2006. Assessing Nursery Habitat Quality for Native Smelts (*Osmeridae*) in the Low-Salinity Zone of the San Francisco Estuary. *Journal of Fish Biology* 69(3):907–922.

Hobbs, J. A., J. Cook, P. Crain, M. Bisson, and C. Parker. 2015. Longfin Smelt Distribution, Abundance and Evidence of Spawning in San Francisco Bay Tributaries. Poster presented at: Interagency Ecological Program Workshop, 2015 March 18–20, Folsom, CA.

Hobbs, J. A., C. Parker, J. Cook, P. Crain, and M. Bisson, and C. Parker. 2015. The Distribution and Abundance of Larval and Adult 1 Longfin Smelt in San Francisco Bay Tributaries Year 1: Pilot Study. Prepared for California Department of Water Resources and the IEP Longfin Smelt Project Work Team. Davis, CA: Department of Wildlife, Fish and Conservation Biology.

Hobbs, J. A., L. S. Lewis, N. Ikemiyagi, T. Sommer, and R. D. Baxter. 2010. The Use of Otolith Strontium Isotopes (87Sr/86Sr) to Identify Nursery Habitat for a Threatened Estuarine Fish. *Environmental Biology of Fishes* 89(3):557–569.

Hobbs, J. A., L. S. Lewis, M. Willmes, C. Denney, and E. Bush. 2019. Complex Life Histories Discovered in a Critically Endangered Fish. *Scientific Reports* 9(1):1–12.

Huber, E. R., and S. M. Carlson. 2015. Temporal Trends in Hatchery Releases of Fall-Run Chinook Salmon in California's Central Valley. *San Francisco Estuary and Watershed Science* 13(2). Available: https://escholarship.org/uc/item/7237t9xn. Accessed: November 3, 2020.

ICF International. 2016a. *Biological Assessment for the California WaterFix*. July. (ICF 00237.15.) Sacramento, CA. Prepared for the United States Department of the Interior, Bureau of Reclamation, Sacramento, CA.

ICF International. 2016b. *State Incidental Take Permit Application for the Construction and Operation of Dual Conveyance Facilities of the State Water Project*. Draft. October. (ICF 00443.12.) Sacramento, CA. Prepared for the California Department of Water Resources, Sacramento, CA.

Independent Science Panel and ESSA Technologies. 2012. *The Effects of Salmon Fisheries on Southern Resident Killer Whales*. Final Report of the Independent Science Panel. Prepared for National Marine Fisheries Service and Fisheries and Oceans Canada. November 30.

Interagency Ecological Program, Management, Analysis, and Synthesis Team. 2015. *An Updated Conceptual Model of Delta Smelt Biology: Our Evolving Understanding of an Estuarine Fish*. January. Technical Report 90. Interagency Ecological Program for the San Francisco Bay/Delta Estuary. Available: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/docs/petitioners_exhibit/dwr/part2/DWR-1089%20IEP_MAST_Team_2015_Delta_Smelt_MAST_Synthesis_Report_January%202015.pdf. Accessed: December 3, 2020.

Israel, J. 2006. Determining Spawning Population Estimates for Green Sturgeon with Microsatellite DNA. Presentation at the 2006 CALFED Science Conference. Sacramento, California. As cited in Department of Water Resources, *Programmatic Biological Assessment for the 2013-17 Temporary Barriers Project for National Marine Fisheries Service-Managed Species*, October 2012.

Israel, J. A.; Cordes, J. F.; Blumberg, M. A.; May, B., 2004: Geographic patterns of genetic differentiation among collections of green sturgeon. N. Am. J. Fish. Manage. 24, 922–931.

Israel J. A., and B. May. 2010. Characterization and evaluation of polymorphic microsatellite markers in the anadromous fish *Spirinchus thaleichthys*. *Conservation Genetic Resources* 2:227–230

Israel, J. A., and A. P. Klimley. 2008. Life History Conceptual Model for North American Green Sturgeon *(Acipenser medirostris)*. December. University of California, Davis. Prepared for California Department of Fish and Game, Delta Regional Ecosystem Restoration and Implementation Program, Sacramento, CA.

Israel, J., A. Drauch, and M. Gingras. 2008. *Life History Conceptual Model for White Sturgeon (*Acipenser transmontanus*)*. University of California, Davis, and California Department of Fish and Game, Stockton, CA. Jackson, Z. 2013. San Joaquin River Sturgeon Investigations—2011/12 Season Summary. Interagency Ecological Program Quarterly Highlights. *Interagency Ecological Program Newsletter* Vol. 26(1):4–6.

Jackson, Z. J., and J. P. Van Eenennaam. 2013. *2012 San Joaquin River Sturgeon Spawning Survey*. U.S. Fish and Wildlife Service, Anadromous Fish Restoration Program, Stockton Fish and Wildlife Office, Stockton, CA.

Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinski. 1995. Isohaline Position as a Habitat Indicator for Estuarine Populations. *Ecological Applications* 5(1):272–289.

Jeffries, K. M., R. E. Connon, B. E. Davis, L. M. Komoroske, M. T. Britton, T. Sommer, A. E. Todgham, and N. A. Fangue. 2016. Effects of High Temperatures on Threatened Estuarine Fishes during Periods of Extreme Drought. *Journal of Experimental Biology* 219(11):1705–1716.

Jeffres, C. A., J. J. Opperman, and P. B. Moyle. 2008. Ephemeral Floodplain Habitats Provide Best Growth Conditions for Juvenile Chinook Salmon in a California River. *Environmental Biology of Fishes* 83:449–458.

Johnston, M. E., A. E. Steel, M. Espe, T. Sommer, A. P. Klimley, P. Sandstrom, and D. Smith. 2018. Survival of Juvenile Chinook Salmon in the Yolo Bypass and the Lower Sacramento River, California. *San Francisco Estuary and Watershed Science* 16(2). Available: https://escholarship.org/uc/item/8bq7t7rr. Accessed: November 3, 2020.

Katz J. V. E., Jeffres C., Conrad J. L., Sommer T. R., Martinez J., Brumbaugh S., Corline, N., and P. B. Moyle. 2017. Floodplain Farm Fields Provide Novel Rearing Habitat for Chinook Salmon. *PLOS ONE* 12(6):e0177409. Available: https://doi.org/10.1371/journal.pone.0177409. Accessed: October 27, 2020.

Kelly, J. T., A. P. Klimley, and C. E. Crocker. 2007. Movements of Green Sturgeon, *Acipenser medirostris*, in the San Francisco Bay Estuary, California. *Environmental Biology of Fishes* 79:281–295.

Kennedy, T., and T. Cannon. 2005. *Stanislaus River Salmonid Density and Distribution Survey Report (2002–2004)*. Final Draft. Prepared for the Bureau of Reclamation by the Fishery Foundation of California. October.

Kimmerer, W. J. 2002. Effects of Freshwater Flow on Abundance of Estuarine Organisms: Physical Effects or Trophic Linkages? *Marine Ecology Progress Series* 243:39–55.

Kimmerer, W. J. 2004. Open Water Processes of the San Francisco Estuary: From Physical Forcing to Biological Processes. *San Francisco Estuary and Watershed Science* 2(1). Available: https://escholarship.org/uc/item/9bp499mv. Accessed: November 3, 2020.

Kimmerer, W. J. 2006. Response of Anchovies Dampens Effects of the Invasive Bivalve *Corbula amurensis* on the San Francisco Estuary foodweb. *Marine Ecology Progress Series* 324:207–218. doi:10.3354/meps324207.

Kimmerer, W. J. 2008. Losses of Sacramento River Chinook Salmon and Delta Smelt to Entrainment in Water Diversions in the Sacramento–San Joaquin Delta. *San Francisco Estuary and Watershed Science* 6(2). Available: https://escholarship.org/uc/item/7v92h6fs. Accessed: October 27, 2020.

Kimmerer, W. J. 2011. Modeling Delta Smelt Losses at the South Delta Export Facilities. *San Francisco Estuary and Watershed Science* 9(1). Available: https://escholarship.org/uc/item/0rd2n5vb. Accessed: November 3, 2020.

Kimmerer, W. J., J. H. Cowan, L. W. Miller, and K. A. Rose. 2000. Analysis of an Estuarine Striped Bass (*Morone saxatilis*) Population: Influence of Density-Dependent Mortality between Metamorphosis and Recruitment. *Canadian Journal of Fisheries and Aquatic Sciences* 57(2):478–486.

Kimmerer, W. J., J. H. Cowan, Jr., L. W. Miller, and K. A. Rose. 2001. Analysis of an Estuarine Striped Bass Population: Effects of Environmental Conditions during Early Life. *Estuaries* 24(4):557–575.

Kimmerer, W. J., E. Gartside, and J. J. Orsi. 1994. Predation by an Introduced Clam as the Likely Cause of Substantial Declines in Zooplankton of San Francisco Bay. *Marine Ecology Progress Series* 113:81–93.

Kimmerer, W. J., E. S. Gross, and M. L. MacWilliams. 2009. Is the Response of Estuarine Nekton to Freshwater Flow in the San Francisco Estuary Explained by Variation in Habitat Volume? *Estuaries and Coasts* 32(2):375–389.

Kimmerer, W. J., E. S. Gross, A. M. Slaughter, and J. R. Durand. 2019. Spatial Subsidies and Mortality of an Estuarine Copepod Revealed Using a Box Model. *Estuaries and Coasts* 42(1):218–236.

Kimmerer, W. J., T. R. Ignoffo, K. R. Kayfetz, and A. M. Slaughter. 2018. Effects of Freshwater Flow and Phytoplankton Biomass on Growth, Reproduction, and Spatial Subsidies of the Estuarine Copepod *Pseudodiaptomus forbesi*. *Hydrobiologia* 807:113–130.

Kimmerer, W. J., and M. L. Nobriga. 2008. Investigating Particle Transport and Fate in the Sacramento–San Joaquin Delta Using a Particle Tracking Model. *San Francisco Estuary and Watershed Science* 6(1). Available: http://escholarship.org/uc/item/547917gn. Accessed: March 27, 2012.

Kimmerer, W., J. Stillman, and L. Sullivan. 2011. *Zooplankton and Clam Analyses in Support of the Interagency Ecological Program's Work Plan on Pelagic Organism Declines (POD). Final Report to the POD Management Team*. Romberg Tiburon Center for Environmental Studies, San Francisco State University.

Kimmerer, W. J., and K. A. Rose. 2018. Individual-Based Modeling of Delta Smelt Population Dynamics in the Upper San Francisco Estuary III. Effects of Entrainment Mortality and Changes in Prey. *Transactions of the American Fisheries Society* 147(1):223–243.

Klimley, A. P., T. V. Agosta, A. J. Ammann, R. D. Battleson, M. D. Pagel, and M. J. Thomas. 2017. Real-Time Nodes Permit Adaptive Management of Endangered Species of Fishes. *Animal Biotelemetry* 5(1):22.

Knowles, N. and D. R. Cayan. 2002. Potential Effects of Global Warming on the Sacramento/San Joaquin Watershed and the San Francisco Estuary. *Geophysical Research Letters* 29(18)38-1–39-4. doi: http://dx.doi.org/10.1029/2001GL014339.

Kogut, N. 2008. Overbite Clam, *Corbula amurensis*, Defecated Alive by White Sturgeon, *Acipenser transmontanus*. *California Fish and Game* 94:143–149.

Kohlhorst, D. W. 1976. Sturgeon Spawning in the Sacramento River, as Determined by Distribution of Larvae. *California Fish and Game Bulletin* 62:32–40.

Kohlhorst, D. W., L. W. Botsford, J. S. Brennan, and G. M. Cailliet. 1991. Aspects of the Structure and Dynamics of an Exploited Central California Population of White Sturgeon (*Acipenser* transmontanus). Pages 277–293. In *Acipenser: actes du Premier Colloque International sur l'Esturgeon* [*Acipenser: proceedings of the First International Colloquium on Sturgeon*], edited by P. Williot, Bordeaux, France: Centre d'Etudes du Machinisme Agricole, du Rural, des Eaux et Foreˆts.

Komoroske, L. M., R. E. Connon, J. Lindberg, B. S. Cheng, G. Castillo, M. Hasenbein, and N. A. Fangue. 2014. Ontogeny Influences Sensitivity to Climate Change Stressors in an Endangered Fish. *Conservation Physiology* 2(1):cou008.

Komoroske, M., K. M. Jeffries, R. E. Connon, J. Dexter, M. Hasenbein, C. Verhille and N. A. Fangue. 2016. Sublethal Salinity Stress Contributes to Habitat Limitation in an Endangered Estuarine Fish. *Evolutionary Applications*. doi: http://dx.doi.org/10.1111/eva.12385.

Kurobe, T., M. O. Park, A. Javidmehr, F.-C. Teh, S. C. Acuña, C. J. Corbin, A. J. Conley, W. A. Bennett, and S. J. Teh. 2016. Assessing Oocyte Development and Maturation in the Threatened Delta Smelt, *Hypomesus transpacificus*. *Environmental Biology of Fishes* 99(4):423–432.

Kynard, B., E. Parker, and T. Parker. 2005. Behavior of Early Life Intervals of Klamath River Green Sturgeon, *Acipenser medirostris*, with a Note on Body Color. *Environmental Biology of Fishes* 72:85–97.

Lampman, R. T. 2011. *Passage, Migration, Behavior, and Autoecology of Adult Pacific Lamprey at Winchester Dam and within the North Umpqua River Basin, Oregon*. Master's thesis. Oregon State University, Department of Fisheries and Wildlife, Corvallis.

Larson, Z. S., and M. R. Belchik. 1998. *A Preliminary Status Review of Eulachon and Pacific Lamprey in the Klamath River Basin*. April. Yurok Tribal Fisheries Program, Klamath, CA.

Lasker, R. 1975. Field Criteria for Survival of Anchovy Larvae: The Relation between Inshore Chlorophyll Maximum Layers and Successful First Feeding. *Fishery Bulletin* 73(3):453–462.

Latour, R. J. 2016. Explaining Patterns of Pelagic Fish Abundance in the Sacramento–San Joaquin Delta. *Estuaries and Coasts* 39(1):233–247. doi: http://dx.doi.org/10.1007/s12237-015-9968-9.

Lee, D. P., and J. Chilton. 2007. *Hatchery and Genetic Management Plan for Nimbus Fish Hatchery Winter-Run Steelhead Program*. Draft Report. Prepared by CDFG under Contract 03CS200006 Modification 0004 with Bureau of Reclamation, Folsom, CA, and Nimbus Fish Hatchery, Rancho Cordova, CA.

Lee, D. S., C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer, Jr. 1980. *Atlas of North American Freshwater Fishes*. North Carolina Biological Survey No. 1980–12. North Carolina State Museum of Natural History, Raleigh, NC.

Leggett, W. C. 1973. The Migrations of the Shad. *Scientific American* 228(3):92–100.

Leggett, W. C. and R. R. Whitney. 1972. Water Temperature and the Migration of American Shad. *U.S. Fish and Wildlife Services Fishery Bulletin* 70(3):659–670.

Lehman, B. M., M. P. Gary, N. Demetras, and C. J. Michel. 2019. Where Predators and Prey Meet: Anthropogenic Contact Points Between Fishes in a Freshwater Estuary. *San Francisco Estuary and Watershed Science* 17(4). Available: https://escholarship.org/uc/item/2dg499z4. Accessed: November 3, 2020.

Lehman, P., T. Kurobe, and S. Teh. 2020. Impact of Extreme Wet and Dry Years on the Persistence of Microcystis Harmful Algal Blooms in San Francisco Estuary. *Quaternary International*. doi: https://doi.org/10.1016/j.quaint.2019.12.003.

Leidy, R. A. 1984. Distribution and ecology of stream fishes in the San Francisco Bay drainage. Hilgardia 52(8): 1-175.

Leidy, R. A. 2007. *Ecology, Assemblage Structure, Distribution, and Status of Fishes in Stream Tributary to the San Francisco Estuary, California*. SFEI Contribution #530. San Francisco Estuary Institute, Oakland, CA.

Leidy, R. A., G. S. Becker, and B. N. Harvey. 2005. *Historical Distribution and Current Status of Steelhead/Rainbow Trout (*Oncorhynchus mykiss*) in Streams of the San Francisco Estuary, California*. Center for Ecosystem Management and Restoration, Oakland, CA.

Leising, A. W., I. D. Schroeder, S. J. Bograd, J. Abell, R. Durazo, G. Gaxiola-Castro, E. P. Bjorkstedt, J. Field, K. Sakuma, R. R. Robertson, R. Goericke, W. T. Peterson, R. Brodeur, C. Barcelo, T. D. Auth, E. A. Daly, R. M. Suryan, A. J. Gladics, J. M. Porquez, S. McClatchie, E. D. Weber, W. Watson, J. A. Santora, W. J. Sydeman, S. R. Melin, F. P. Chavez, R. T. Golightly, S. R. Schneider, J. Fisher, C. Morgan, R. Bradley, and P. Warybok. 2015. State of the California Current 2014–15: Impacts of the Warm-Water "Blob." *California Cooperative Oceanic Fisheries Investigations Reports* 56:31–68.

Lewis, L. S., M. Willmes, A. Barros, P. K. Crain, and J. A. Hobbs. 2020. Newly Discovered Spawning and Recruitment of Threatened Longfin Smelt in Restored and Under-Explored Tidal Wetlands. *Ecology* 101(1), e02868:1–4.

Lindberg, J. C., G. Tigan, L. Ellison, T. Rettinghouse, M. M. Nagel, and K. M. Fisch. 2013. Aquaculture Methods for a Genetically Managed Population of endangered Delta Smelt. *North American Journal of Aquaculture* 75(2):186–196. doi: http://dx.doi.org/10.1080/15222055.2012.751942.

Lindberg, J. C., Y.-J. J. Tsai, B. D. Kammerer, B. Baskerville-Bridges, and T.-C. Hung. 2020. Spawning Microhabitat Selection in Wild-Caught Delta Smelt *Hypomesus transpacificus* under Laboratory Conditions. *Estuaries and Coasts* 43:174–181.

Lindley, S. T., C. B. Grimes, M. S. Mohr, W. Peterson, J. Stein, J. T. Anderson, C. A. Busack, L. W. Botsford, T. K. Collier, D. L. Bottom, J. C. Garza, A. M. Grover, D. G. Hankin, R. G. Kope, P.W. Lawson, A. Low, J. Ferguson, R. B. MacFarlane, M. Palmer-Zwahlen, F. B. Schwing, J. Smith, C. Tracy, R. Webb, and B. K. Wells. 2009. *What Caused the Sacramento River Fall Chinook Salmon Stock Collapse?* NOAA, Tech. Memo., NMFS-SWFSC-447. Southwest Fisheries Science Center.

Lindley, S. T., M. L. Moser, D. L. Erickson, M. Belchik, D. W. Welch, E. L. Rechisky, J. T. Kelly, J. Heublein, and A. P. Klimley. 2008. Marine Migration of North American Green Sturgeon. *Transactions of the American Fisheries Society* 137(1):182–194.

Lindley, S. T., R. Schick, B. P. May, J. J. Anderson, S. Greene, C. Hanson, A. Low, D. McEwan, R. B. MacFarlane, C. Swanson, and J. G. Williams. 2004. *Population Structure of Threatened and Endangered Chinook Salmon ESU in California's Central Valley Basin*. Public Review Draft. NOAA Technical Memorandum NMFS, Southwest Science Center, Santa Cruz, CA.

Lindley, S. T., R. Schick, E. Mora, P. B. Adams, J. J. Anderson, S. Greene, C. Hanson, B. P. May, D. R. McEwan, R. B. MacFarlane, C. Swanson, and J. G. Williams. 2007. Framework for Assessing Viability of Threatened and Endangered Chinook Salmon and Steelhead in the Sacramento–San Joaquin Basin. *San Francisco Estuary and Watershed Science* 5(1):26.

Loboschefsky, E., G. Benigno, T. Sommer, K. Rose, T. Ginn, A. Massoudieh, and F. Loge. 2012. Individual-Level and Population-Level Historical Prey Demand of San Francisco Estuary Striped Bass Using a Bioenergetics Model. *San Francisco Estuary and Watershed Science* 10(1). Available: https://escholarship.org/uc/item/1c788451. Accessed: November 3, 2020.

Lott, J. 1998. Feeding Habits of Juvenile and Adult Delta Smelt from the Sacramento–San Joaquin River Estuary. *Interagency Ecological Program for the Sacramento–San Joaquin Estuary Newsletter* 11(1):14–19. Available: http://iep.water.ca.gov/report/newsletter/.

Lower American River Task Force. 2002. *River Corridor Management Plan (RCMP) for the Lower American River*. 116 pages + 4 Appendices. Available: http://www.safca.org/Protection/NR_Documents/RCMP_5_Appendix.A.Chapter3.pdf.

Mac Nally, R., J. R. Thomson, W. J. Kimmerer, F. Feyrer, K. B. Newman, A. Sih, W. A. Bennett, L. Brown, E. Fleishman, S. D. Culberson, and G. Castillo. 2010. Analysis of Pelagic Species Decline in the Upper San Francisco Estuary Using Multivariate Autoregressive Modeling (MAR). *Ecological Applications* 20(5):1417–1430.

MacFarlane, R. B., and E. C. Norton. 2002. Physiological Ecology of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) at the Southern End of Their Distribution, the San Francisco Estuary and Gulf of the Farallones, California. *Fishery Bulletin* 100(2), 244–257.

MacKenzie, C., L. S. Weiss-Glanz, and J. R. Moring. 1985. Species Profiles: Life Histories and Environmental Requirements of Coast Fishes and Invertebrates (Mid-Atlantic) – American Shad. *U.S. Fish and Wildlife Service Biological Report* 82(11.37). U.S. Army Corps of Engineers, TR EL-82-4.

MacWilliams, M., A. J. Bever, and E. Foresman. 2016. 3-D Simulations of the San Francisco Estuary with Subgrid Bathymetry to Explore Long-Term Trends in Salinity Distribution and Fish Abundance. *San Francisco Estuary and Watershed Science* 14(2). Available: https://escholarship.org/uc/item/5qj0k0m6. Accessed: November 3, 2020.

Mager, R. C. 1996. *Gametogenesis, Reproduction and Artificial Propogation of Delta Smelt, Hypomesus transpacificus*. PhD dissertation. University of California, Davis, Davis, CA. Cited on: https://www.dfg.ca.gov/delta/data/skt/eggstages.asp.

Mahardja B., M. J. Young, B. Schreier, and T. Sommer. 2017. Understanding Imperfect Detection in a San Francisco Estuary Long-Term Larval and Juvenile Fish Monitoring Programme. *Fisheries Management and Ecology* 24(6):488–503.

Manly, B. F., J. D. Fullerton, A. N. Hendrix, K. P. Burnham. 2015. Comments on Feyrer et al. Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish. *Estuaries and Coasts* 38(5):1815–1820.

Marston, D., C. Mesick, A. Hubbard, D. Stanton, S. Fortmann-Roe, S. Tsao, and T. Heyne. 2012. Delta Flow Factors Influencing Stray Rate of Escaping Adult San Joaquin River Fall-Run Chinook Salmon (*Oncorhynchus tshawytscha*). *San Francisco Estuary and Watershed*

Science 10(4). Available: https://escholarship.org/uc/item/6f88q6pf. Accessed: November 3, 2020.

Martin, C. D., P. D. Gaines, and R. R. Johnson. 2001. *Estimating the Abundance of Sacramento River Winter Chinook Salmon with Comparisons to Adult Escapement*. Red Bluff Research Pumping Plant Report Series, Volume 5. U.S. Fish and Wildlife Service.

Martin, B. T., A. Pike, S. N. John, N. Hamda, J. Roberts, S. T. Lindley, and E. M. Danner. 2017. Phenomenological vs. Biophysical Models of Thermal Stress in Aquatic Eggs. *Ecology Letters* 20(1):50–59.

Maunder, M. N., and R. B. Deriso. 2011. A State-Space Multistage Life Cycle Model to Evaluate Population Impacts in the Presence of Density Dependence: Illustrated with Application to Delta Smelt (*Hyposmesus transpacificus*). *Canadian Journal of Fisheries and Aquatic Science* 68(7):1285–1306. Available: https://doi.org/10.1139/f2011-071.

Maunder, M. N., R. B. Deriso, and C. H. Hanson. 2015. Use of State-Space Population Dynamics Models in Hypothesis Testing: Advantages over Simple Log-Linear Regressions for Modeling Survival, Illustrated with Application to Longfin Smelt (*Spirinchus thaleichthys*). *Fisheries Research* 164:102–111.

McAllister, D. E. 1963. *A Revision of the Smelt Family, Osmeridae*. National Museum of Canada, Biological Series 71, Bulletin No. 191:1–53.

McCabe, G. T., and C. A. Tracy. 1994. Spawning and Early-Life History of White Sturgeon, *Acipenser transmontanus*, in the Lower Columbia River. *Fishery Bulletin* 92(4):760–772.

McCrae, J. 1994. *Oregon Developmental Species, Pacific Sardine*. Oregon Department of Fisheries and Wildlife.

McEnroe, M., and J. J. Cech, Jr. 1985. Osmoregulation in Juvenile and Adult White Sturgeon, *Acipenser transmontanus*. *Environmental Biology of Fishes* 14:23–30.

McEwan, D. 2001. Central Valley Steelhead. In *Fish Bulletin 179(1): Contributions to the Biology of Central Valley Salmonids*, edited by R. L. Brown, 1–44. Sacramento, CA: California Department of Fish and Game.

McEwan, D. R., and T. Jackson. 1996. *Steelhead Restoration and Management Plan for California.* 22 February. California Department of Fish and Game, Sacramento, CA.

Meng, L. and P. B. Moyle. 1995. Status of Splittail in the Sacramento–San Joaquin Estuary. *Transactions of the American Fisheries Society* 124(4):538–549.

Merz, J., P. S. Bergman, J. F. Melgo, and S. Hamilton. 2013. Longfin Smelt: Spatial Dynamics and Ontogeny in the San Francisco Estuary, California. *California Fish and Game* 99(3):122–148.

Merz, J. E., S. Hamilton, P. S. Bergman, and B. Cavallo. 2011. Spatial Perspective for Delta Smelt: A Summary of Contemporary Survey Data. *California Fish and Game* 97(4):164–189. Available: https://www.baydeltalive.com/assets/06942155460a79991fdf1b57f641b1b4/application/pdf/CFG_097-4_2011-2-DeltaSmelt1.pdf. Accessed: June 10, 2020.

Mesick, C. 2001. The Effects of San Joaquin River Flows and Delta Export Rates during October on the Number of Adult San Joaquin Chinook Salmon that Stray. In *Fish Bulletin 179(2): Contributions to the Biology of Central Valley Salmonids*, edited by R. L. Brown, 139–161. Sacramento, CA: California Department of Fish and Game.

Michel, C. J. 2019. Decoupling outmigration from marine survival indicates outsized influence of streamflow on cohort success for California's Chinook salmon populations. *Canadian Journal of Fisheries and Aquatic Sciences* 76:1398–1410.

Michel, C. J., A. J. Ammann, E. D. Chapman, P. T. Sandstrom, H. E. Fish, M. J. Thomas, A. P. Klimley, and R. B. MacFarlane. 2012. The Effects of Environmental Factors on the Migratory Movement Patterns of Sacramento River Yearling Late-Fall Run Chinook Salmon (*Oncorhynchus tshawytscha*). *Environmental Biology of Fishes* 96:257–271.

Michel, C. J., J. M. Smith, N. J. Demetras, D. D. Huff, and S. A. Hayes. 2018. Non-Native Fish Predator Density and Molecular-Based Diet Estimates Suggest Differing Impacts of Predator Species on Juvenile Salmon in the San Joaquin River, California. *San Francisco Estuary and Watershed Science* 16(4). Available: https://escholarship.org/uc/item/9cb0v4fz. Accessed: November 3, 2020.

Miller W.J. 2011. Revisiting Assumptions that Underlie Estimates of Proportional Entrainment of Delta Smelt by State and Federal Water Diversions from the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 9(1).

Miller, D. J., and R. N. Lea. 1972. *Fish Bulletin 157: Guide to the Coastal Marine Fishes of California.* Sacramento, CA: California Department of Fish and Game.

Miller, W. J., B. F. J. Manly, D. D. Murphy, D. Fullerton, and R. R. Ramey. 2012. An Investigation of Factors Affecting the Decline of Delta Smelt (*Hypomesus transpacificus*) in the Sacramento–San Joaquin Estuary. *Reviews in Fisheries Science* 20(1):1–19.

Mitchell, L., K. Newman, and R. Baxter. 2017. A Covered Cod End and Tow-Path Evaluation of Midwater Trawl Gear Efficiency for Catching Delta Smelt (*Hypomesus transpacificus*). *San Francisco Estuary and Watershed Science* 15(4). Available: https://escholarship.org/uc/item/4wj0979x. Accessed: November 3, 2020.

Moffett, J. 1949. The First Four Years of King Salmon Maintenance below Shasta Dam, Sacramento River, California. California Fish and Game 35(2):77–102.

Mora, E. A., R. D. Battleson, S. T. Lindley, M. J. Thomas, R. Bellmer, L. J. Zarri, and A. P. Klimley. 2018. Estimating the Annual Spawning Run Size and Population Size of the

Southern Distinct Population Segment of Green Sturgeon. *Transactions of the American Fisheries Society* 147(1):195–203.

Mount, J., W. Fleenor, B. Gray, B. Herbold, and W. Kimmerer. 2013. *Panel Review of the Draft Bay-Delta Conservation Plan*. Prepared for the Nature Conservancy and American Rivers. September. Saracino & Mount, LLC, Sacramento, CA.

Moyle, P. B. 1976. *Inland Fishes of California*. Berkeley, CA: University of California Press.

Moyle, P. B. 2002. *Inland Fishes of California*. Revised and expanded. Berkeley, CA: University of California Press.

Moyle, P. B., and W. A. Bennett. 2008. *The Future of the Delta Ecosystem and Its Fish*: *Technical Appendix D.* An appendix to *Comparing Futures for the Sacramento–San Joaquin Delta.* Public Policy Institute of California. Available: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/cmnt081712/sldmwa/moyleandbennett2008.pdf. Accessed: November 24, 2020.

Moyle, P. B., R. D. Baxter, T. Sommer, T. C. Foin, and S. A. Matern. 2004. Biology and Population Dynamics of Sacramento Splittail (*Pogonichthys macrolepidotus*) in the San Francisco Estuary: A Review. *San Francisco Estuary and Watershed Science* 2(2). Available: https://escholarship.org/uc/item/61r48686. Accessed: November 3, 2020.

Moyle, P. B., L. R. Brown, S. D. Chase, and R. M. Quiñones. 2009. Status and Conservation of Lampreys in California. In *Biology, Management, and Conservation of Lampreys in North America: American Fisheries Society Symposium 72*, edited by L. R. Brown, S. D. Chase, M. G. Mesa, R. J. Beamish, and P. B. Moyle, 279–292. Bethesda, MD: American Fisheries Society.

Moyle, P. B., L. R. Brown and J. R. Durand. 2016. Delta Smelt: Life History and Decline of a Once Abundant Species in the San Francisco Estuary. *San Francisco Estuary and Watershed Science* 14(2). Available: http://escholarship.org/uc/item/09k9f76s. Accessed: November 3, 2020.

Moyle, P. B., B. Herbold, D. E. Stevens, and L. W. Miller. 1992. Life History and Status of Delta Smelt in the Sacramento–San Joaquin Estuary, California. *Transactions of the American Fisheries Society* 121(1):67–77.

Moyle, P. B., R. M. Quiñones, J. V. Katz, and J. Weaver. 2015. *Fish Species of Special Concern in California*. Sacramento: California Department of Fish and Wildlife. Available: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=104282&inline. Accessed: June 12, 2020.

Moyle, P. B., R. M. Yoshiyama, J. E. Williams, and E. D. Wikramanayake. 1995. *Fish Species of Special Concern in California*. Second edition. Davis, CA: Department of Wildlife and Fisheries Biology, University of California, Davis. Prepared for the California Department of Fish and Game, Rancho Cordova, CA.

Mueller Solger, A., C. Hall, A. Jassby, and C. Goldman. 2006. Food Resources for Zooplankton in the Sacramento–San Joaquin River Delta. Final Report. May 2006. CALFED Project ERP-01-N50/CALFED 2001-K221.

Murphy, D. D., and S. A. Hamilton. 2013. Eastern Migration or Marshward Dispersal: Exercising Survey Data to Elicit an Understanding of Seasonal Movement of Delta Smelt. *San Francisco Estuary and Watershed Science* 11(3). Available: https://escholarship.org/uc/item/4jf862qz. Accessed: November 3, 2020.

Murphy, D. D., and P. S. Weiland. 2019. The Low-Salinity Zone in the San Francisco Estuary as a Proxy for Delta Smelt Habitat: A Case Study in the Misuse of Surrogates in Conservation Planning. *Ecological Indicators* 105:29–35.

Myrick, C. A. and J. J. Cech. 2004. Temperature Effects on Juvenile Anadromous Salmonids in California's Central Valley: What Don't We Know? *Reviews in Fish Biology and Fisheries* 14(1):113–123.

National Marine Fisheries Service. 2005. *Green Sturgeon (*Acipenser medirostris*) Status Review Update, February 2005*. Biological review team, Santa Cruz Laboratory, Southwest Fisheries Science Center.

National Marine Fisheries Service. 2008. *Recovery Plan for Southern Resident Killer Whales (*Orcinus orca*)*. National Marine Fisheries Service, Northwest Region, Seattle, WA.

National Marine Fisheries Service. 2009b. *Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project*. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Region, Long Beach, CA.

National Marine Fisheries Service. 2012. Final Recovery Plan for Central California Coast coho salmon Evolutionarily Significant Unit. National Marine Fisheries Service, Southwest Region, Santa Rosa, California.

National Marine Fisheries Service. 2014. *Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-Run Chinook Salmon and Central Valley Spring-Run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead*. July 2014. California Central Valley Area Office, Sacramento, CA.

National Marine Fisheries Service. 2015. *Southern Distinct Population Segment of the North American Green Sturgeon (*Acipenser medirostris*) 5-Year Review: Summary and Evaluation*. National Marine Fisheries Service, West Coast Region, Long Beach, CA.

National Marine Fisheries Service. 2016. *5-Year Review: Summary and Evaluation of Central Valley Spring-Run Chinook Salmon*. National Marine Fisheries Service, West Coast Region. Sacramento, CA.

National Marine Fisheries Service. 2018. *Draft Recovery Plan for the Southern Distinct Population Segment of North American Green Sturgeon (*Acipenser medirostris*)*. January. National Marine Fisheries Service, West Coast Region, Sacramento, CA.

National Marine Fisheries Service. 2019. *Biological Opinion on Long-Term Operation of the Central Valley Project and the State Water Project*. WCRO-2016-00069. October. West Coast Region, Sacramento, CA.

National Marine Fisheries Service, Bureau of Reclamation, and California Department of Fish and Wildlife. 2017. *Hatchery and Genetics Management Plan for Trinity River Hatchery Coho Salmon*. December. Arcata, CA.

National Marine Fisheries Service, West Coast Region and Washington Department of Fish and Wildlife. 2018. *Southern Resident Killer Whale Priority Chinook Stocks Report*. June 22.

National Oceanic and Atmospheric Administration Fisheries. 2020a. *Researchers Probe Deaths of Central Valley Chinook, with Possible Ties to Ocean Changes*. Last updated by West Coast Regional Office on 12/1/2020. Available: https://www.fisheries.noaa.gov/feature-story/researchers-probe-deaths-central-valley-chinook-possible-ties-ocean-changes. Accessed: January 25, 2021.

National Oceanic and Atmospheric Administration Fisheries. 2020b. *San Joaquin River Restoration Program*. Last updated by West Coast Regional Office on 01/15/2020. Available: https://www.fisheries.noaa.gov/west-coast/habitat-conservation/san-joaquin-river-restoration#san-joaquin-river-spring-run-chinook-salmon-reintroduction. Accessed: May 12, 2020.

National Park Service. 1999. *Whiskeytown-Shasta-Trinity National Recreation Area General Management Plan and Environmental Impact Statement*. June. Pacific West Region. Available: http://www.nps.gov/whis/parkmgmt/upload/GMPfinal.pdf. Accessed: January 26, 2012.

Newcomb, J. and L. Pierce. 2010. *Low Dissolved Oxygen Levels in the Stockton Deep Water Shipping Channel: Adverse Effects on Salmon and Steelhead and Potential Beneficial Effects of Raising Dissolved Oxygen Levels with the Aeration Facility*. Fish Passage Improvement Program, FloodSAFE Environmental Stewardship and Statewide Resources Office, Department of Water Resources. 28 pp.

Newman, K. B., and P. L. Brandes. 2010. Hierarchical Modeling of Juvenile Chinook Salmon Survival as a Function of Sacramento–San Joaquin Delta Water Exports. *North American Journal of Fisheries Management* 30(1):157–169.

Newman, K. B., and J. Rice. 2002. Modeling the Survival of Chinook Salmon Smolts Outmigrating Through the Lower Sacramento River System. *Journal of the American Statistical Association* 97(460):983–993.

Nielsen, J. L., S. A. Pavey, T. Wiacek, and I. Williams. 2005. Genetics of Central Valley O. mykiss populations: Drainage and Watershed Scale Analysis. *San Francisco Estuary and*

Watershed Science 3(2). Available: https://escholarship.org/uc/item/6sc3905g. Accessed: November 3, 2020.

Nobriga, M. L. 2002. Larval Delta Smelt Diet Composition and Feeding Incidence: Environmental and Ontogenetic Influences. *California Fish and Game* 88(4):149–164.

Nobriga, M. L., and P. Cadrett. 2001. Differences Among Hatchery and Wild Steelhead: Evidence from Delta Fish Monitoring Programs. *IEP Newsletter* 14(3):30–38.

Nobriga, M. L., and F. Feyrer. 2007. Shallow-Water Piscivore-Prey Dynamics in California's Sacramento–San Joaquin Delta. *San Francisco Estuary and Watershed Science* 5(2). Available: http://escholarship.org/uc/item/387603c0. Accessed: November 3, 2020.

Nobriga M. L., F. Feyrer, R. D. Baxter, and M. Chotkowski. 2005. Fish Community Ecology in an Altered River Delta: Spatial Patterns in Species Composition, Life History Strategies, and Biomass. *Estuaries* 28(5):776–785.

Nobriga, M. L., Loboschefsky, E., & Feyrer, F. 2013. Common Predator, Rare Prey: Exploring Juvenile Striped Bass Predation on Delta Smelt in California's San Francisco Estuary. *Transactions of the American Fisheries Society* 142(6):1563–1575.

Nobriga, M. L., and J. A. Rosenfield. 2016. Population Dynamics of an Estuarine Forage Fish: Disaggregating Forces Driving Long-Term Decline of Longfin Smelt in California's San Francisco Estuary. *Transactions of the American Fisheries Society* 145(1):44–58.

Nobriga, M. L., T. R. Sommer, F. Feyrer, and K. Fleming. 2008. Long-Term Trends in Summertime Habitat Suitability for Delta Smelt. *San Francisco Estuary and Watershed Science* 6(1). Available: http://escholarship.org/uc/item/5xd3q8tx. Accessed: November 3, 2020.

Nobriga, M. L., and W. E. Smith. 2020. Did a Shifting Ecological Baseline Mask the Predatory Effect of Striped Bass on Delta Smelt? *San Francisco Estuary and Watershed Science* 18(1). Available: https://escholarship.org/uc/item/46f3j55m. Accessed: November 3, 2020.

Notch, J. J., A. S. McHuron, C. J. Michel, F. Cordoleani, M. Johnson, M. J. Henderson, and A. J. Ammann. 2020. Outmigration Survival of Wild Chinook Salmon Smolts through the Sacramento River during Historic Drought and High Water Conditions. *Environmental Biology of Fishes* 103:561–576. DOI: https://doi.org/10.1007/s10641-020-00952-1.

Orcutt, H. G. 1950. *Fish Bulletin 78: The Life History of the Starry Flounder, Platichthys stellatus (*Pallas*)*. California Department of Fish and Game.

Orsi, J., and W. L. Mecum. 1986. Zooplankton Distribution and Abundance in the Sacramento–San Joaquin Delta in Relation to Certain Environmental Factors. *Estuaries* 9(4B):326–339.

Pacific States Marine Fisheries Commission 2014. Juvenile Salmonid Emigration Monitoring in the Lower American River, California January – June 2013. Unpublished Report prepared for the U.S. Fish and Wildlife Service and California Department of Fish and Wildlife, Sacramento, California. 54 pp.

Painter, R. L., L. Wixom, and L. Meinz. 1979. *American Shad Management Plan for the Sacramento River Drainage*. Anadromous Fish Conservation Act Project AFS-17, Job 5. California Department of Fish and Game, Sacramento, CA.

Palmer-Zwahlen, M., V. Gusman, and B. Kormos. 2018. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2013. Joint Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife Report. October 2018.

Pearson, D. E. 1989. *Survey of Fishes and Water Properties of South San Francisco Bay, California, 1973–82*. NOAA-NMFS Technical Report 78. August. U.S. Department of Commerce.

Perry, R. W., P. L. Brandes, J. R. Burau, A. P. Klimley, B. MacFarlane, C. J. Michel, and J. R. Skalski. 2013. Sensitivity of Survival to Migration Routes Used by Juvenile Chinook Salmon to Negotiate the Sacramento–San Joaquin River Delta. *Environmental Biology of Fishes* 96:381–392.

Perry, R. W., P. L. Brandes, P. T. Sandstrom, A. P. Klimley, A. Ammann, and B. MacFarlane. 2010. Estimating Survival and Migration Route Probabilities of Juvenile Chinook Salmon in the Sacramento–San Joaquin River Delta. *North American Journal of Fisheries Management* 30(1):142–156.

Perry, R. W., A. C. Pope, J. G. Romine, P. L. Brandes, J. R. Burau, A. R. Blake, A. J. Ammann, C. J. Michel. 2018. Flow-Mediated Effects on Travel Time, Routing, and Survival of Juvenile Chinook Salmon in a Spatially Complex, Tidally Forced River Delta. *Canadian Journal of Fisheries and Aquatic Sciences* 75(11):1886–1901.

Perry, R. W., J. G. Romine, S. J. Brewer, P. E. LaCivita, W. N. Brostoff, and E. D. Chapman. 2012. *Survival and Migration Route Probabilities of Juvenile Chinook Salmon in the Sacramento–San Joaquin River Delta During the Winter of 2009–10.* U.S. Geological Survey Open-File Report 2012-1200.

Petersen, J. H., and J. F. Kitchell. 2001. Climate Regimes and Water Temperature Changes in the Columbia River: Bioenergetic Implications for Predators of Juvenile Salmon. *Canadian Journal of Fisheries and Aquatic Sciences* 58(9):1831–1841.

Petersen Lewis, R. 2009. Yurok and Karuk traditional ecological knowledge: insights into Pacific lamprey populations of the Lower Klamath Basin. Pages 1-39 in L. R. Brown, S. D. Chase, M. G. Mesa, R. J. Beamish, and P. B. Moyle, editors. Biology, management, and conservation of lampreys in North America. American Fisheries Society, Symposium 72, Bethesda, Maryland.

Peterson, J. T., and M. F. Barajas. 2018. An Evaluation of Three Fish Surveys in the San Francisco Estuary, 1995–2015. *San Francisco Estuary and Watershed Science* 16(4).

Peterson, M. L., A. N. Fuller, and D. Demko. 2017. Environmental Factors Associated with the Upstream Migration of Fall-Run Chinook Salmon in a Regulated River. *North American Journal of Fisheries Management* 37(1):78–93.

Phillis, C. C., A. M. Sturrock, R. C. Johnson, P. K. Weber. 2018. Endangered Winter-Run Chinook Salmon Rely on Diverse Rearing Habitats in a Highly Altered Landscape. January. *Biological Conservation* 217:358–362.

Pickard, A., A. Grover, and F. Hall. 1982. *An Evaluation of Predator Composition at Three Locations on the Sacramento River*. Technical Report No. 2. Interagency Ecological Study Program for the Sacramento–San Joaquin Estuary.

Pinnix, W. D., T. A. Shaw, and N. J. Hetrick. 2004. *Fish Communities in Eelgrass, Oyster Culture, and Mud Flat Habitat of North Humboldt Bay, California Progress Report*. U.S. Fish and Wildlife Service. Arcata Fisheries Technical Report Number AFWO-F-07-04. Arcata, CA.

Polansky, L., L. Mitchell, and K. B. Newman. 2019. Using Multistage Design-Based Methods to Construct Abundance Indices and Uncertainty Measures for Delta Smelt. *Transactions of the American Fisheries Society* 148(4):710–724.

Polansky, L., K. B. Newman and M. L. Nobriga and L. Mitchell. 2018. Spatiotemporal Models of an Estuarine Fish Species to Identify Patterns and Factors Impacting Their Distribution and Abundance. *Estuaries and Coasts* 41(2):572–581.

Pope, A. C., R. W. Perry, D. J. Hance, and H. C. Hansel. 2018. *Survival, Travel Time, and Utilization of Yolo Bypass, California, by Outmigrating Acoustic-Tagged Late-Fall Chinook Salmon*. U.S. Geological Survey Open-File Report 2018-1118. Reston, VA.

Poytress, W. R., J. J. Gruber, C. E. Praetorius, and J. P. Van Eenennaam. 2013. *2012 Upper Sacramento River Green Sturgeon Spawning Habitat and Young-of-the-Year Migration Surveys*. Annual Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation. Red Bluff, CA.

Provins, S. S., and C. D. Chamberlain. 2019. *Distribution and Abundance of Rainbow Trout/Steelhead and Late-Fall Run Chinook Salmon Redds in Clear Creek, Winter 2011 to Spring 2012*. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.

Purkey, D. R., B. Joyce, S. Vicuna, M. W. Hanemann, L. L. Dale, D. Yates, and J. A. Dracup. 2008. Robust Analysis of Future Climate Change Impacts on Water for Agriculture and Other Sectors: A Case Study in the Sacramento Valley. *Climatic Change* 87(1):109–122.

Radtke, L. D. 1966. Distribution of Smelt, Juvenile Sturgeon, and Starry Flounder in the Sacramento–San Joaquin Delta with Observations on Food of Sturgeon. In *Fish Bulletin*

136: Ecological Studies of the Sacramento–San Joaquin Delta, Part II—Fishes of the Delta, edited by S. L. Turner and D. W. Kelley, 115–129. Sacramento, CA: California Department of Fish and Game.

Reis-Santos, P., S. D. McCormick, and J. M. Wilson. 2008. Ionoregulatory Changes during Metamorphosis and Salinity Exposure of Juvenile Sea Lamprey (*Petromyzon marinus* L.). *The Journal of Experimental Biology* 211:978–988.

Robinson, T. C., and J. M Bayer. 2005. Upstream Migration of Pacific Lampreys in the John Day River, Oregon: Behavior, Timing, and Habitat Use. *Northwest Science* 79(2&3):106–119.

Rose, K. A., W. J. Kimmerer, K. P. Edwards and W. A. Bennett. 2013a. Individual-Based Modeling of Delta Smelt Population Dynamics in the Upper San Francisco Estuary: I. Model Description and Baseline Results. *Transactions of the American Fisheries Society* 142(5):1238–1259.

Rose, K. A., W. J. Kimmerer, K. P. Edwards and W. A. Bennett. 2013b. Individual-Based Modeling of Delta Smelt Population Dynamics in the Upper San Francisco Estuary: II. Alternative Baselines and Good versus Bad Years. *Transactions of the American Fisheries Society* 142(5):1260–1272.

Rosenfield, J. A. 2010. *Life History Conceptual Model and Sub-Models for Longfin Smelt, San Francisco Estuary Population for the Delta Regional Ecosystem Restoration Implementation Plan*. May. Sacramento, CA.

Rosenfield, J. A., and R. D. Baxter. 2007. Population Dynamics and Distribution Patterns of Longfin Smelt in the San Francisco Estuary. *Transactions of the American Fisheries Society* 136(6):1577–1592.

Rutter, C. 1908. *The Fishes of the Sacramento–San Joaquin Basin, with a Study of Their Distribution and Variation*. Document No. 637.

Sabal, M. C., E. L. Hazen, S. J. Bograd, R. B. MacFarlane, I. D. Schroeder, S. A. Hayes, J. A. Harding, K. L. Scales, P. I. Miller, and A. J. Ammann. 2020. California Current Seascape Influences Juvenile Salmon Foraging Ecology at Multiple Scales. *Marine Ecology Progress Series* 634:159–173.

Sabal, M. C., C. J. Michel, J. M. Smith, A. Hampton, and S. A. Hayes. 2019. Seasonal Movement Patterns of Striped Bass (*Morone saxatilis*) in Their Nonnative Range. *Estuaries and Coasts* 42:567–579.

Saiki, M. K. 1984. Environmental Conditions and Fish Faunas in Low Elevation Rivers on the Irrigated San Joaquin Valley Floor, California. *California Fish and Game* 70:145–157.

Salmonid Scoping Team (SST). 2017. *Effects of Water Project Operations on Juvenile Salmonid Migration and Survival in the South Delta. Volume 1: Findings and Recommendations*. Prepared for Collaborative Adaptive Management Team. January.

San Joaquin River Group Authority. 2010. *2009 Annual Technical Report on Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP)*. Prepared for the California Water Resources Control Board in compliance with D-1641. San Joaquin River Group Authority.

San Joaquin River Group Authority. 2011. *2010 Annual Technical Report on Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan (VAMP)*. Prepared for the California Water Resources Control Board in compliance with D-1641. San Joaquin River Group Authority.

San Joaquin River Group Authority. 2013. *2011 Annual Technical Report on Implementation and Monitoring of the San Joaquin River Agreement and the Vernalis Adaptive Management Plan.* Prepared for the California Water Resource Control Board in compliance with D-1641. February. San Joaquin River Group Authority.

Satterthwaite, W. H., F. Cordoleani, M. R. O'Farrell. 2018. Central Valley Spring-Run Chinook Salmon and Ocean Fisheries: Data Availability and Management Possibilities. *San Francisco Estuary and Watershed Science* 16(1). Available: https://escholarship.org/uc/item/1258q4ms. Accessed: November 3, 2020.

Schaffter, R. 1997. White Sturgeon Spawning Migrations and Location of Spawning Habitat in the Sacramento River, California. *California Department of Fish and Game* 83:1–20.

Schick, R. S., A. L. Edsall, and S. T. Lindley. 2005. *Historical and Current Distribution of Pacific Salmonids in the Central Valley, CA*. Technical Memorandum 369. National Marine Fisheries Service, Santa Cruz, CA.

Schraml, C. M., J. T. Earley, and C. D. Chamberlain. 2018. *Brood Year 2011 Juvenile Salmonid Monitoring in Clear Creek, California.* USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, CA.

Schreier, B. M., M. R. Baerwald, J. L. Conrad, G. Schumer, and B. May. 2016. Examination of Predation on Early Life Stage Delta Smelt in the San Francisco Estuary Using DNA Diet Analysis. *Transactions of the American Fisheries Society* 145(4):723–733.

Schultz, L., M. Mayfield, G. Sheoships, L. Wyss, B. Clemens, B. Chasco, and C. Schreck. 2014. *The Distribution and Relative Abundance of Spawning and Larval Pacific Lamprey in the Willamette River Basin.* Final Report to the Columbia Inter-Tribal Fish Commission for Project Years 2011–2014. May 2014.

Seesholtz, A. and M. Manuel. 2012. *Preliminary Report: Passage, Abundance, Distribution and Potential Spawning Areas of Adult Green Sturgeon in the Lower Feather River during 2011 and 2012*. California Department of Water Resources, West Sacramento, CA.

Seesholtz A., B. J. Cavallo, J. Kindopp, and R. Kurth. 2004. Juvenile Fishes of the Lower Feather River: Distribution, Emigration Patterns, and Associations with Environmental Variables. In *Early Life History of Fishes in the San Francisco Estuary and Watershed:*

American Fisheries Society Symposium 39, edited by F. Feyrer, L. R. Brown, R. L. Brown, and J. J. Orsi, 141–168. Bethesda, MD: American Fisheries Society.

Seesholtz, A. M., M. J. Manuel, and J. P. Van Eenennaam. 2015. First Documented Spawning and Associated Habitat Conditions for Green Sturgeon in the Feather River, California. *Environmental Biology of Fishes* 98(3):905–912.

Skinner, J. E. 1962. *An Historical Review of the Fish and Wildlife Resources of the San Francisco Bay Area.* Water Projects Branch Report No. 1. California Department of Fish and Game. Sacramento, CA.

Slater, S. B. 2008. *Feeding Habits of Longfin Smelt in the Upper San Francisco Estuary*. Poster Session, 2008 CALFED Science Conference. Available: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=98374. Accessed: September 9, 2016.

Slater, S. B., and R. D. Baxter. 2014. Diet, Prey Selection, and Body Condition of Age-0 Delta Smelt, in the Upper San Francisco Estuary. *San Francisco Estuary Watershed Science* 12(3). doi: http://dx.doi.org/10.15447/sfews.2014v12iss3art1.

Slater, S. B., A. Schultz, B.G. Hammock, A. Hennessy, and C. Burdi. 2019. Chapter 1: Patterns of Zooplankton Consumption by Juvenile and Adult Delta Smelt (*Hypomesus transpacificus*). Pages 9–54 in A. A. Schultz (ed.), *Directed Outflow Project: Technical Report 1*. U.S. Bureau of Reclamation, Bay-Delta Office, Mid-Pacific Region, Sacramento, CA. November 2019.

Smith, W. E. 2019. Integration of Transport, Survival, and Sampling Efficiency in a Model of South Delta Entrainment. *San Francisco Estuary and Watershed Science* 17(4). Available: https://escholarship.org/uc/item/893826f3. Accessed: November 3, 2020.

Smith, W. E., K. B. Newman, and L. Mitchell. 2020. A Bayesian Hierarchical Model of Postlarval Delta Smelt Entrainment: Integrating Transport, Length Composition, and Sampling Efficiency in Estimates of Loss. *Canadian Journal of Fisheries and Aquatic Sciences* 77:789–813.

Smith, S. E., and S. Kato. 1979. The Fisheries of San Francisco Bay: Past, Present, and Future. In *San Francisco Bay: The Urbanized Estuary,* edited by T. J. Conomos, 445–468. Pacific Division, American Association for the Advancement of Science, San Francisco, CA.

Smith, S. G., W. D. Muir, and J. G. Willams. 2002. Factors Associated with Travel Time and Survival of Migrant Yearling Chinook Salmon and Steelhead in the Lower Snake River. *North American Journal of Fisheries Management* 22(2):385–405.

Snider, B. and R. G. Titus. 1995. Lower American River Emigration Survey November 1993-July 1994. Calif. Dept. Fish Game, Environmental Services Division, unpublished report. 102 pp.

Snider, B. R. and R. G. Titus, 2000. *Timing, Composition, and Abundance of Juvenile Anadromous Salmonid Emigration in the Sacramento River Near Knights Landing. October 1997-September 1998*. December. California Department of Fish and Game, Habitat Conservation Division, Native Anadromous Fish and Watershed Branch, Stream Evaluation Program.

Snider, B. and R. Titus. 2002. *Lower American River Emigration Survey October 1998–September 1999.* California Department of Fish and Game, Habitat Conservation Division, Stream Evaluation Program.

Sommer, T. 2007. *The Decline of Pelagic Fishes in the San Francisco Estuary: An Update*. Presented to the California State Water Resources Control Board, Sacramento, CA, March 22, 2007. Available: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/pelagic_organism/docs/dwr_032207sommer.pdf.

Sommer, T. and F. Mejia. 2013. A Place to Call Home: A Synthesis of Delta Smelt Habitat in the Upper San Francisco Estuary. *San Francisco Estuary and Watershed Science* 11(2). Available: https://escholarship.org/uc/item/32c8t244. Accessed: November 3, 2020.

Sommer, T. R., R. Baxter, B. Herbold. 1997. Resilience of Splittail in the Sacramento–San Joaquin Estuary. *Transactions of the American Fisheries Society* 126(6):961–976.

Sommer, T., C. Armor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski, S. Culberson, F. Feyrer, M. Gingras, B. Herbold, W. Kimmerer, A. Mueller-Solger, M. Nobriga, and K. Souza. 2007. The Collapse of Pelagic Fishes in the Upper San Francisco Estuary. *Fisheries* 32(6):270–277.

Sommer, T. R., W. C. Harrell, and F. Feyrer. 2014. Large-Bodied Fish Migration and Residency in a Flood Basin of the Sacramento River, California, USA. *Ecology of Freshwater Fish* 23(3):414–423.

Sommer, T. R., W. C. Harrell, Z. Matica, and F. Feyrer. 2008. Habitat Associations and Behavior of Adult and Juvenile Splittail (Cyprinidae: *Pogonichthys macrolepidotus*) in a Managed Seasonal Floodplain Wetland. *San Francisco Estuary and Watershed Science* 6(2). Available: http://www.escholarship.org/uc/item/85r15611. Accessed: July 15, 2013.

Sommer, T. C., Mejia, F., Nobriga, M. L., Feyrer, F., and L. Grimaldo. 2011. The Spawning Migration of Delta Smelt in the Upper San Francisco Estuary. *San Francisco Estuary and Watershed Science*, 9(2). San Francisco Estuary and Watershed Science, John Muir Institute of the Environment, UC Davis. Available: http://escholarship.org/uc/item/86m0g5sz.

Sommer, T. R., M. L. Nobriga, W. C. Harrell, W. Batham, and W. J. Kimmerer. 2001. Floodplain Rearing of Juvenile Chinook Salmon: Evidence of Enhanced Growth and Survival. *Canadian Journal of Fisheries and Aquatic Sciences* 58(2):325–333.

Sopher, T. R. 1974. *A Trawl Survey of the Fishes of Arcata Bay, California*. Master's thesis, Humboldt State University, Arcata, CA. 103 pp.

Speegle, J., J. Kirsch, and J. Ingram. 2013. *Annual Report: Juvenile Fish Monitoring During the 2010 and 2011 Field Seasons within the San Francisco Estuary, California*. January. U.S. Fish and Wildlife Service, Stockton Fish and Wildlife Office, Lodi, CA.

Stanislaus River Fish Group. 2003. *A Plan to Restore Anadromous Fish Habitat in the Lower Stanislaus River*. Review Draft. May 31.

Stanislaus River Fish Group. 2004. *A Summary of Fisheries Research in the Lower Stanislaus River*. Working Draft. March 10.

Stanley S. E., P. B. Moyle, and H. B. Shaffer. 1995. Allozyme Analysis of Delta Smelt, *Hypomesus transpacificus*, and Longfin Smelt, *Spirinchus thaleichthys*, in the Sacramento-San Joaquin Estuary, California. *Copeia* 2:390–396.

State Water Resources Control Board. 2015. *Response from U.S. Bureau of Reclamation on New Melones Operations.* E-mail from Ronald Milligan (Reclamation) to Tom Howard (SWRCB) with attachments. April 8. Available: http://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/tucp/index.shtml.

Steel, A., M. Thomas, and A. Klimley. 2019. Reach Specific Use of Spawning Habitat by Adult Green Sturgeon (*Acipenser medirostris*) under Different Operation Schedules at Red Bluff Diversion Dam. *Journal of Applied Ichthyology* 35(1):22–29.

Stevens, D. E. 1966. Distribution and Food Habits of the American Shad, *Alosa Sapidissima*, in the Sacramento–San Joaquin Delta. In *Ecological Studies of the Sacramento–San Joaquin Delta, Part II: Fishes of the Delta,* edited by J. L. Turner and D. W. Kelley, 97–107. Sacramento, CA: California Department of Fish and Game.

Stevens, D. E., and L. W. Miller. 1970. Distribution of Sturgeon Larvae in the Sacramento–San Joaquin River System. *California Fish and Game* 56:80–86.

Stevens, D. E., H. K. Chadwick, and R. E. Painter. 1987. American Shad and Striped Bass in California's Sacramento–San Joaquin River system. *American Fisheries Society Symposium* 1:66–78.

Stevens, D. E., D. W. Kohlhorst, L. W. Miller, and D. W. Kelley. 1985. The Decline of Striped Bass in the Sacramento–San Joaquin Estuary, California. *Transactions of the American Fisheries Society* 114(1):12–30.

Stewart, A. R., S. N. Luoma, C. E. Schlekat, M. A. Doblin, and K. A Hieb. 2004. Food Web Pathway Determines How Selenium Affects Aquatic Ecosystems: A San Francisco Bay Case Study. *Environmental Science and Technology* 38:4519–4526.

Stompe, D. K., P. B. Moyle, A. Kruger, and J. R. Durand. 2020. Comparing and Integrating Fish Surveys in the San Francisco Estuary: Why Diverse Long-Term Monitoring Programs are Important. *San Francisco Estuary and Watershed Science* 18(2).

Strange, E. 2020. *2020 (January 2020 – December 2020) Technical Memorandum Regarding the Accounting of San Joaquin River Spring-Run Chinook Salmon at the Central Valley Project and State Water Project Sacramento–San Joaquin Delta Fish Collection Facilities*. 15 January. California Central Valley Office, West Coast Region, National Marine Fisheries Service, Sacramento, CA.

Strong, A. L., M. M. Mills, I. B. Huang, G. L. van Dijken, S. E. Driscoll, G. Berg, R. M. Kudela, S. G. Monismith, C. A. Francis, and K. R. Arrigo. 2021. Response of Lower Sacramento River phytoplankton to high-ammonium wastewater effluent. *Elementa: Science of the Anthropocene* 9(1).

Sturrock, A. M., W. H. Satterthwaite, K. M. Cervantes-Yoshida, E. R. Huber, H. J. W. Sturrock, S. Nusslé, and S. M. Carlson. 2019. Eight Decades of Hatchery Salmon Releases in the California Central Valley: Factors Influencing Straying and Resilience. *Fisheries* 44(9):433–444.

Sturrock, A. M, J. D. Wikert, T. Heyne, C. Mesick, A. E. Hubbard, T. M. Hinkelman, P. K. Weber, G. E. Whitman, J. J. Glessner, and R. C. Johnson. 2015. Reconstructing the Migratory Behavior and Long-Term Survivorship of Juvenile Chinook Salmon under Contrasting Hydrologic Regimes. *PLOS ONE* 10(5):e0122380. doi:10.1371/journal.pone.012238.

Surface Water Resources, Inc. 2001. *Aquatic Resources of the Lower American River: Baseline Report.* Draft Report. Prepared for the Lower American River Fisheries and Instream Habitat (FISH) Working Group.

Swanson, C., T. Reid, P. S. Young, J. J. Cech, Jr. 2000. Comparative Environmental Tolerances of Threatened Delta Smelt (*Hypomesus transpacificus*) and Introduced Wakasagi (*H. nipponensis*) in an Altered California Estuary. *Oecologia* 123:384–390.

Swanson, C., P. S. Young, and J. J. Cech Jr. 1998. Swimming Performance of Delta Smelt: Maximum Performance and Behavioral and Kinematic Limitations of Swimming at Submaximal Velocities. *Journal of Experimental Biology* 201:333–345.

Sweetnam, D. A. 1999. *Status of Delta Smelt in the Sacramento–San Joaquin Estuary*. California Fish and Game 85(1):22–27.

Tehama-Colusa Canal Authority. 2008. Fishery Resources, Appendix B. In *Fish Passage Improvement Project at the Red Bluff Diversion Dam EIS/EIR.* Prepared by CH2M HILL, State Clearinghouse No. 2002-042-075. Willows, CA: Tehama-Colusa Canal Authority.

The Bay Institute (Bay Institute), Center for Biological Diversity, and the Natural Resources Defense Council. 2007. *Petition to the State of California Fish and Game Commission* *and Supporting Information for Listing the Delta Smelt (*Hypomesus transpacificus*) as an Endangered Species under the California Endangered Species Act*. February 7.

Thomas, J. L. 1967. The Diet of Juvenile and Adult Striped Bass, *Roccus saxatilis*, in the Sacramento–San Joaquin River System. *California Fish and Game* 53(1):49–62.

Thomas, M. J., M. L. Peterson, E. D. Chapman, N. A. Fangue, and A. P. Klimley. 2019. Individual Habitat Use and Behavior of Acoustically-Tagged Juvenile Green Sturgeon in the Sacramento–San Joaquin Delta*. Environmental Biology of Fishes* 102:1025–1037.

Thompson, L. C., N. A. Fangue, J. J. Cech, Jr., D. E. Cocherell, and R. C. Kaufman. 2012. *Juvenile and Adult Hardhead Thermal Tolerances and Preferences: Temperature Preference, Critical Thermal Limits, Active and Resting Metabolism, and Blood-Oxygen Equilibria*. Center for Aquatic Biology and Aquaculture Technical Report, University of California, Davis. Davis, CA.

Thomson, J. R., W. J. Kimmerer, L. R. Brown, K. B. Newman, R. Mac Nally, W. A. Bennett, F. Feyrer, and E. Fleishman. 2010. Bayesian Change Point Analysis of Abundance Trends for Pelagic Fishes in the Upper San Francisco Estuary. *Ecological Applications* 20(5):1431–1448.

Tobias, V. 2021. Simulated Fishing to Untangle Catchability and Availability in Fish Abundance Monitoring. *Preprints* 2020, 2020020177. Available: https://doi.org/10.20944/preprints202002.0177.v2. Accessed: January 22, 2021.

Tucker, M. E., C. M. Williams, and R. R. Johnson. 1998. *Abundance, Food Habits, and Life History Aspects of Sacramento Squawfish and Striped Bass at the Red Bluff Diversion Complex, Including the Research Pumping Plant, Sacramento River, California, 1994-1996: Annual Report*. U.S. Fish and Wildlife Service, Red Bluff, CA.

Turner, J. L. 1966. Distribution of Threadfin Shad, *Dorosoma petenense*; Tule Perch, *Hysterocarpus traski*; Sculpin Spp. and Crayfish Spp. in the Sacramento–San Joaquin Delta. In *Fish Bulletin 136: Ecological Studies of the Sacramento–San Joaquin Estuary: Part II—Fishes of the Delta,* edited by J. L. Turner and D. W. Kelley, 160–168. Sacramento, CA: California Department of Fish and Game.

University of California, Agriculture and Natural Resources. 2019a. California Fish Website. Smallmouth Bass. Available: http://calfish.ucdavis.edu/species/?uid=150&ds=698.

University of California, Agriculture and Natural Resources. 2019b. California Fish Website. Spotted Bass. Available: http://calfish.ucdavis.edu/species/?uid=157&ds=698.

U.S. Bureau of Reclamation. 2008. *Biological Assessment on the Continued Long-Term Operations of the Central Valley Project and the State Water Project*. Sacramento, CA: Mid-Pacific Region.

U.S. Bureau of Reclamation. 2012. Stanislaus River Focus Group Meeting October 10, 2012, Handouts.

U.S. Bureau of Reclamation. 2014. *Upper San Joaquin River Basin Storage Investigation, Draft Environmental Impact Statement*.

U.S. Bureau of Reclamation. 2019. *Reinitiation of Consultation on the Coordinated Long-Term Operation of the Central Valley Project and State Water Project*. Final Biological Assessment. January. Mid-Pacific Region, U.S. Bureau of Reclamation.

U.S. Bureau of Reclamation and California Department of Water Resources. 2015. *Biological Review for Endangered Species Act Compliance with the WY 2015 Drought Contingency Plan April through September Project Description*. Prepared for State Water Resources Control Board. Available: http://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/docs/tucp/2015/apr2015_req032415.pdf. Accessed: November 3, 2020.

U.S. Bureau of Reclamation and Trinity County. 2006. *Indian Creek Rehabilitation Site: Trinity River Mile 93.7 to 96.5.* Revised Environmental Assessment/Recirculated Partial Draft Environmental Impact Report. November 14.

U.S. Fish and Wildlife Service. 1967. *Biology and Management of the American Shad and Status of the Fisheries, Atlantic Coast of the U.S.*

U.S. Fish and Wildlife Service. 1995. *Working Paper: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California*. Volume 2. May 9, 1995.

U.S. Fish and Wildlife Service. 2001. *Abundance and Survival of Juvenile Chinook Salmon in the Sacramento–San Joaquin Estuary: 1997 and 1998*. Annual Progress Report Sacramento–San Joaquin Estuary.

U.S. Fish and Wildlife Service. 2002. *Stanislaus River Anadromous Fish Surveys 2000-2001. Snorkel Survey*. Anadromous Fish Restoration Program.

U.S. Fish and Wildlife Service. 2008. *Biological Opinion on the Effects of Long Term Coordinated Operations of the Central Valley (CVP) and State Water Project (SWP) on Delta Smelt and Its Designated Critical Habitat.* December.

U.S. Fish and Wildlife Service. 2010. Endangered and Threatened Wildlife and Plants; 12-Month Finding on a Petition to Reclassify the Delta Smelt from Threatened to Endangered Throughout Its Range. *Federal Register* 75:17667–17680. https://www.gpo.gov/fdsys/pkg/FR-2010-04-07/pdf/2010-7904.pdf.

U.S. Fish and Wildlife Service. 2012. Endangered and Threatened Wildlife and Plants; 12-Month Finding on a Petition to List the San Francisco Bay-Delta Population of the Longfin Smelt as Endangered or Threatened. *Federal Register* 77:17756–17797.

U.S. Fish and Wildlife Service. 2019. *Biological Opinion for the Reinitiation of Consultation on the Long Term Operation of the Central Valley Project and State Water Project.* USFWS Pacific Southwest Region. Sacramento, CA.

U.S. Fish and Wildlife Service. 2020. *700 Winter-Run Chinook Salmon Return to Battle Creek*. October 22. Available: https://www.fws.gov/news/ShowNews.cfm?ref=700-winter-run-chinook-salmon-return-to-battle-creek&_ID=36797. Accessed: January 28, 2021.

Van Eenennaam, J. P., J. Linares-Casenave, X. Deng, and S. I. Doroshov. 2005. Effect of Incubation Temperature on Green Sturgeon Embryos, *Acipenser medirostris*. *Environmental Biology of Fishes* 72:145–154.

Van Eenennaam, J. P., M. A. H. Webb, X. Deng, S. I. Doroshov, R. B. Mayfield, J. J. Cech Jr, D. C. Hillemeier, and T. E. Willson. 2001. Artificial Spawning and Larval Rearing of Klamath River Green Sturgeon. *Transactions of the American Fisheries Society* 130(1):159–165.

Vladykov, V. D., and W. I. Follett. 1958. Redescription of *Lampetra ayersii* (Gunther) of Western North America, a Species of Lamprey (Petromyzontidae) Distinct from *Lampetra fluviatilis* (Linnaeus) of Europe. *Journal of the Fisheries Research Board of Canada* 15(1):47–77.

Vogel, D. A. 2008. *Evaluation of Adult Sturgeon Migration at the Glenn-Colusa Irrigation District Gradient Facility on the Sacramento River*.

Vogel, D. 2011. *Insights into the Problems, Progress, and Potential Solutions for Sacramento River Basin Native Anadromous Fish Restoration*. Prepared for Northern California Water Association and Sacramento Valley Water Users. April. Natural Resource Scientists, Inc., Red Bluff, CA.

Vogel, D. A., and K. R. Marine. 1991. *Guide to Upper Sacramento Chinook Salmon Life History. Report to U.S. Bureau of Reclamation, Central Valley Project*. CH2M Hill, Inc., Redding, CA. 55 pp.

Wagner, R. W., M. Stacey, L. R. Brown, and M. Dettinger. 2011. Statistical Models of Temperature in the Sacramento–San Joaquin Delta under Climate-Change Scenarios and Ecological Implications. *Estuaries and Coasts* 34(3):544–556.

Wang, J. C. S. 2010. *Fishes of the Sacramento–San Joaquin Estuary and Adjacent Waters, California: A Guide to the Early Life Histories*. Interagency Ecological Study Program for the Sacramento–San Joaquin Estuary, Technical Report 9. Stockton, CA.

Water Forum. 2005. Lower American River, State of the River Report. April. Available: http://www.waterforum.org./wp-content/uploads/2015/09/State-of-the-River-2005.pdf. Accessed: November 3, 2020.

Watry, C. B., A. Gray, R. Cuthbert, B. Pyper, and K. Arendt. 2007. *Out-Migrant Abundance Estimates and Coded Wire Tagging Pilot Study for Juvenile Chinook Salmon at Caswell Memorial State Park in the Lower Stanislaus River, California. 2007 Annual Data Report.* Prepared by Cramer Fish Sciences for U.S. Fish and Wildlife Service Anadromous Fish Restoration Program. Grant No. 813326G008. 45 pp.

Watry, C. B., A. Gray, K. Jones, K. Sellheim, and J. Merz. 2012. *Juvenile Salmonid Out-Migration Monitoring at Caswell Memorial State Park in the Lower Stanislaus River, California. 2010–2011 Biannual Report.* Prepared by Cramer Fish Sciences for U.S. Fish and Wildlife Service's Comprehensive Assessment and Monitoring Program. Grant No. 813326G008. 48 pp.

White, J. 2019. *Fall Midwater Trawl 2018 Annual Fish Abundance Summary*. Memorandum to Gregg Erickson, Regional Manager, California Department of Fish and Wildlife, Bay Delta Region. 2 January.

Williams, J. G., 2001. Chinook Salmon in the Lower American River, California's Largest Urban Stream. In *Fish Bulletin 179(2): Contributions to the Biology of the Central Valley Salmonids*, edited by R. L. Brown, 1–38. Sacramento, CA: California Department of Fish and Game.

Williams, J. G., 2006. Central Valley Salmon: A Perspective on Chinook and Steelhead in the Central Valley of California. *San Francisco Estuary and Watershed Science* 4(3). Available: https://escholarship.org/uc/item/21v9x1t7. Accessed: November 3, 2020.

Williams, J. G. 2010. *Life History Conceptual Model for Chinook Salmon and Steelhead. DRERIP Delta Conceptual Model*. Sacramento, CA: Delta Regional Ecosystem Restoration Implementation Plan.

Williams, T. H., J. C. Garza, N. Hetrick, S. T. Lindley, M. S. Mohr, J. M. Myers, M. R. O'Farrell, R. M. Quiñones, and D. J. Teel. 2011. Upper Klamath and Trinity River Chinook Salmon Biological Review Team Report. National Marine Fisheries Service, Southwest Region.

Williams, T. H., B. C. Spence, D. A. Boughton, R. C. Johnson, L. Crozier, N. Mantua, M. O'Farrell, and S. T. Lindley. 2016. *Viability Assessment for Pacific Salmon and Steelhead Listed under the Endangered Species Act: Southwest*. 2 February 2016 Report to National Marine Fisheries Service, West Coast Region from Southwest Fisheries Science Center.

Winder, M., and A. D. Jassby. 2011. Shifts in Zooplankton Community Structure: Implications for Food Web Processes in the Upper San Francisco Estuary. *Estuaries and Coasts* 34(4):675–690.

Wood, S. A., P. T. Holland, L. MacKenzie. 2011. Development of Solid Phase Adsorption Toxin Tracking (SPATT) for Monitoring Anatoxin-a and Homoanatoxin-a in river water. *Chemosphere* 82(6):888–894.

Wulff, M. L., J. T. May, and L. R. Brown. 2012. Upper Clear Creek Watershed Aquatic Chemistry and Biota Surveys, 2004–5, Whiskeytown National Recreation Area, Shasta County, California: U.S. Geological Survey Open-File Report 2012–1173. 8 pp.

Wydoski, R. S., and R. R. Whitney. 1979. *Inland Fishes of Washington*. Seattle, WA: University of Washington Press. 220 pp.

Yoshiyama, R. M., F. W. Fisher, P. B. Moyle. 1998. Historical Abundance and Decline of Chinook Salmon in the Central Valley Region of California. *North American Journal of Fisheries Management* 18:487–521.

Yoshiyama, R. M., E. R. Gerstung, F. W. Fisher, and P. B. Moyle. 1996. Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California. In *Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. III, Assessments, Commissioned Reports, and Background Information*. Davis, CA: University of California, Davis, Centers for Water and Wildland Resources.

Yoshiyama, R. M., E. R. Gerstung, F. W. Fisher, and P. B. Moyle. 2001. Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California. In *Fish Bulletin 179(1): Contributions to the Biology of Central Valley Salmonids*, edited by R. L. Brown, 71–176. Sacramento, CA: California Department of Fish and Game.

Zabel, R. W., J. J. Anderson, and P. A. Shaw. 1998. A Multiple-Reach Model Describing the Migratory Behavior of the Snake River Yearling Chinook Salmon (*Oncorhynchus tshawytscha*). *Canadian Journal of Fisheries and Aquatic Sciences* 55(3):658–667.

Zeug, S. C., K. Sellheim, C. Watry, J. D. Wikert, and J. Merz. 2014. Response of Juvenile Chinook Salmon to Managed Flow: Lessons Learned from a Population at the Southern Extent of their Range in North America. *Fisheries Management and Ecology* 21(2):155–168.

Zimmerman, C. E., G. W. Edwards, and K. Perry. 2009. Maternal Origin and Migratory History of Steelhead and Rainbow Trout Captured in Rivers of the Central Valley, California. *Transactions of the American Fisheries Society* 138(2):280–291.

Attachment 1. Juvenile Salmonid Monitoring, Sampling, and Salvage Timing Summary from SacPAS

1.1 Introduction

This attachment to Appendix 11A, *Aquatic Species Life History*, contains graphical summaries of juvenile salmonid monitoring, sampling, and salvage timing in the Central Valley, as produced by the Central Valley Prediction and Assessment of Salmon database (SacPAS) (Columbia Basin Research 2020). The appendix is organized by species, monitoring location, and hatchery origin (clipped or unclipped). The maximum number of years (25) was selected in each case, giving summaries from 1993 onwards where available. Trawl and beach seine data are presented as catch indices (trawls = 10 tows/day; beach seines = 8 hauls/day). Beach seine data represent stations in the vicinity of Sacramento (Verona, Elkhorn, Sand Cove, Miller Park, Sherwood Harbor, Discovery Park, American River, and Garcia Bend).

Contents

1.2 Winter-Run Chinook Salmon

1.2.1 Winter-Run Chinook Salmon: Red Bluff Diversion Dam Rotary Screw Traps

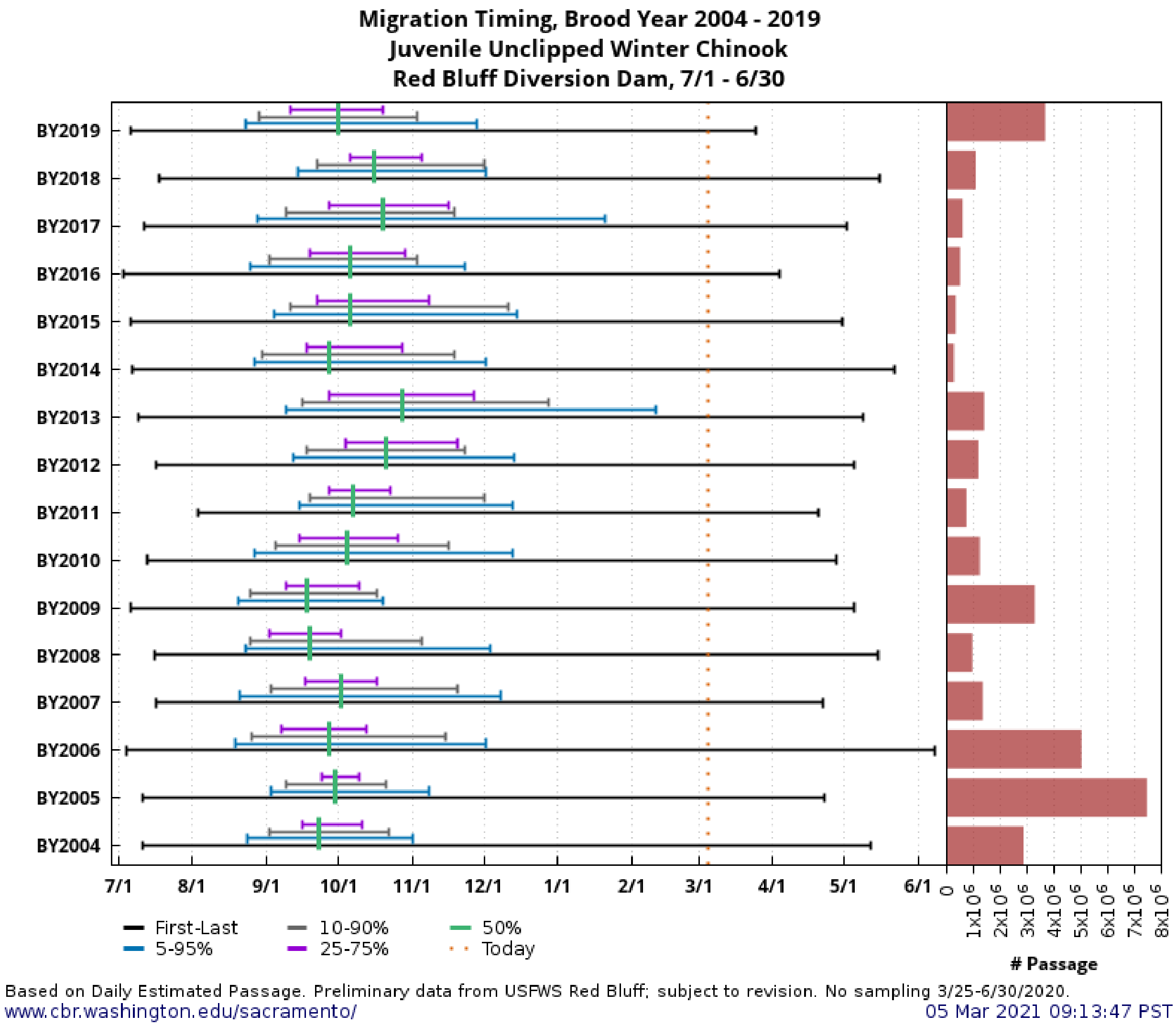


Figure 11A-Att1-1. Timing and Number of Juvenile Winter-Run Chinook Salmon in Red Bluff Diversion Dam Rotary Screw Traps.

1.2.2 Winter-Run Chinook Salmon: Tisdale Weir Rotary Screw Traps

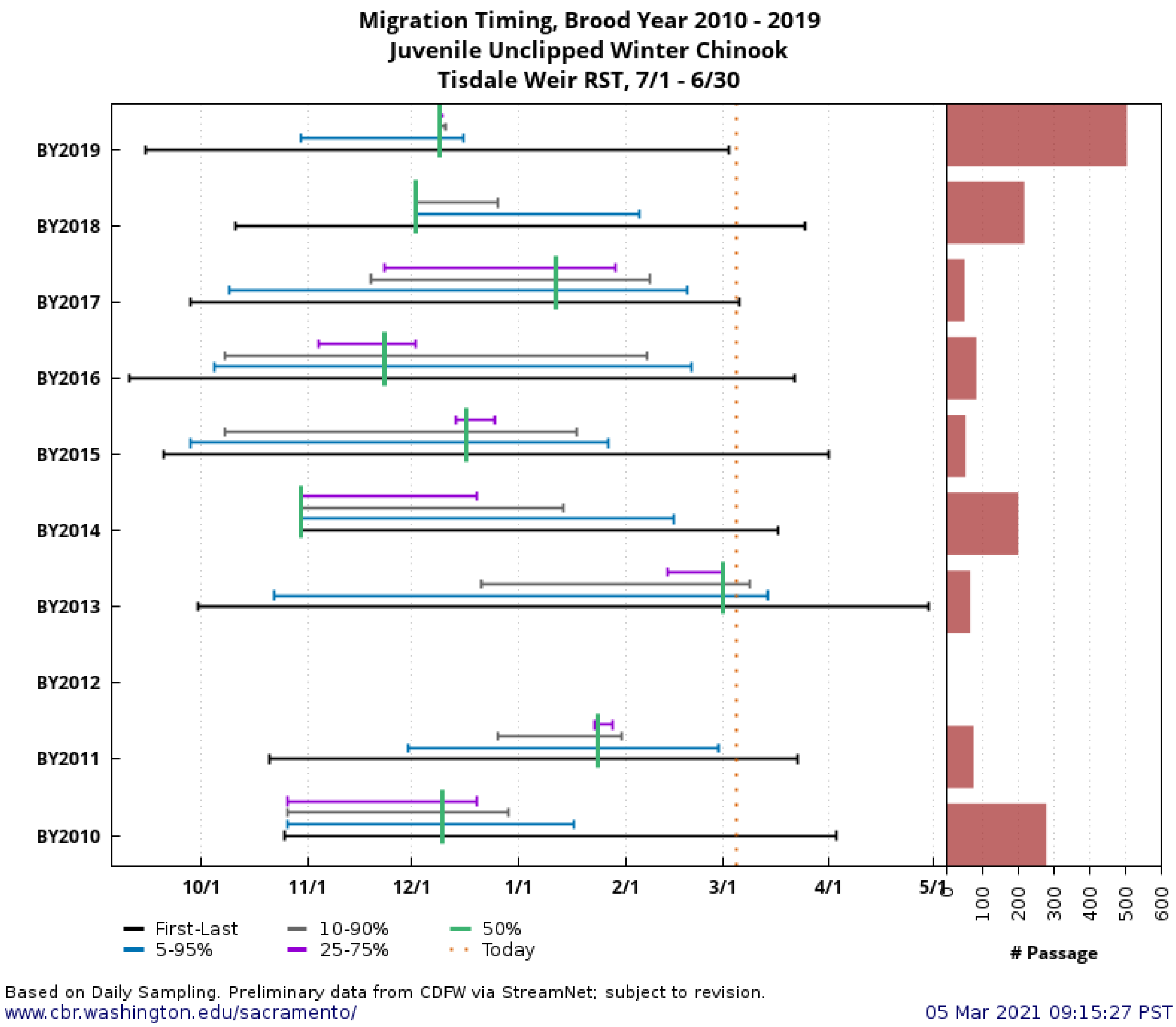


Figure 11A-Att1-2. Timing and Number of Juvenile Winter-Run Chinook Salmon in Tisdale Weir Rotary Screw Traps.

1.2.3 Winter-Run Chinook Salmon: Knights Landing Rotary Screw Traps

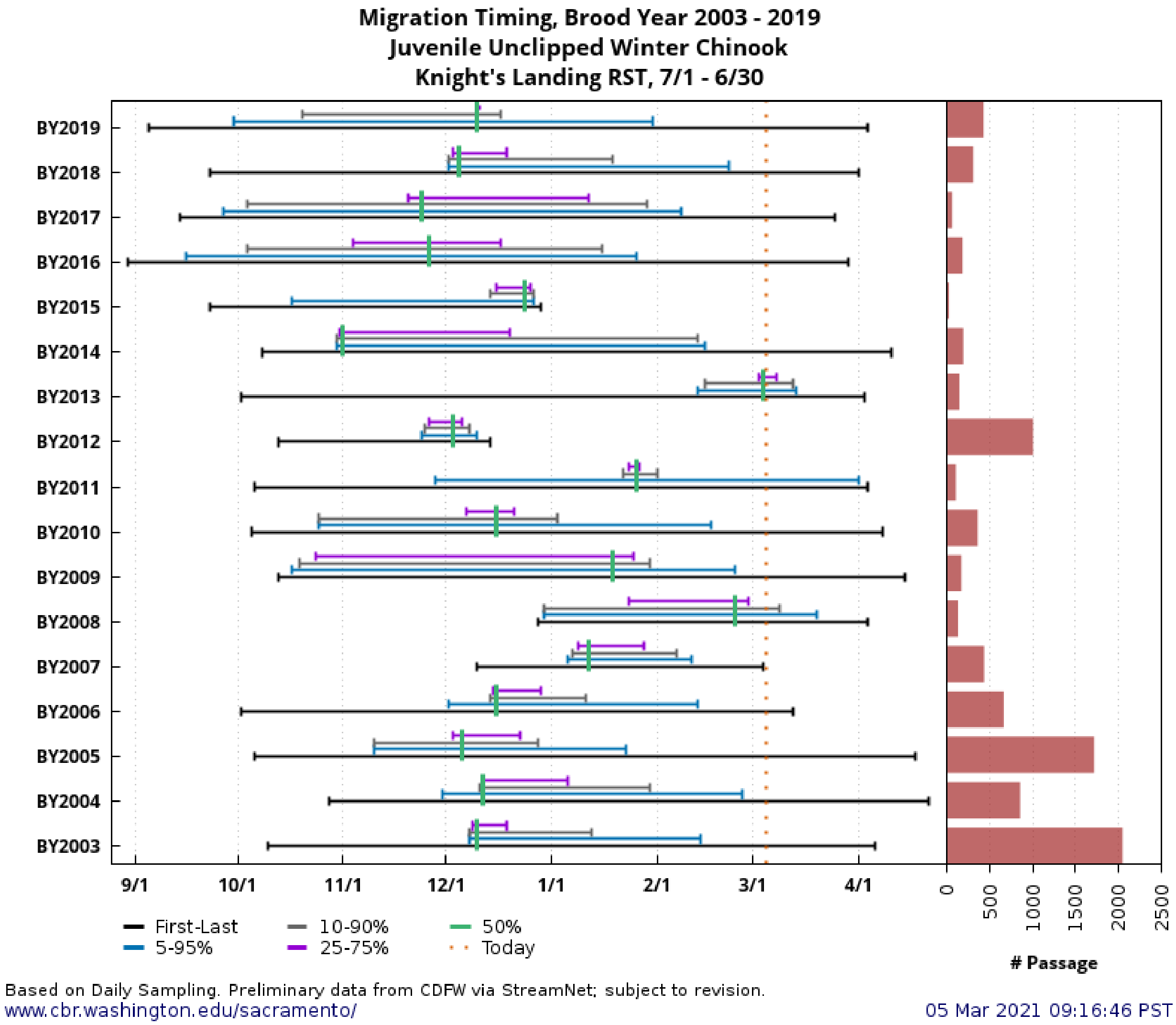


Figure 11A-Att1-3. Timing and Number of Juvenile Winter-Run Chinook Salmon in Knights Landing Rotary Screw Traps.

1.2.4 Winter-Run Chinook Salmon: Sacramento Beach Seines Combined

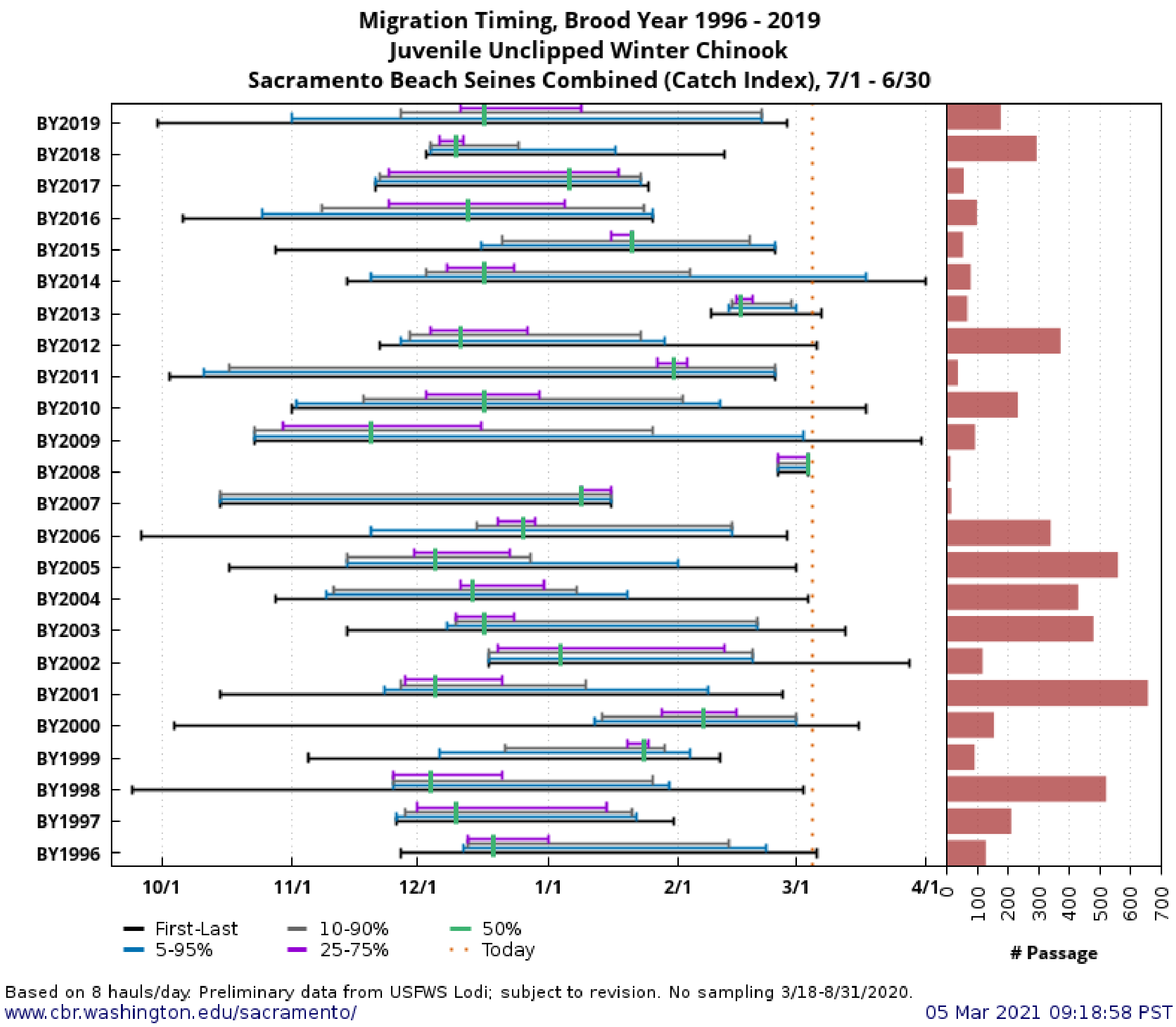


Figure 11A-Att1-4. Catch Index Timing and Number of Juvenile Winter-Run Chinook Salmon in Sacramento Beach Seines.

1.2.5 Winter-Run Chinook Salmon: Sacramento Trawls (Sherwood Harbor)

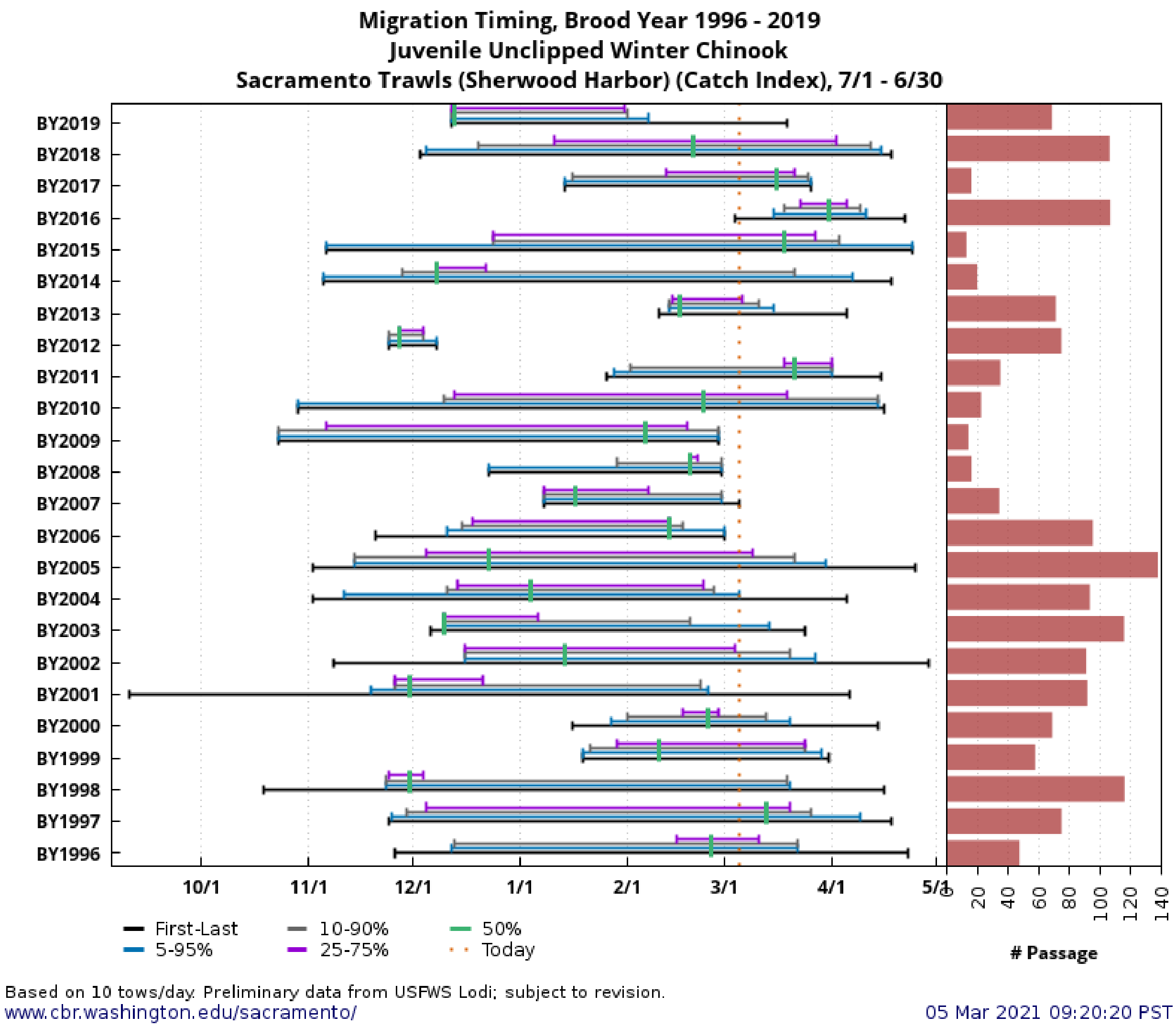


Figure 11A-Att1-5. Catch Index Timing and Number of Juvenile Winter-Run Chinook Salmon in Sacramento Trawls at Sherwood Harbor.

1.2.6 Winter-Run Chinook Salmon: Chipps Island Trawls

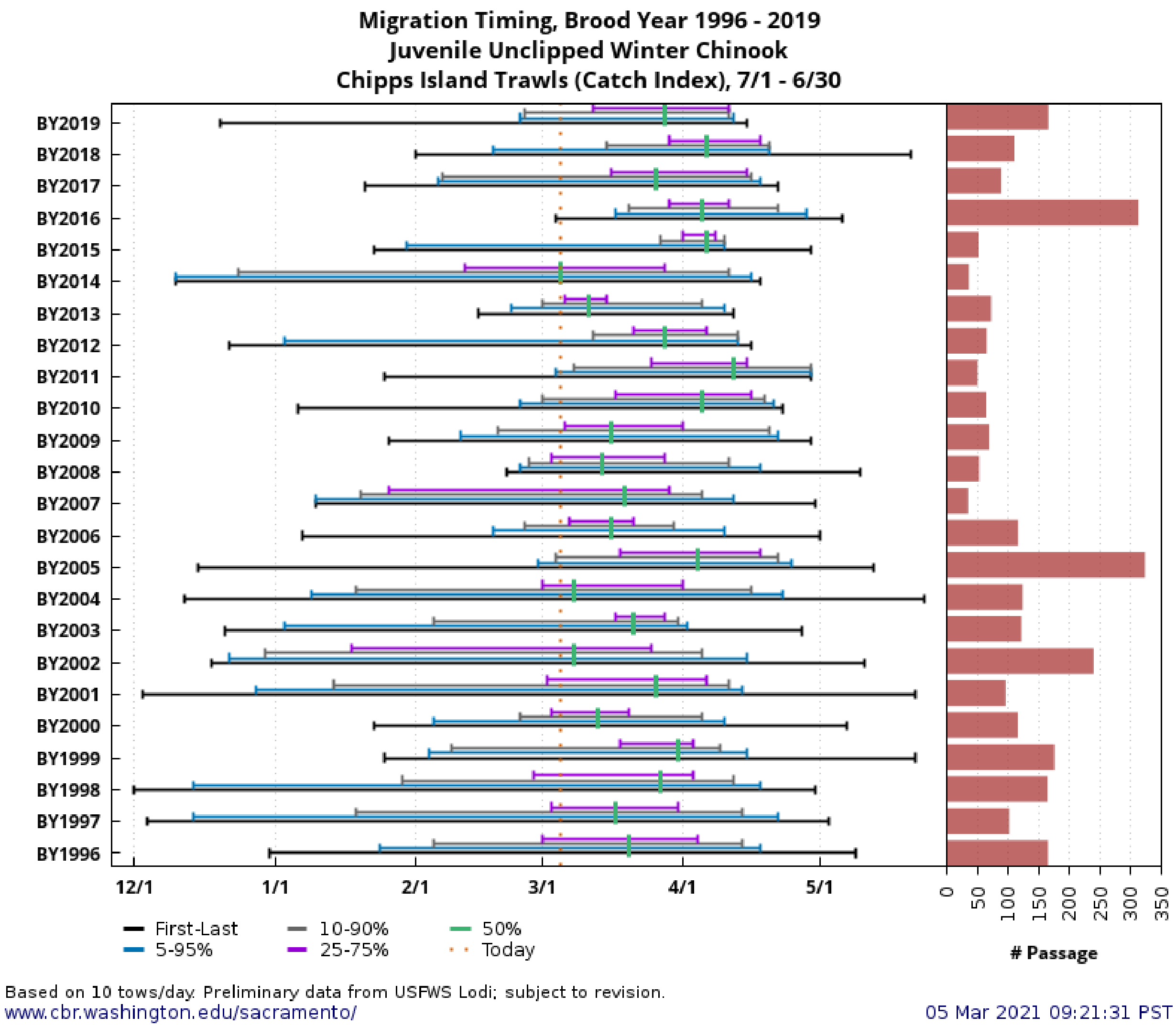


Figure 11A-Att1-6. Catch Index Timing and Number of Juvenile Winter-Run Chinook Salmon in Chipps Island Trawls.

1.2.7 Winter-Run Chinook Salmon Salvage: Unclipped (Length-at-Date)

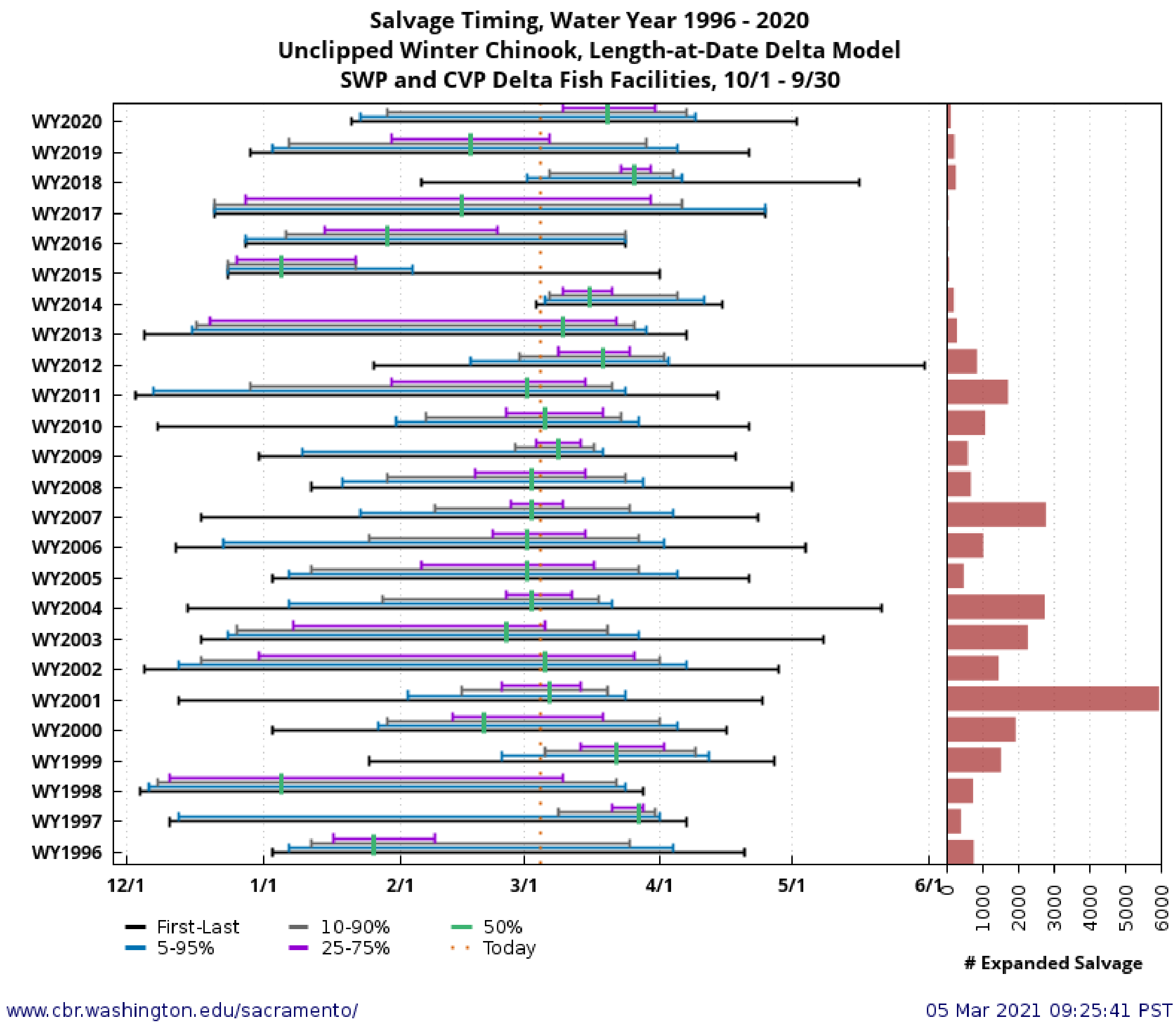


Figure 11A-Att1-7. Timing and Number of Unclipped Juvenile Winter-Run Chinook Salmon (Race Determined from Length at Date) at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.

1.2.8 Winter-Run Chinook Salmon Salvage: Clipped (Length-at-Date)

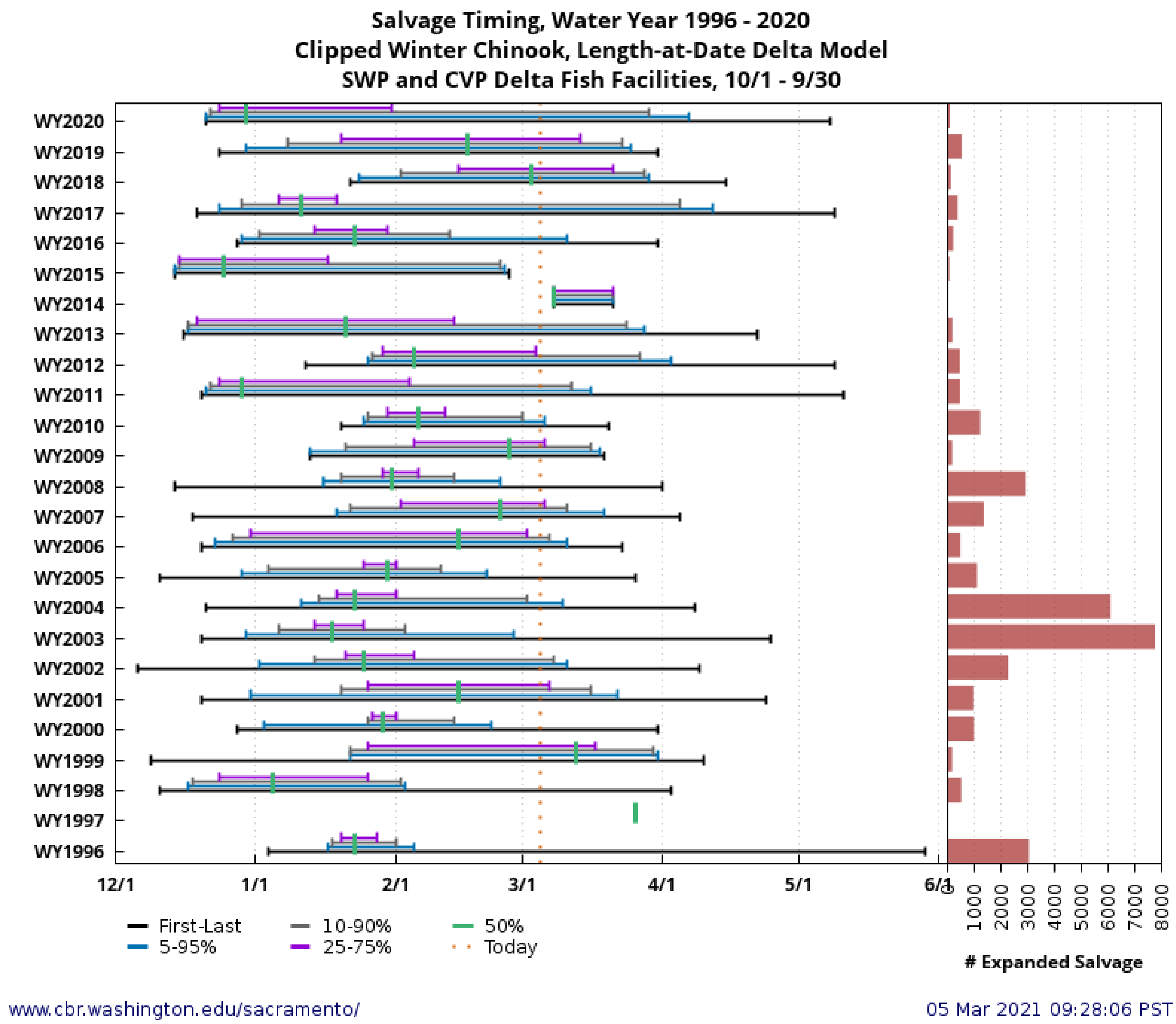
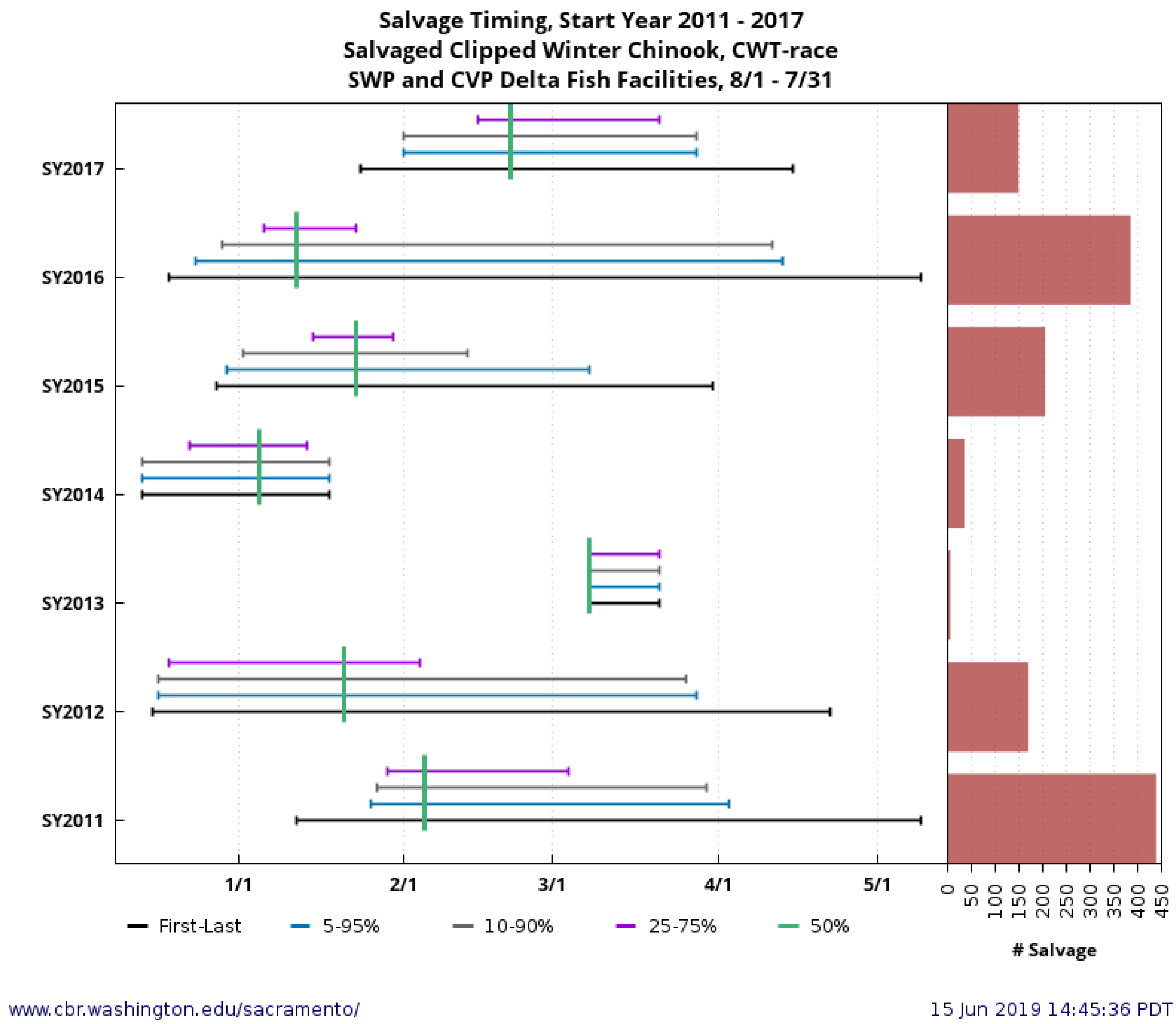


Figure 11A-Att1-8. Timing and Number of Clipped Juvenile Winter-Run Chinook Salmon (Race Determined from Length at Date) at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.

1.2.9 Winter-Run Chinook Salmon Salvage: Clipped (CWT-Race)



Note: Attempts to update this figure in 2021 with more recent data were not successful because only two years of data were provided when entering the same query.

Figure 11A-Att1-9. Timing and Number of Clipped Winter-Run Juvenile Chinook Salmon (Race Determined from Coded Wire Tag) at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.

1.3 Spring-Run Chinook Salmon

1.3.1 Spring-Run Chinook Salmon: Red Bluff Diversion Dam Rotary Screw Traps

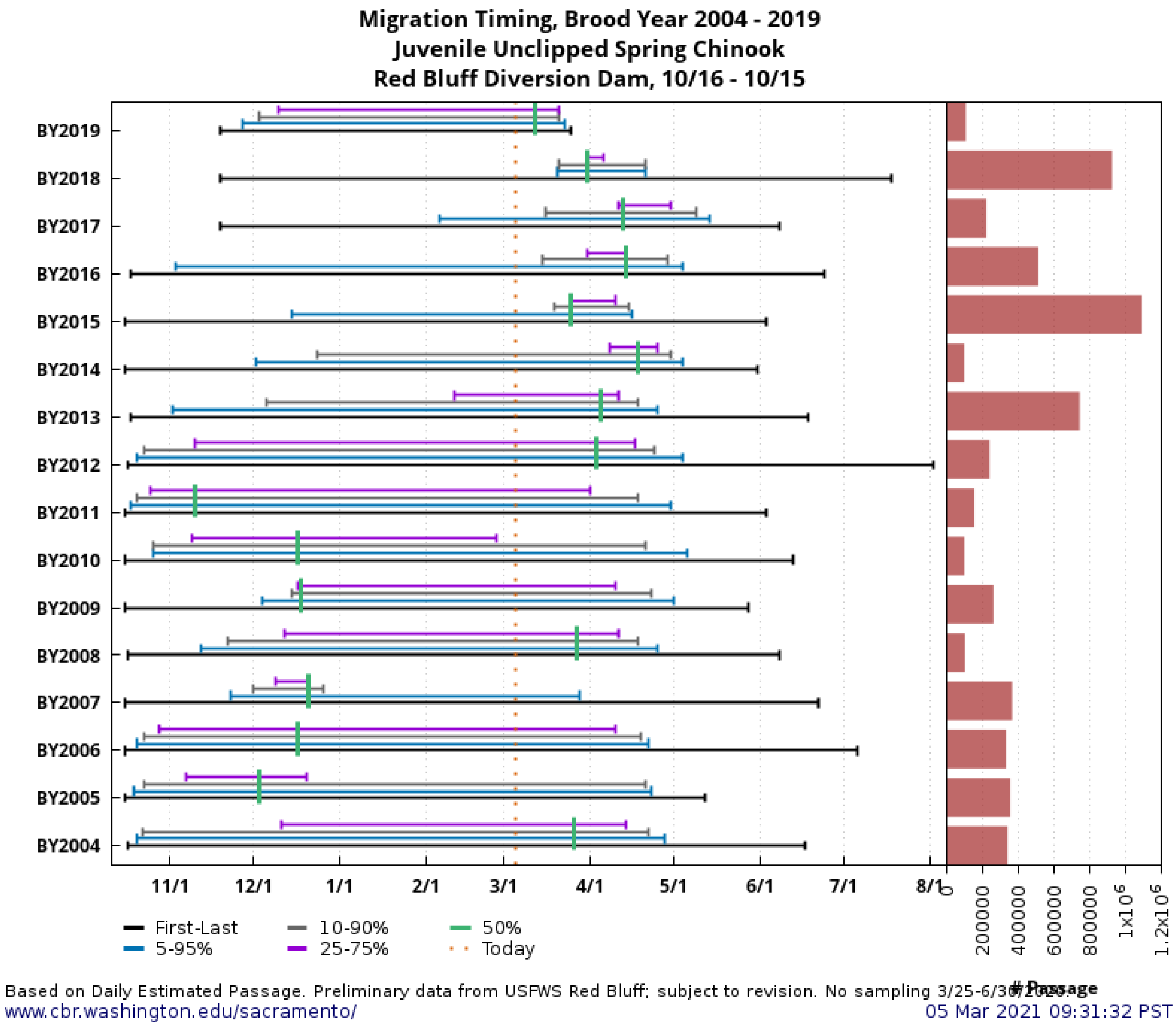


Figure 11A-Att1-10. Timing and Number of Juvenile Spring-Run Chinook Salmon in Red Bluff Diversion Dam Rotary Screw Traps.

1.3.2 Spring-Run Chinook Salmon: Tisdale Weir Rotary Screw Traps

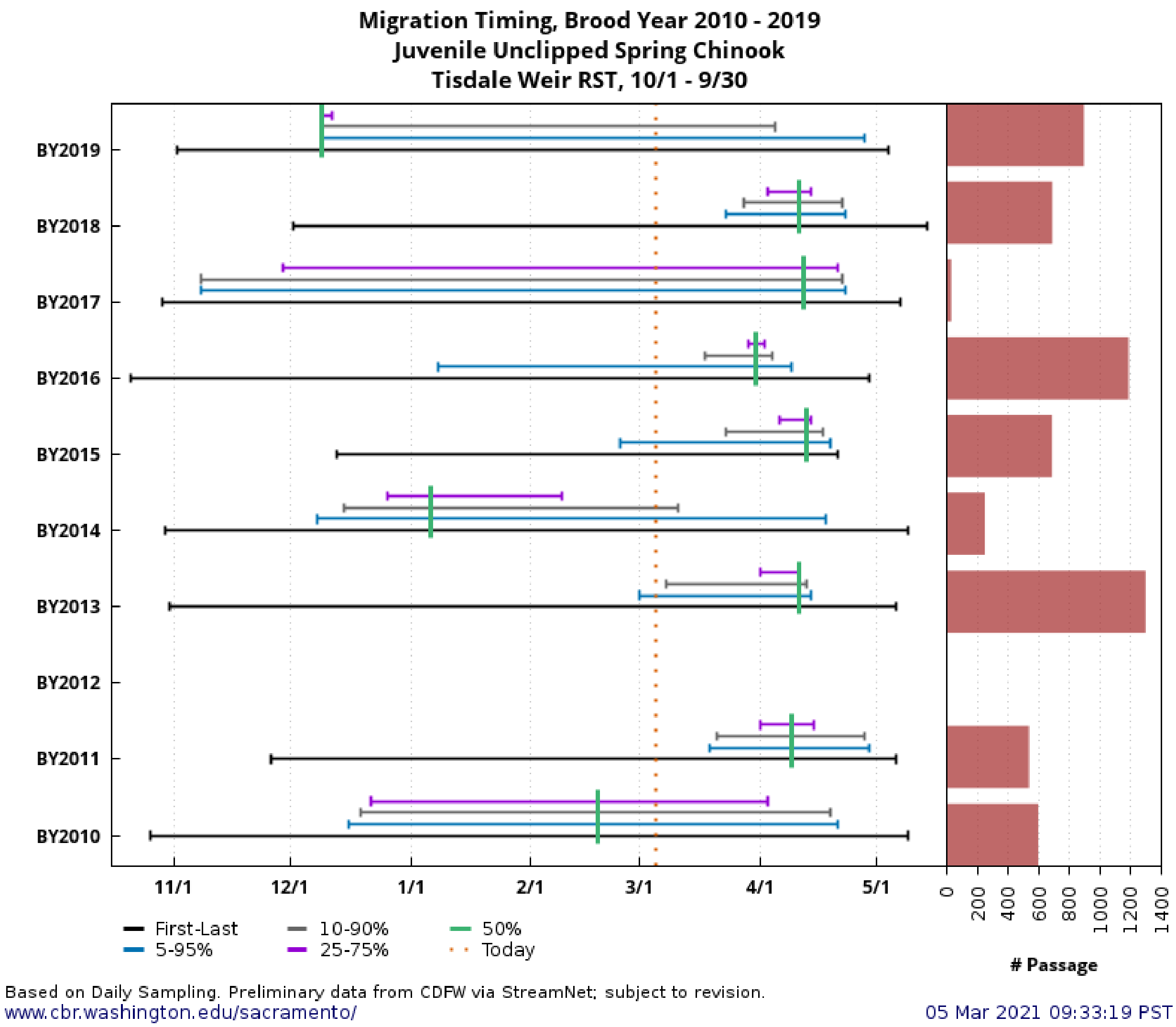


Figure 11A-Att1-11. Timing and Number of Juvenile Spring-Run Chinook Salmon in Tisdale Weir Rotary Screw Traps.

1.3.3 Spring-Run Chinook Salmon: Knights Landing Rotary Screw Traps

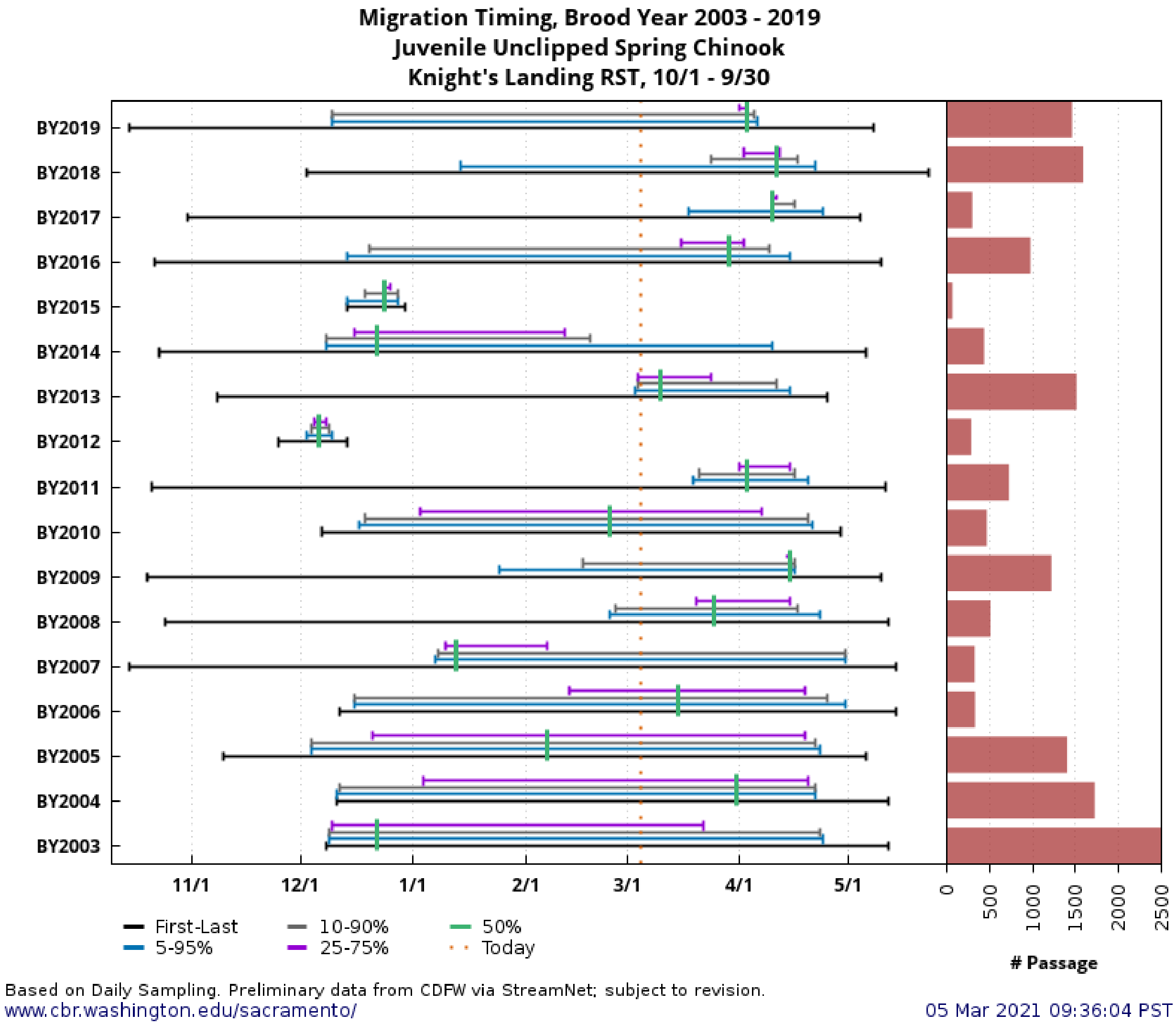


Figure 11A-Att1-12. Timing and Number of Juvenile Spring-Run Chinook Salmon in Knights Landing Rotary Screw Traps.

1.3.4 Spring-Run Chinook Salmon: Sacramento Beach Seines Combined

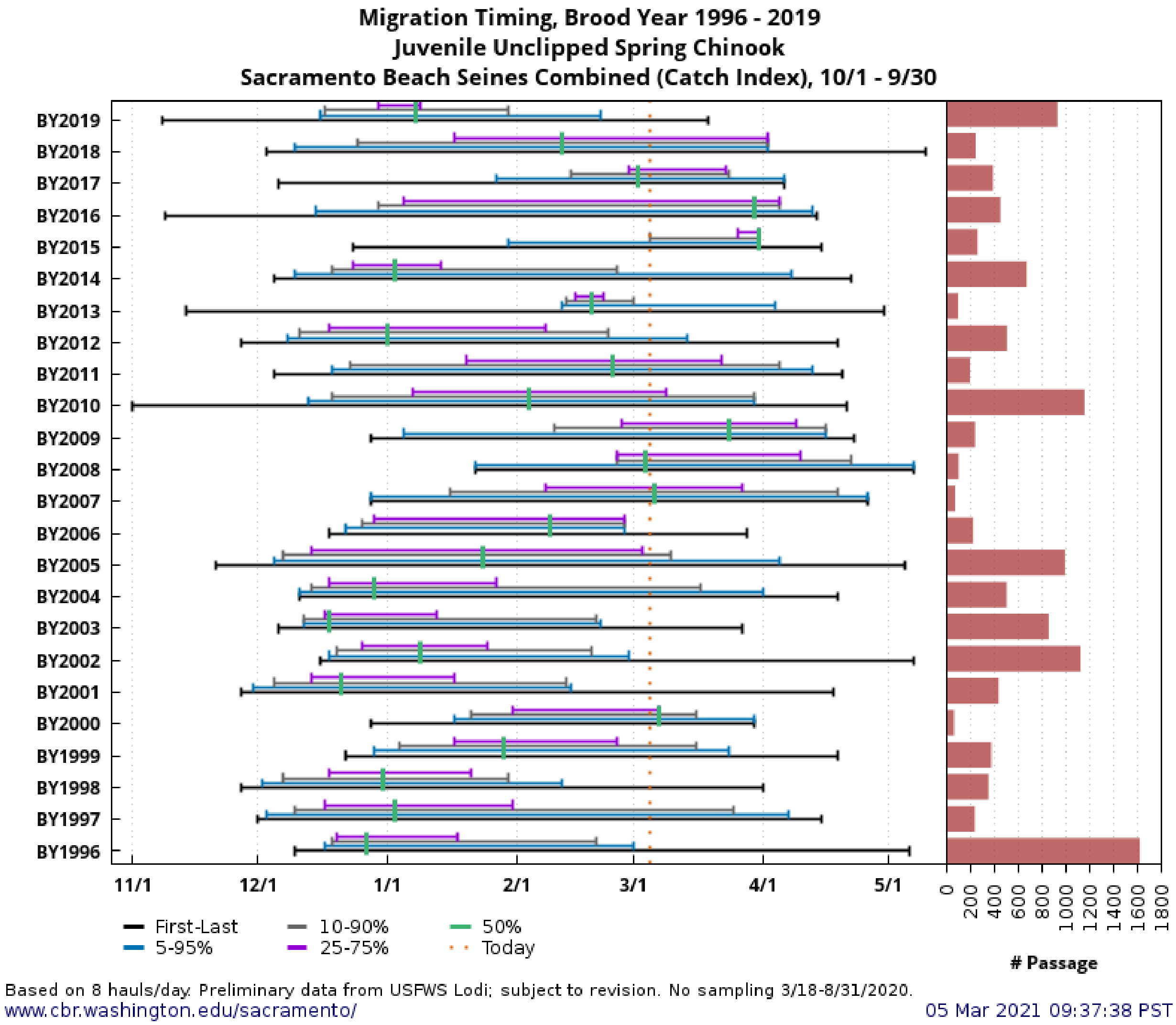


Figure 11A-Att1-13. Catch Index Timing and Number of Juvenile Spring-Run Chinook Salmon in Sacramento Beach Seines.

1.3.5 Spring-Run Chinook Salmon: Sacramento Trawls (Sherwood Harbor)

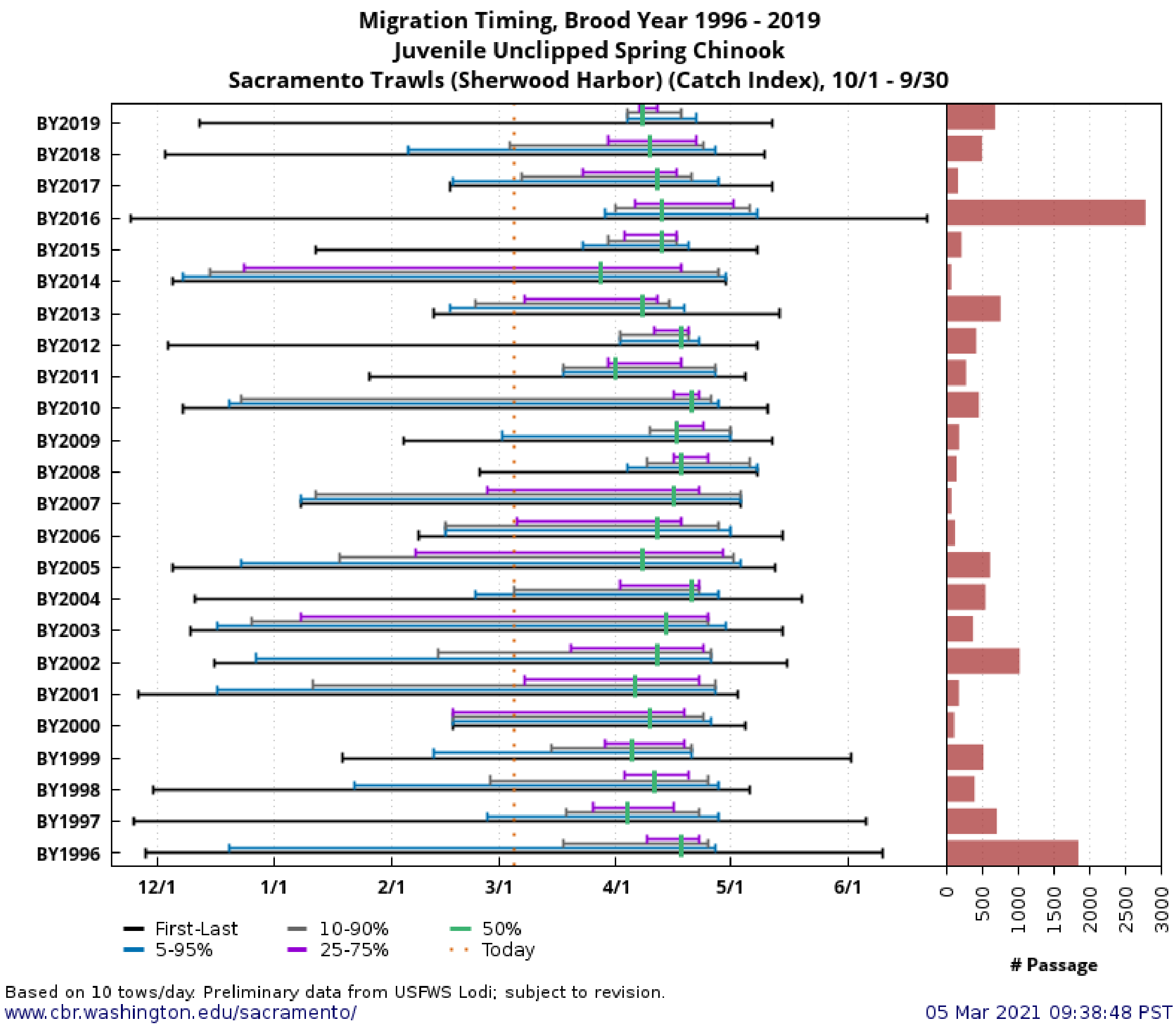


Figure 11A-Att1-14. Catch Index Timing and Number of Juvenile Spring-Run Chinook Salmon in Sacramento Trawls at Sherwood Harbor.

1.3.6 Spring-Run Chinook Salmon: Chipps Island Trawls

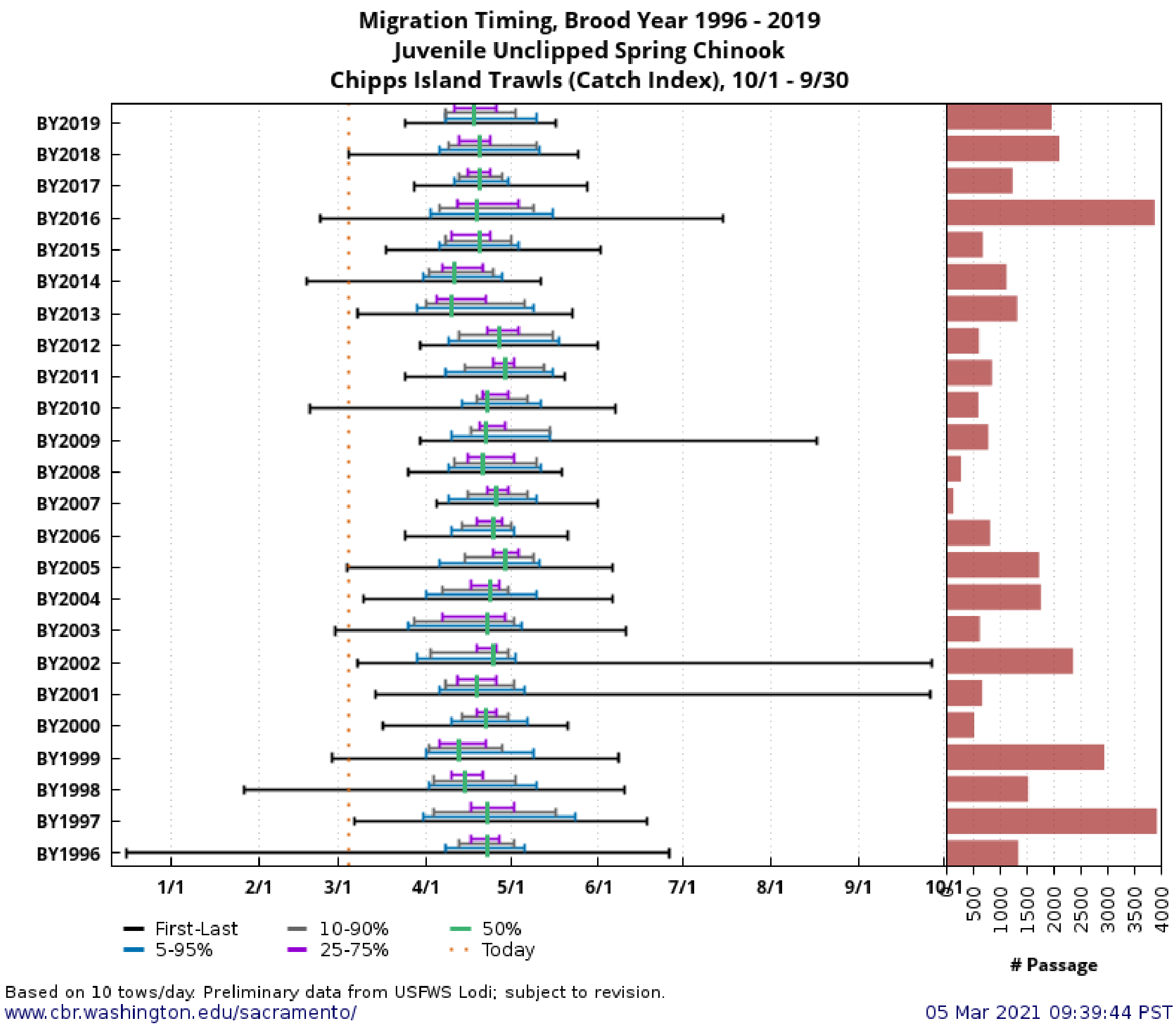


Figure 11A-Att1-15. Catch Index Timing and Number of Juvenile Spring-Run Chinook Salmon in Chipps Island Trawls.

1.3.7 Spring-Run Chinook Salmon Salvage: Unclipped (Length-at-Date)

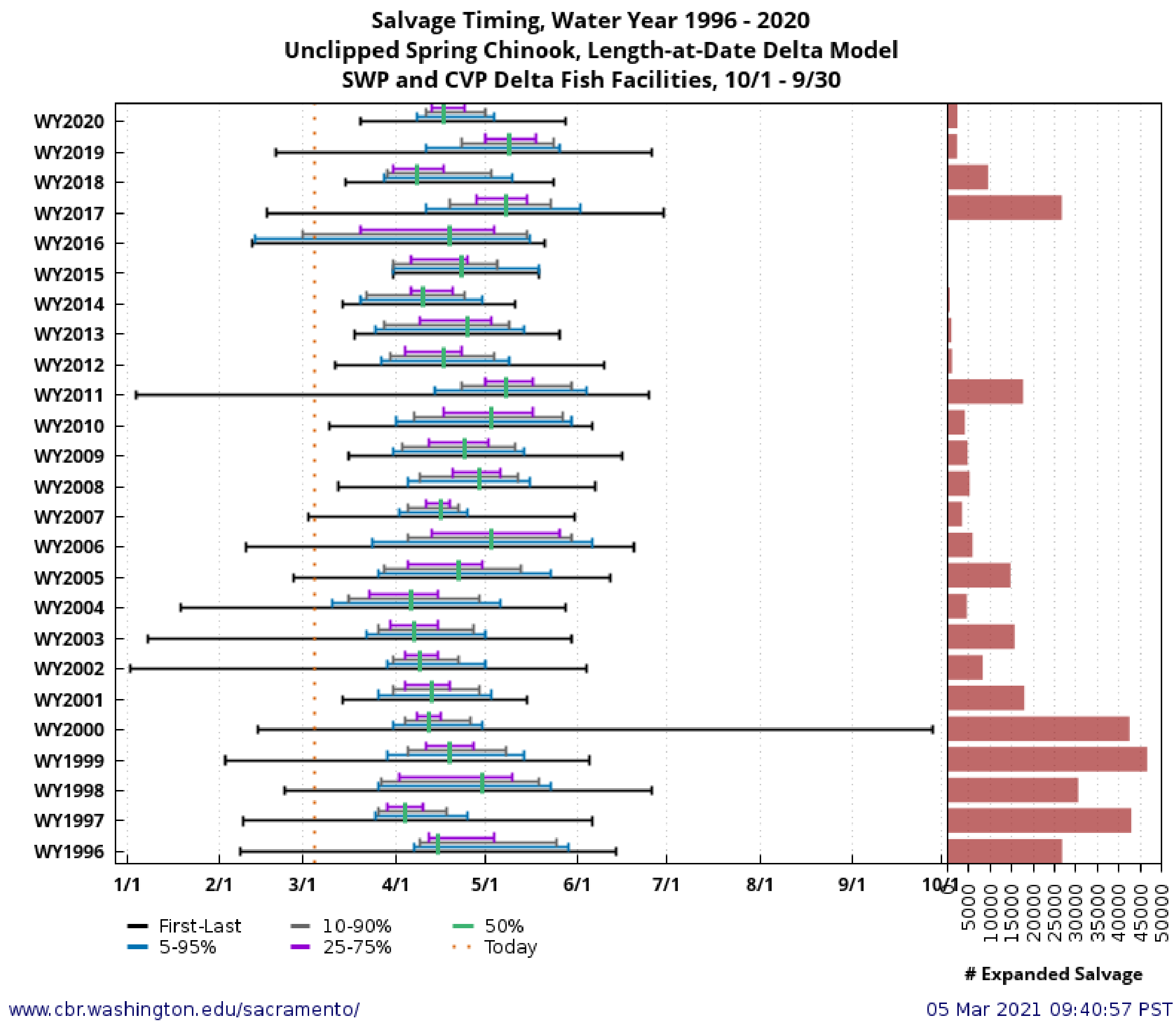


Figure 11A-Att1-16. Timing and Number of Unclipped Juvenile Spring-Run Chinook Salmon (Race Determined from Length at Date) at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.

1.3.8 Spring-Run Chinook Salmon Salvage: Clipped (Length-at-Date)

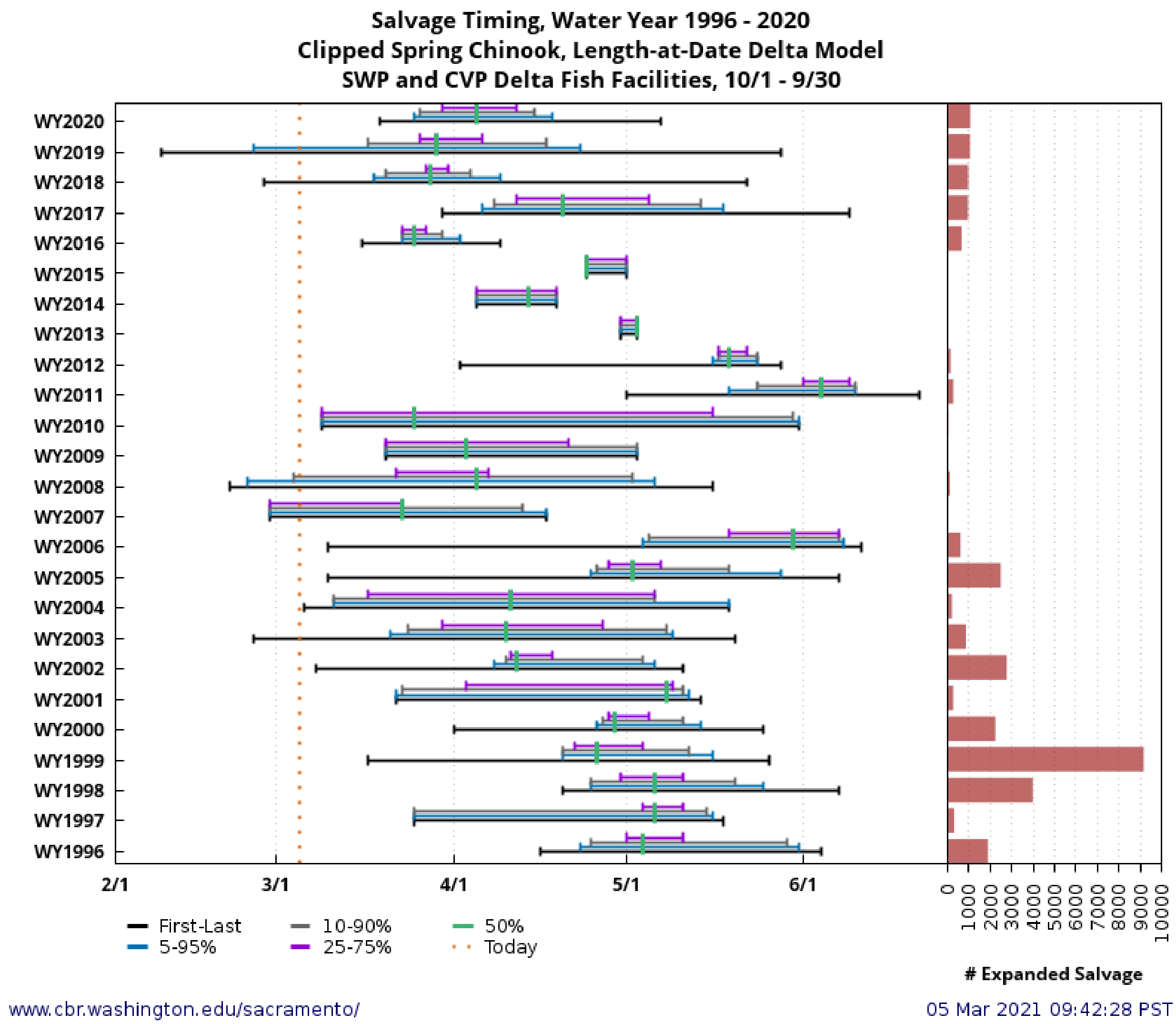


Figure 11A-Att1-17. Timing and Number of Clipped Juvenile Spring-Run Chinook Salmon (Race Determined from Length at Date) at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.

1.3.9 Spring-Run Chinook Salmon Salvage: Clipped (CWT-Race)

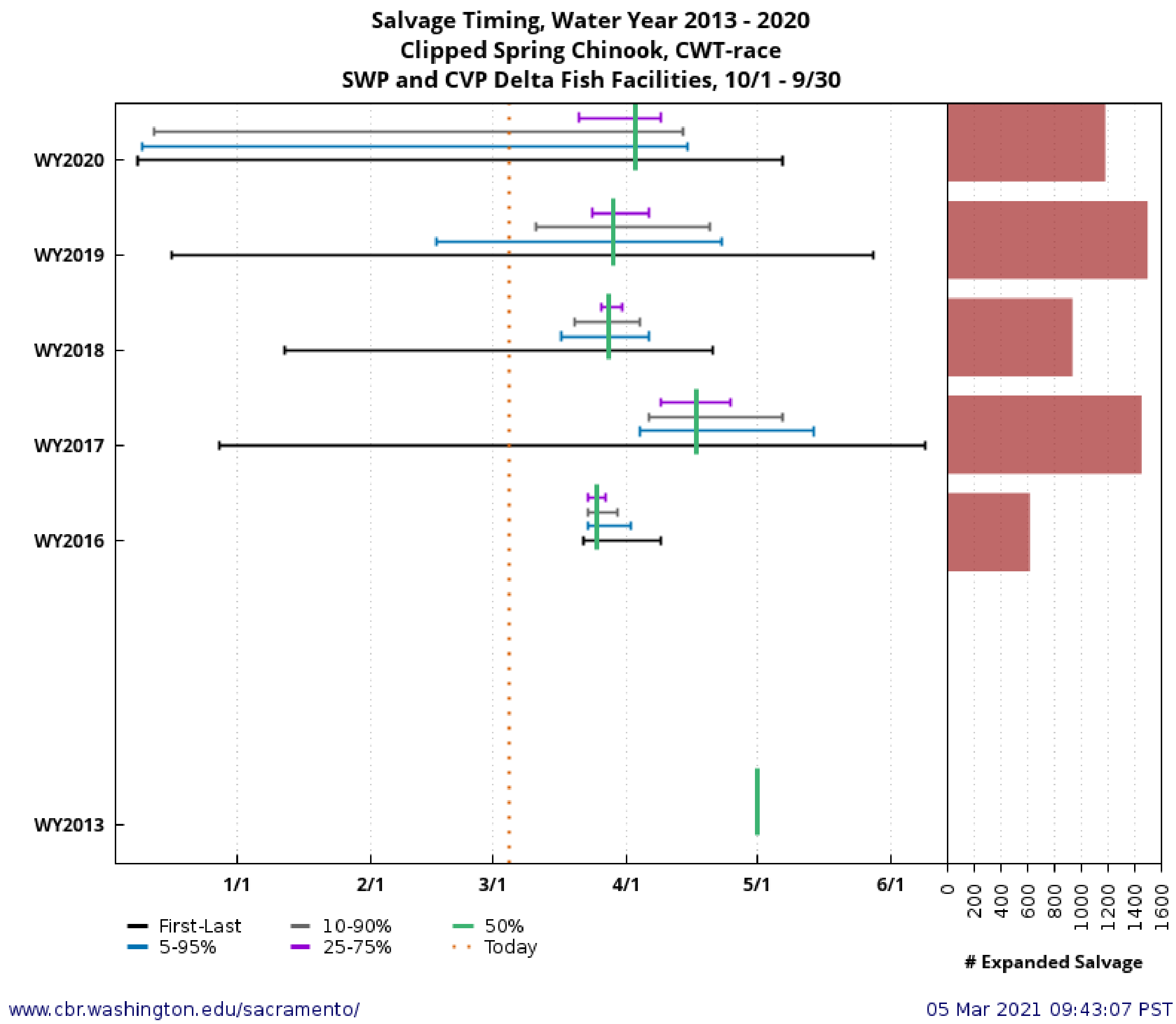


Figure 11A-Att1-18. Timing and Number of Clipped Spring-Run Juvenile Chinook Salmon (Race Determined from Coded Wire Tag) at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.

1.4 Fall-Run Chinook Salmon

1.4.1 Fall-Run Chinook Salmon: Red Bluff Diversion Dam Rotary Screw Traps

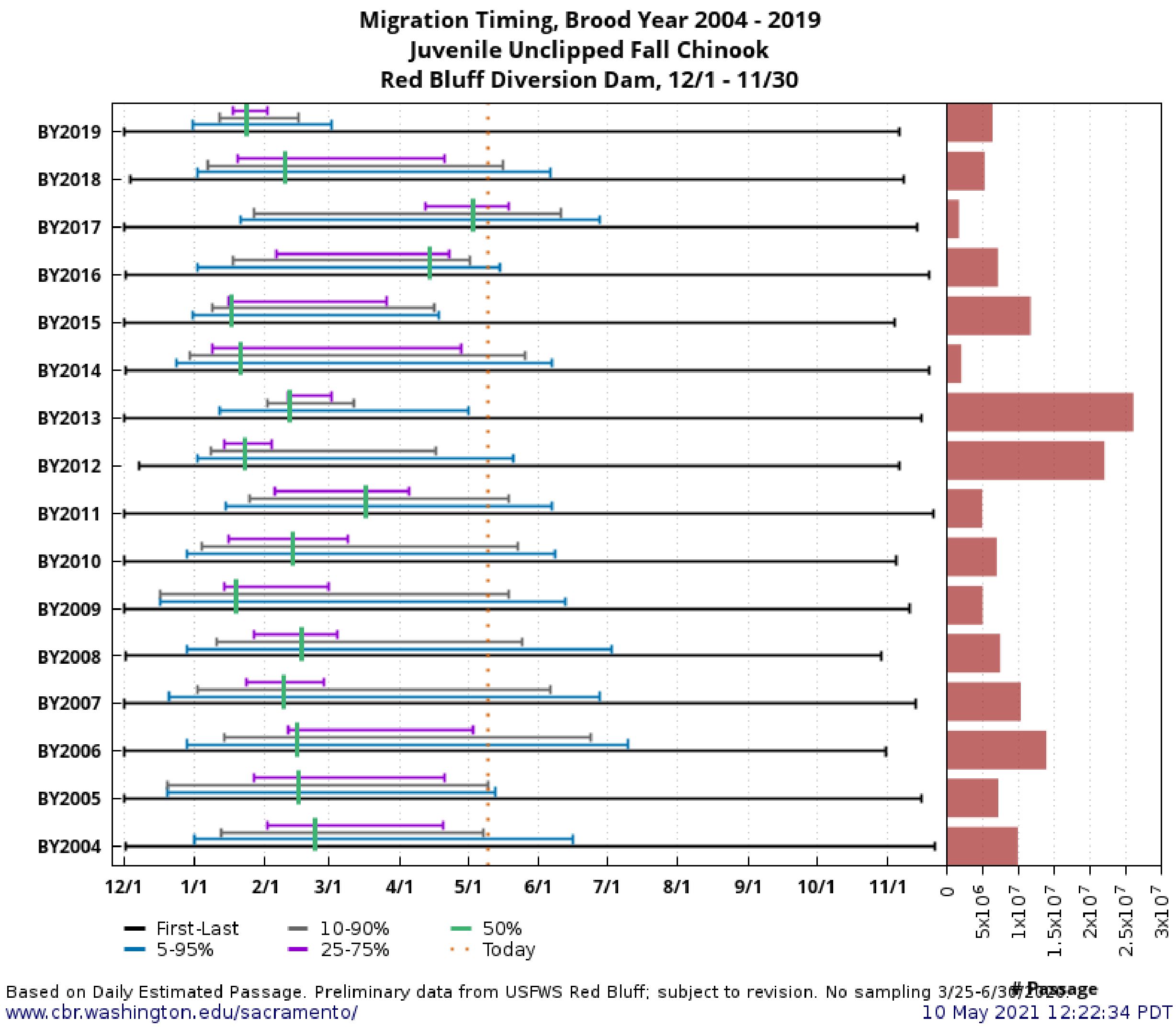


Figure 11A-Att1-19. Timing and Number of Juvenile Fall-Run Chinook Salmon in Red Bluff Diversion Dam Rotary Screw Traps.

1.4.2 Fall-Run Chinook Salmon: Tisdale Weir Rotary Screw Traps

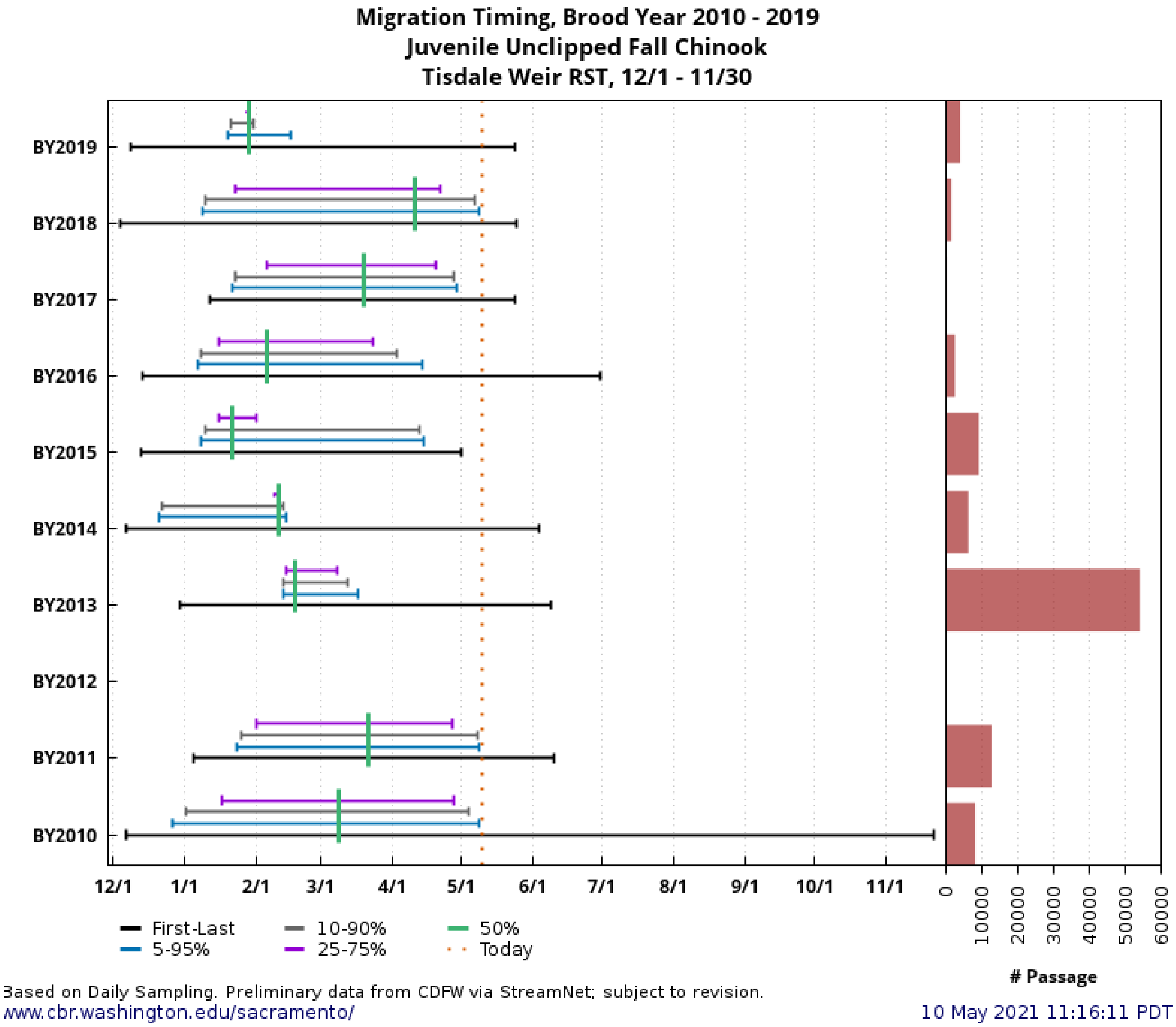


Figure 11A-Att1-20. Timing and Number of Juvenile Fall-Run Chinook Salmon in Tisdale Weir Rotary Screw Traps.

1.4.3 Fall-Run Chinook Salmon: Knights Landing Rotary Screw Traps

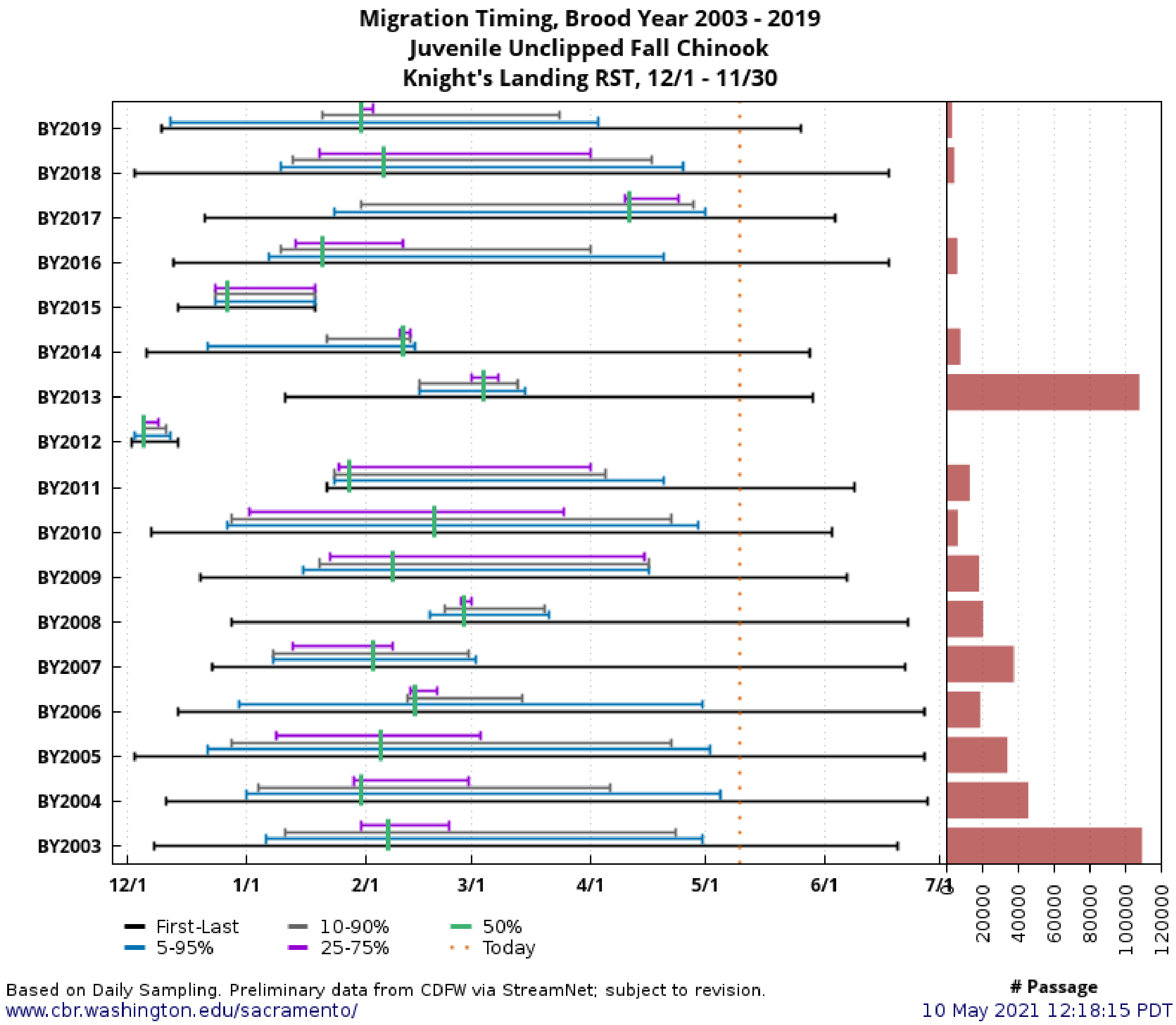


Figure 11A-Att1-21. Timing and Number of Juvenile Fall-Run Chinook Salmon in Knights Landing Rotary Screw Traps.

1.4.4 Fall-Run Chinook Salmon: Sacramento Beach Seines Combined

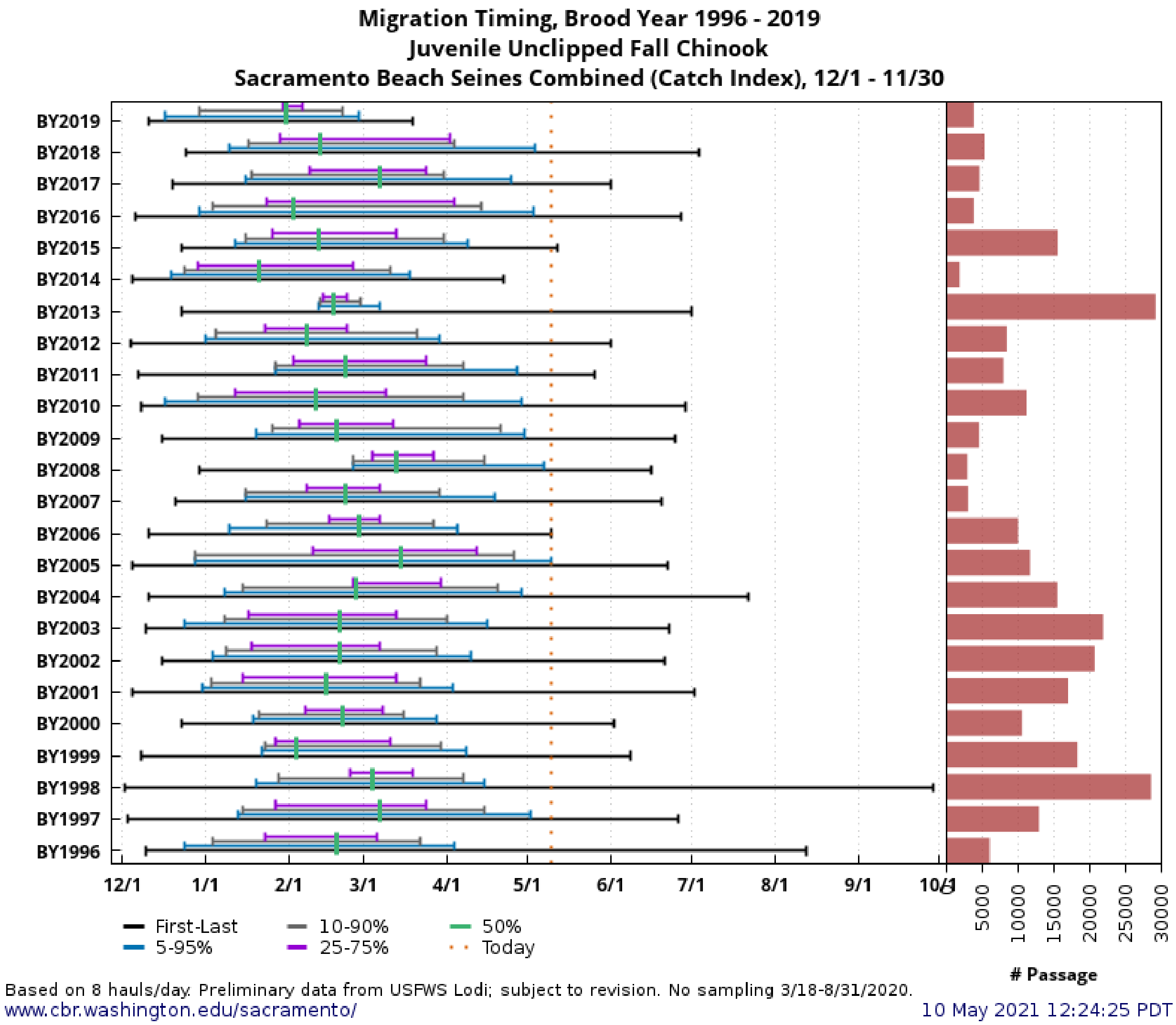


Figure 11A-Att1-22. Catch Index Timing and Number of Juvenile Fall-Run Chinook Salmon in Sacramento Beach Seines.

1.4.5 Fall-Run Chinook Salmon: Sacramento Trawls (Sherwood Harbor)

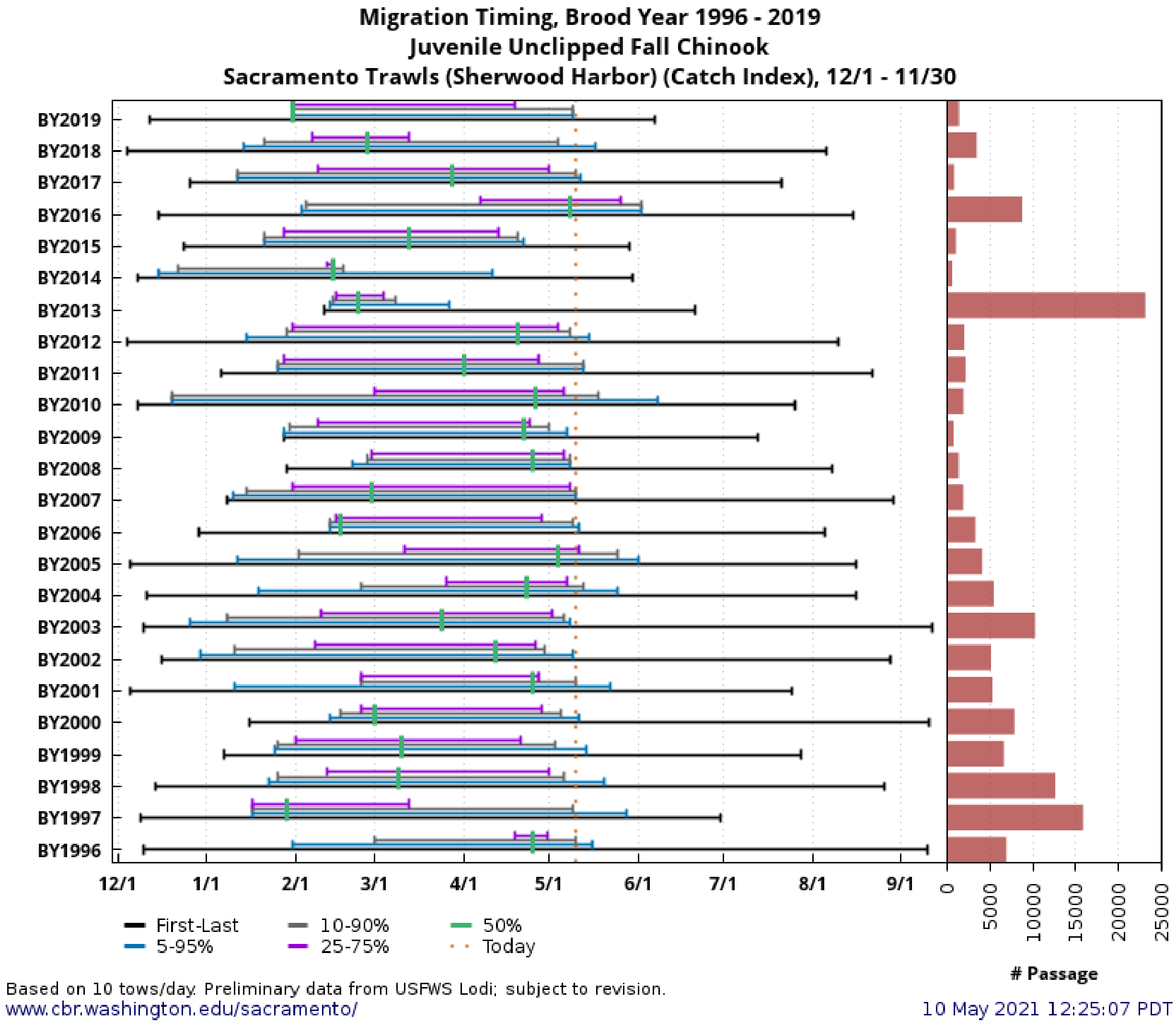


Figure 11A-Att1-23. Catch Index Timing and Number of Juvenile Fall-Run Chinook Salmon in Sacramento Trawls at Sherwood Harbor.

1.4.6 Fall-Run Chinook Salmon: Chipps Island Trawls

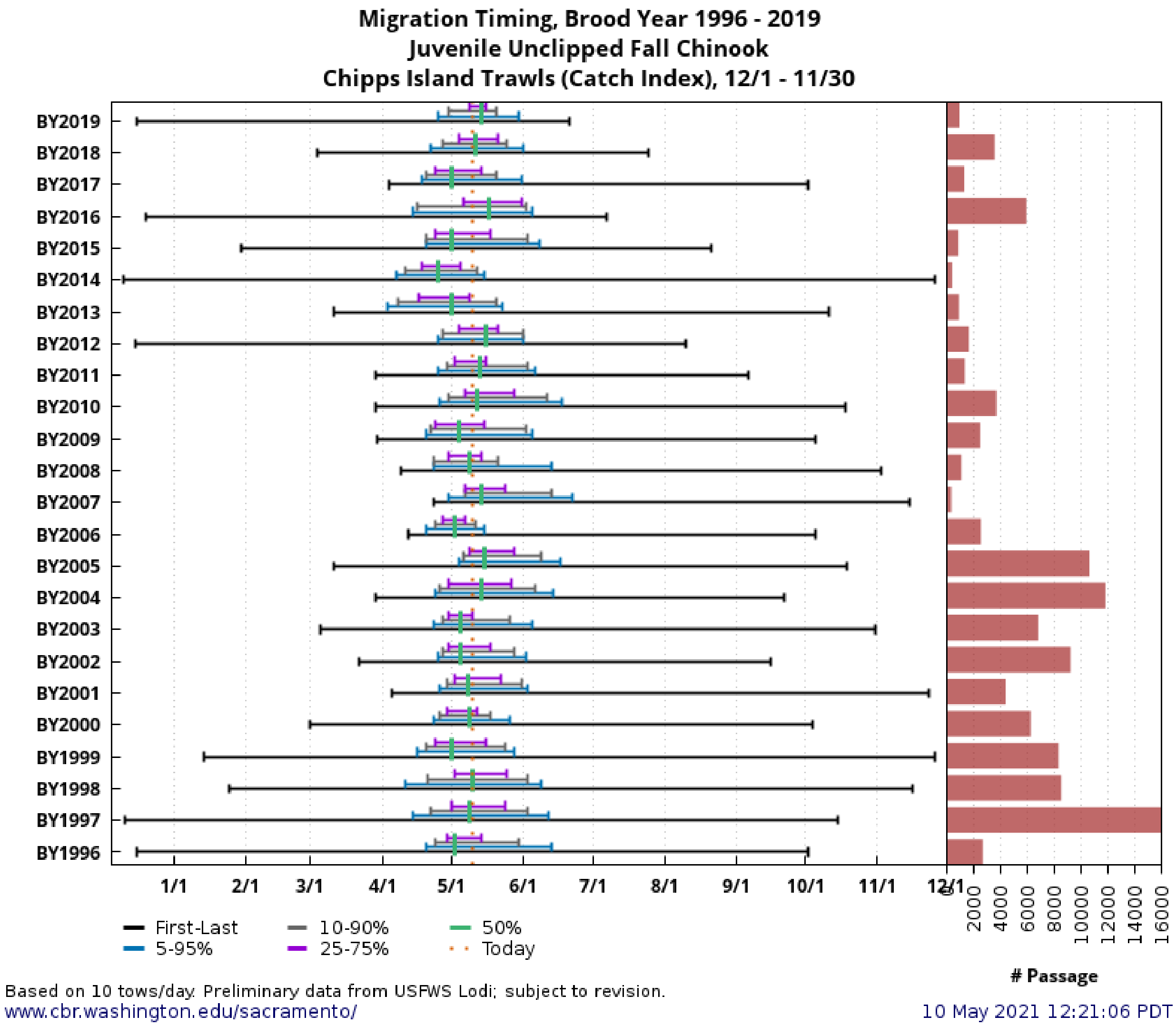


Figure 11A-Att1-24. Catch Index Timing and Number of Juvenile Fall-Run Chinook Salmon in Chipps Island Trawls.

1.4.7 Fall-Run Chinook Salmon Salvage: Unclipped (Length-at-Date)

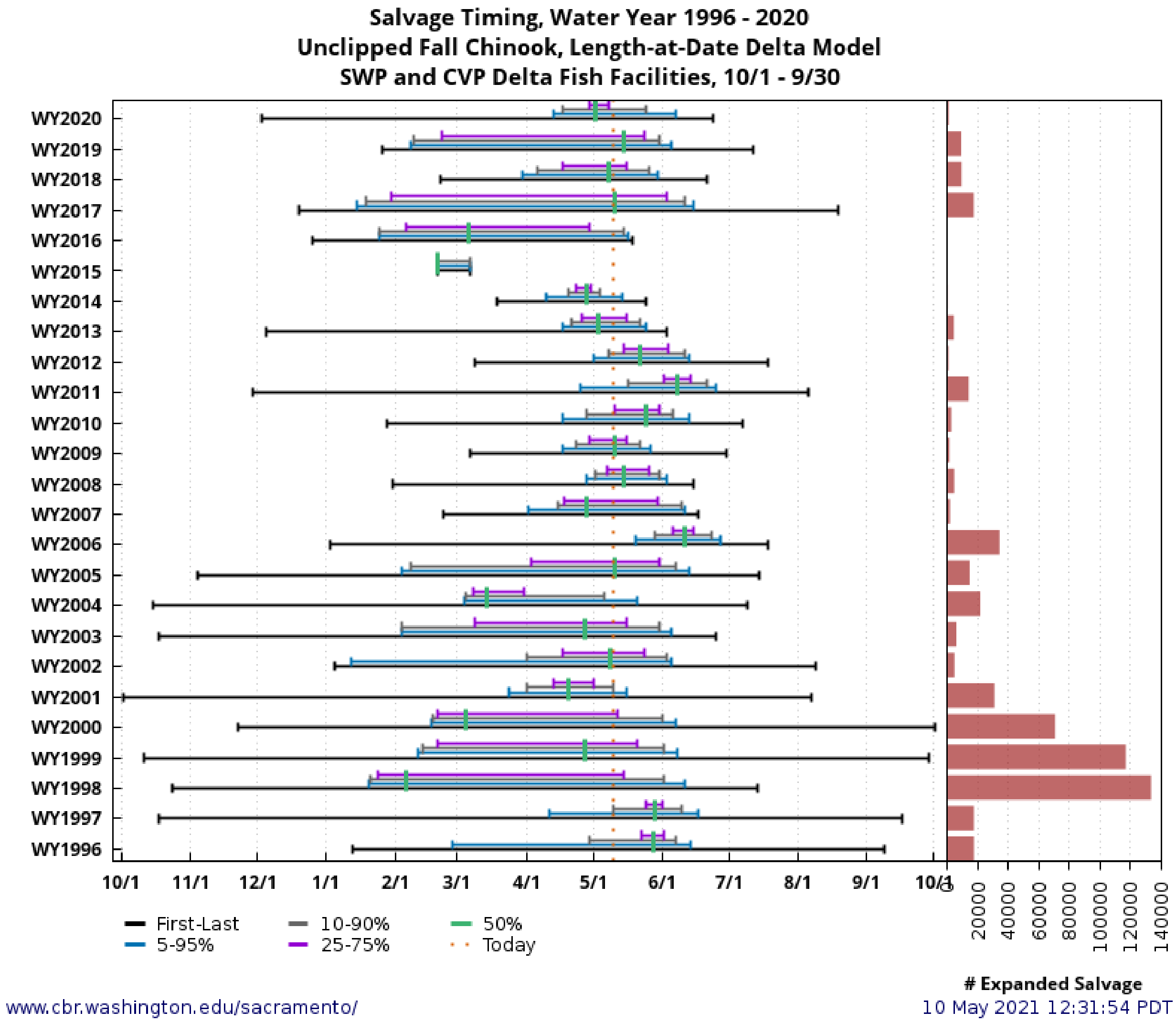


Figure 11A-Att1-25. Timing and Number of Unclipped Juvenile Fall-Run Chinook Salmon (Race Determined from Length at Date) at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.

1.4.8 Fall-Run Chinook Salmon Salvage: Clipped (Length-at-Date)

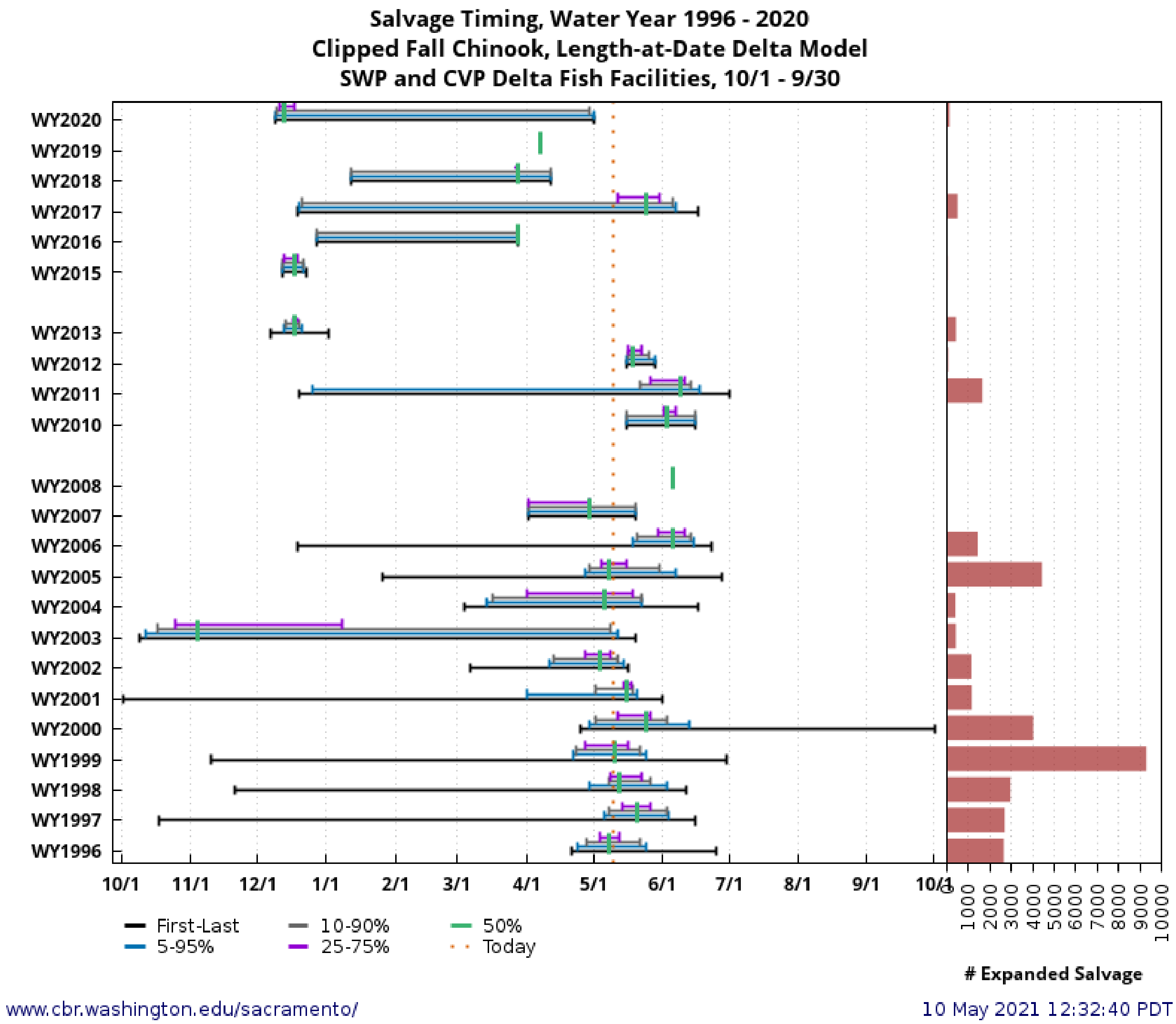


Figure 11A-Att1-26. Timing and Number of Clipped Juvenile Fall-Run Chinook Salmon (Race Determined from Length at Date) at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.

1.4.9 Fall-Run Chinook Salmon Salvage: Clipped (CWT-Race)

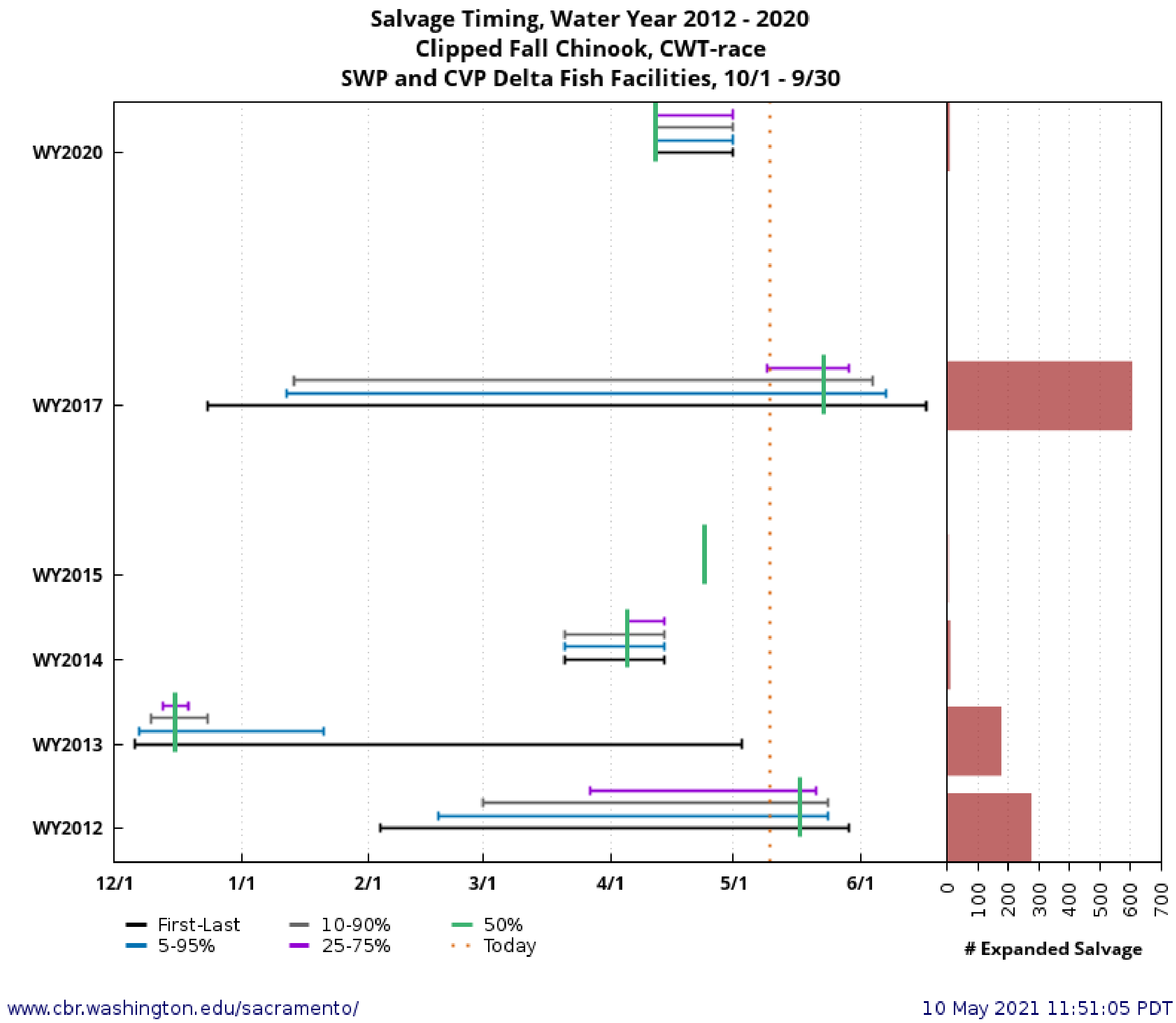


Figure 11A-Att1-27. Timing and Number of Clipped Fall-Run Juvenile Chinook Salmon (Race Determined from Coded Wire Tag) at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.

1.5 Late Fall-Run Chinook Salmon

1.5.1 Late Fall-Run Chinook Salmon: Red Bluff Diversion Dam Rotary Screw Traps

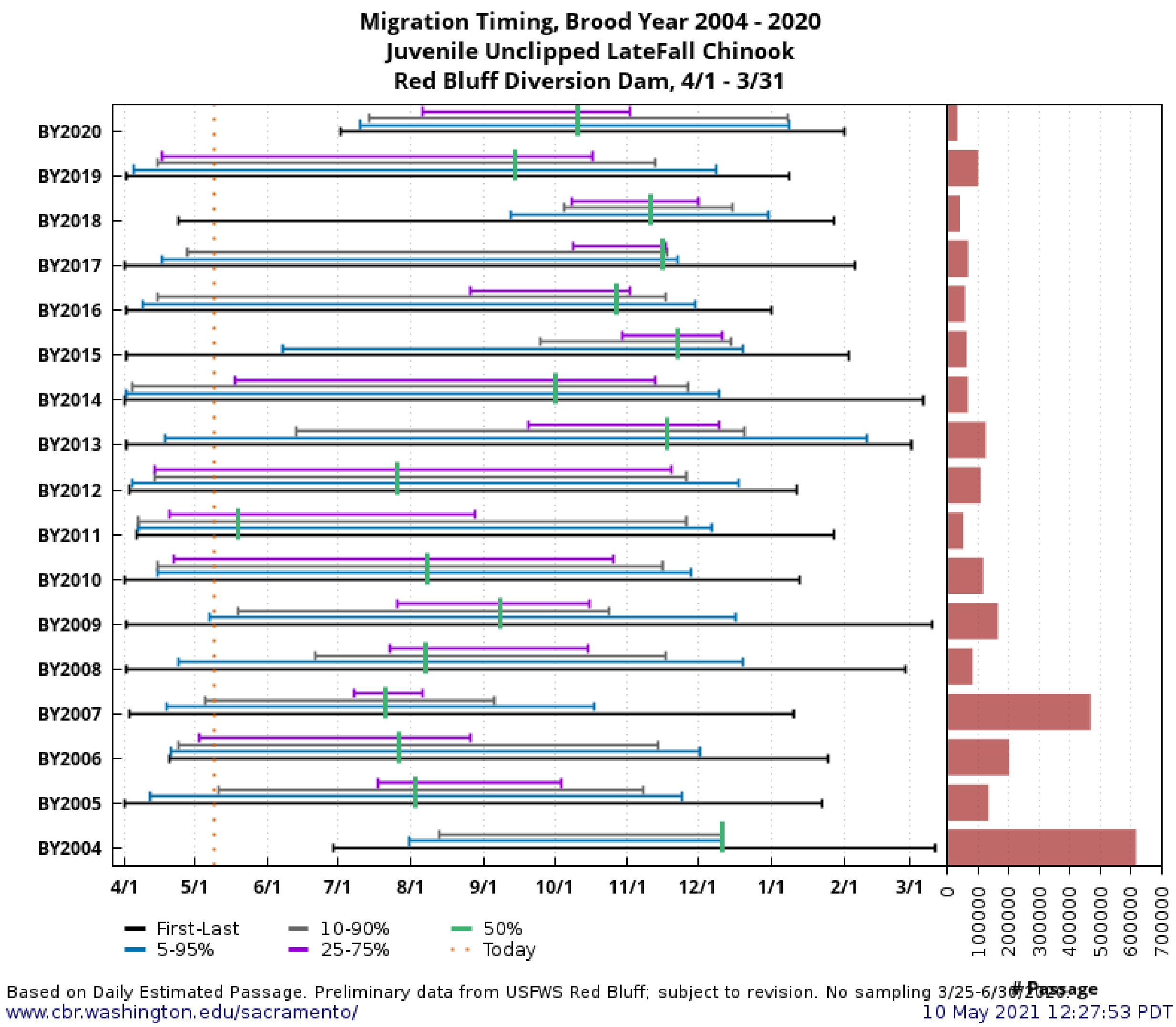


Figure 11A-Att1-28. Timing and Number of Juvenile Late Fall-Run Chinook Salmon in Red Bluff Diversion Dam Rotary Screw Traps.

1.5.2 Late Fall-Run Chinook Salmon: Tisdale Weir Rotary Screw Traps

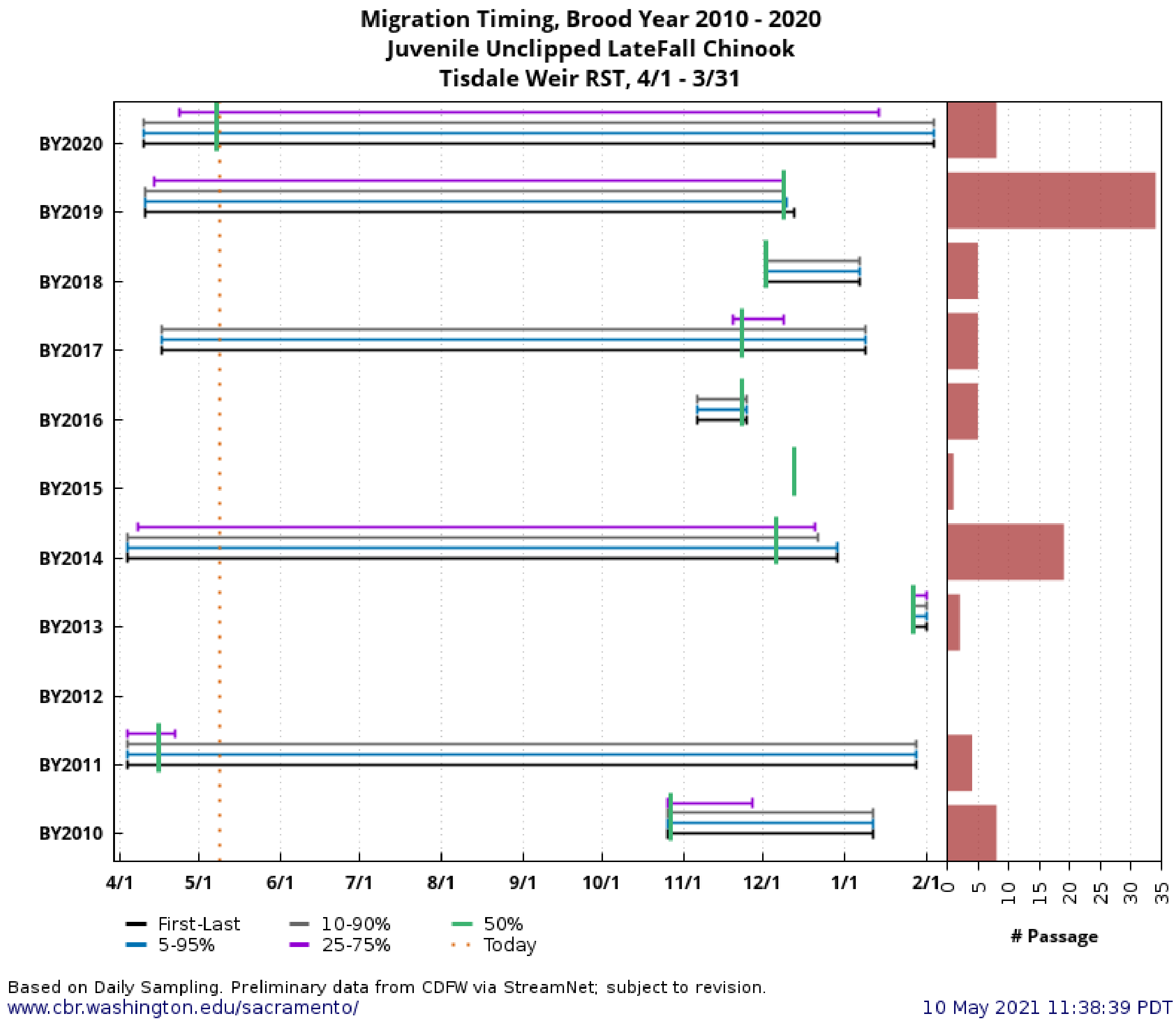


Figure 11A-Att1-29. Timing and Number of Juvenile Late Fall-Run Chinook Salmon in Tisdale Weir Rotary Screw Traps.

1.5.3 Late Fall-Run Chinook Salmon: Knights Landing Rotary Screw Traps

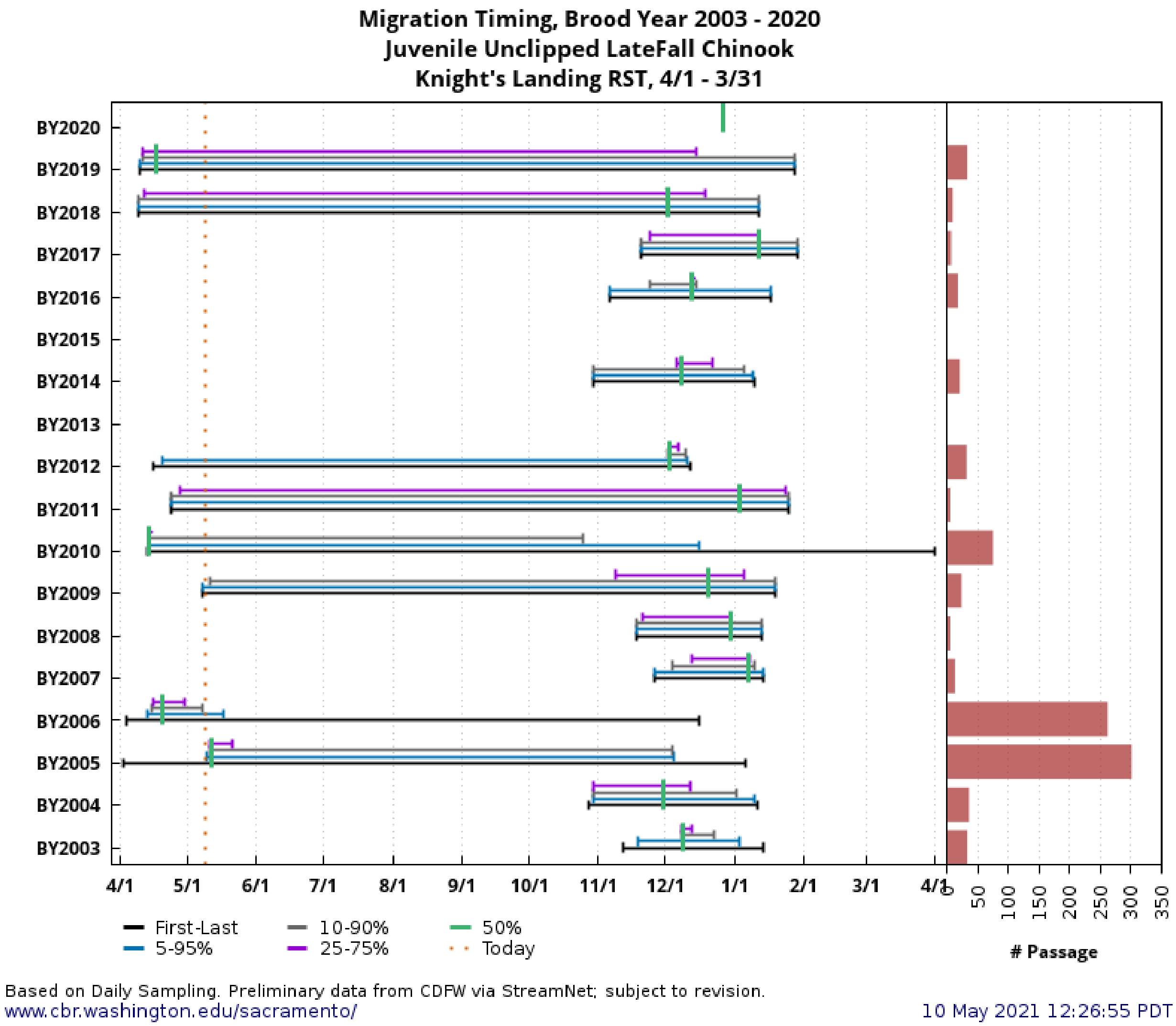


Figure 11A-Att1-30. Timing and Number of Juvenile Late Fall-Run Chinook Salmon in Knights Landing Rotary Screw Traps.

1.5.4 Late Fall-Run Chinook Salmon: Sacramento Beach Seines Combined

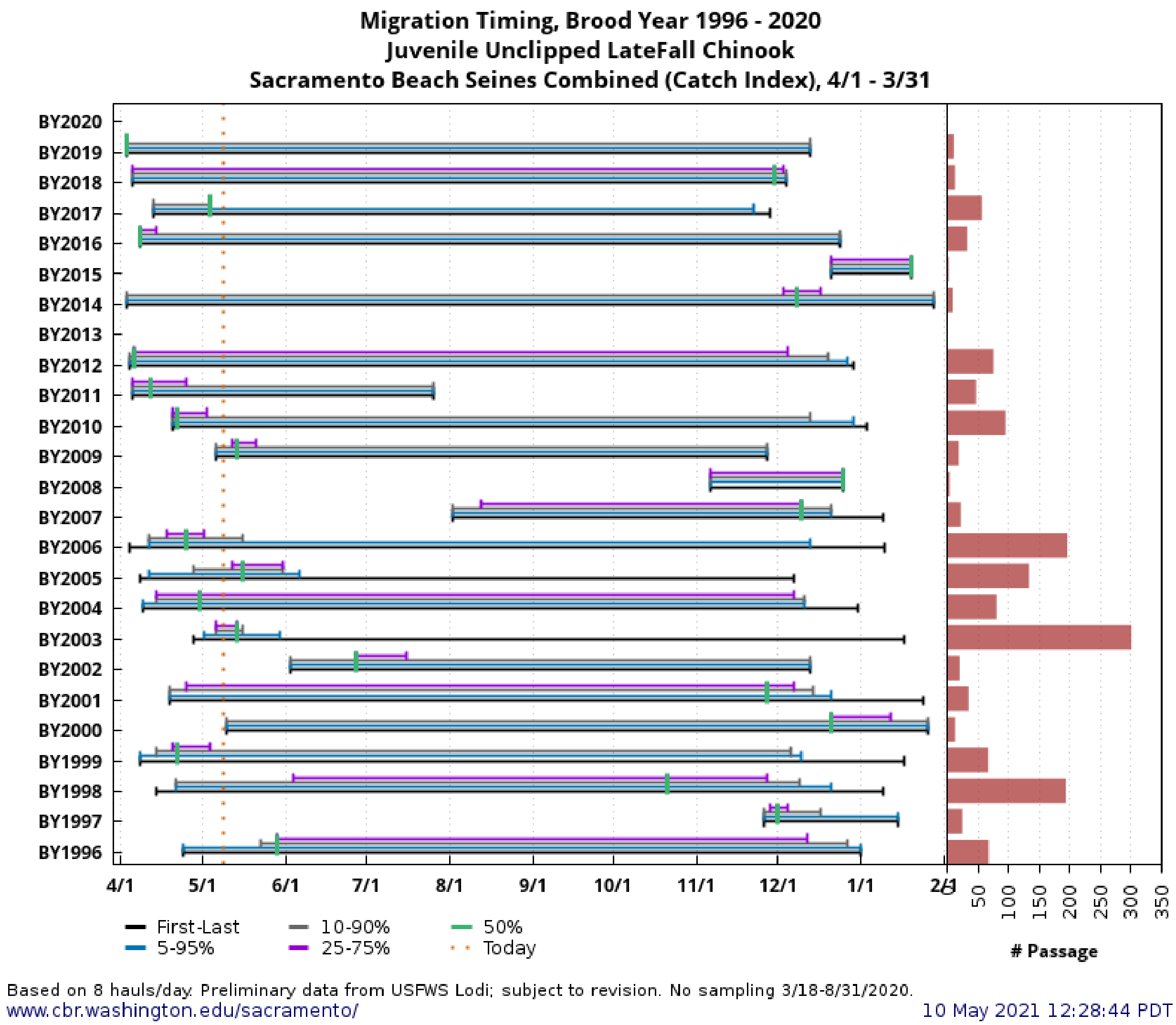


Figure 11A-Att1-31. Catch Index Timing and Number of Juvenile Late Fall-Run Chinook Salmon in Sacramento Beach Seines.

1.5.5 Late Fall-Run Chinook Salmon: Sacramento Trawls (Sherwood Harbor)

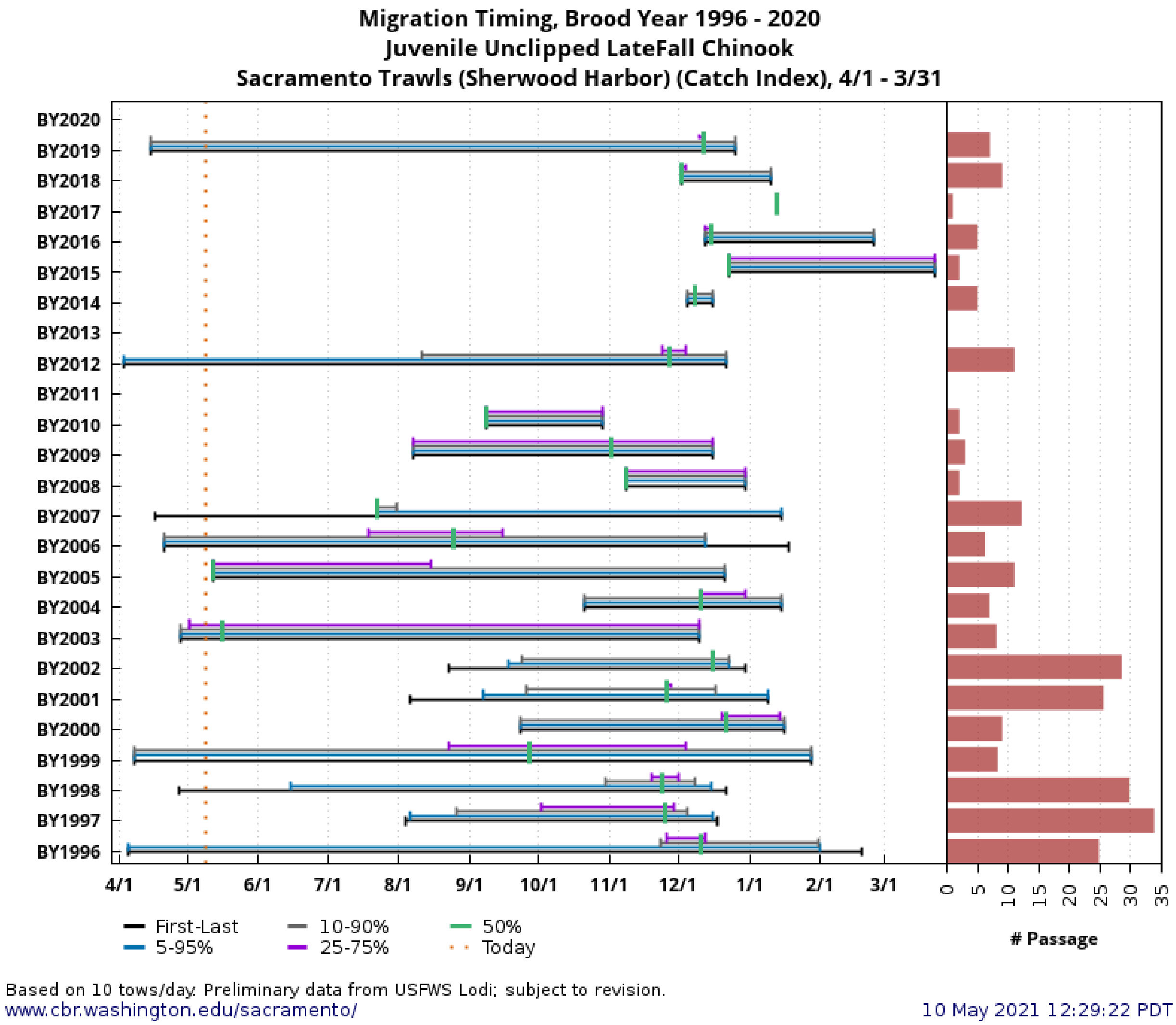


Figure 11A-Att1-32. Catch Index Timing and Number of Juvenile Late Fall-Run Chinook Salmon in Sacramento Trawls at Sherwood Harbor.

1.5.6 Late Fall-Run Chinook Salmon: Chipps Island Trawls

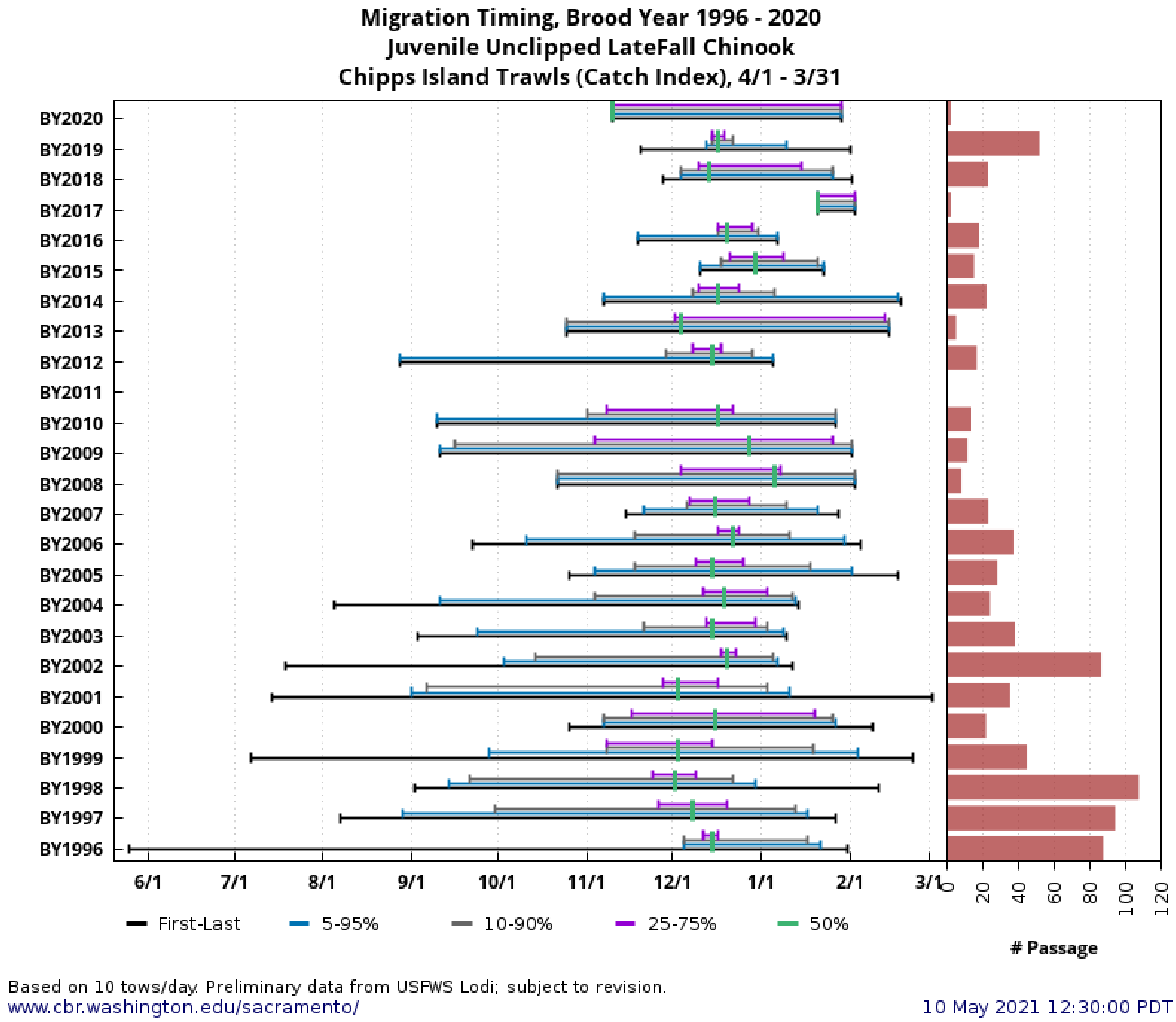


Figure 11A-Att1-33. Catch Index Timing and Number of Juvenile Late Fall-Run Chinook Salmon in Chipps Island Trawls.

1.5.7 Late Fall-Run Chinook Salmon Salvage: Unclipped (Length-at-Date)

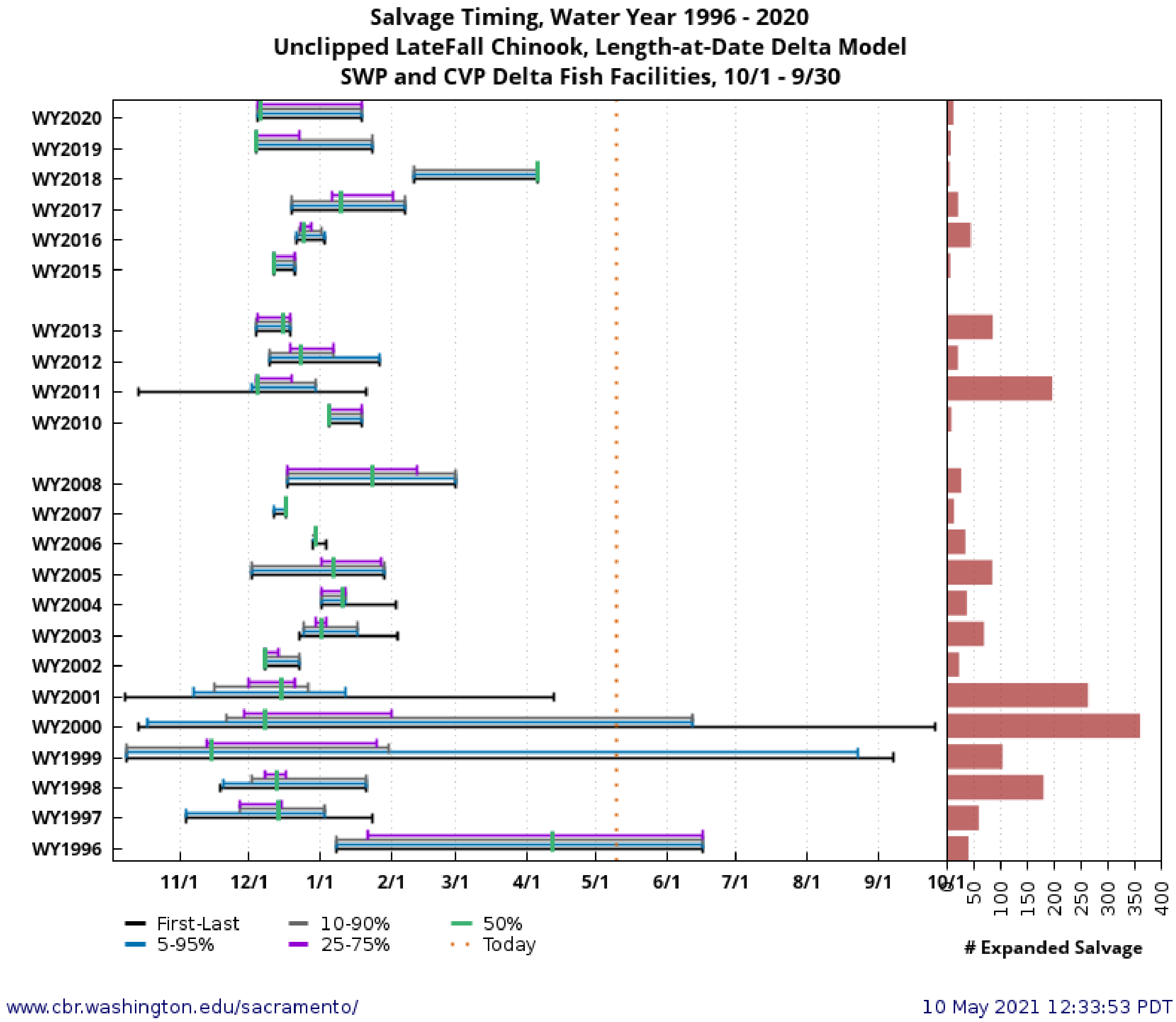


Figure 11A-Att1-34. Timing and Number of Unclipped Juvenile Late Fall-Run Chinook Salmon (Race Determined from Length at Date) at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.

1.5.8 Late Fall-Run Chinook Salmon Salvage: Clipped (Length-at-Date)

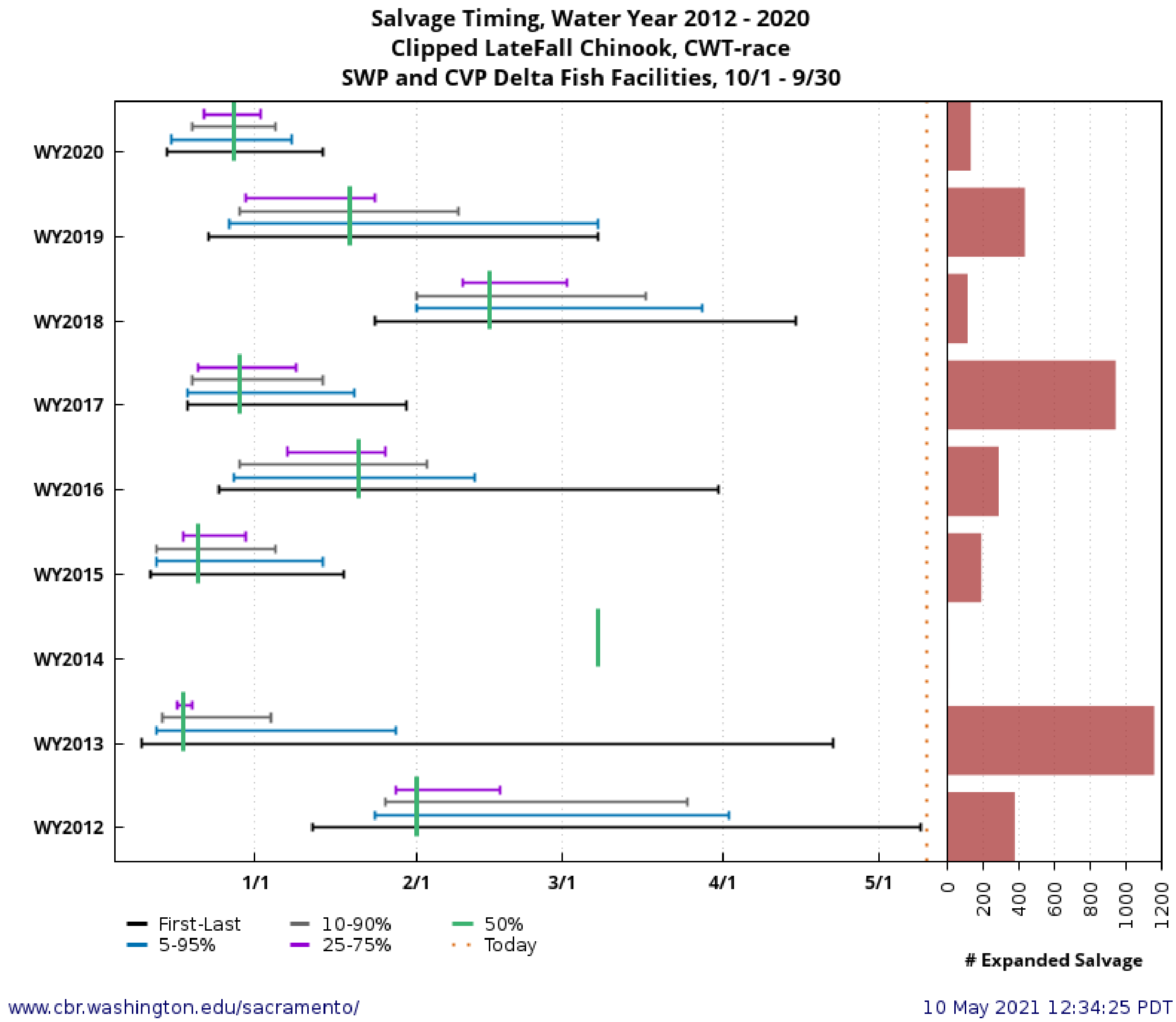


Figure 11A-Att1-35. Timing and Number of Clipped Juvenile Late Fall-Run Chinook Salmon (Race Determined from Length at Date) at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.

1.5.9 Late Fall-Run Chinook Salmon Salvage: Clipped (CWT-Race)

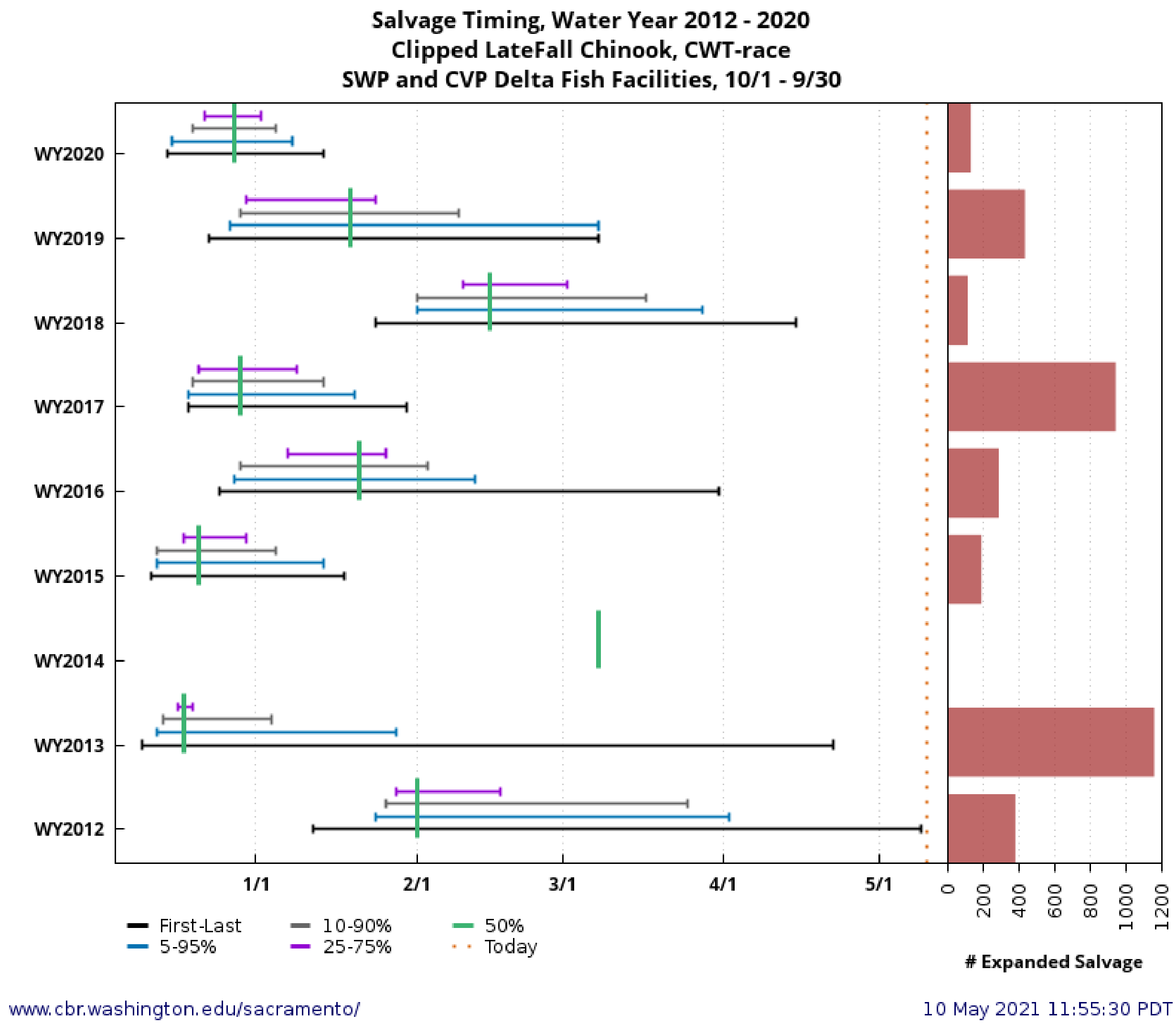


Figure 11A-Att1-36. Timing and Number of Clipped Late Fall-Run Juvenile Chinook Salmon (Race Determined from Coded Wire Tag) at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.

1.6 Steelhead

1.6.1 Steelhead: Red Bluff Diversion Dam Rotary Screw Traps

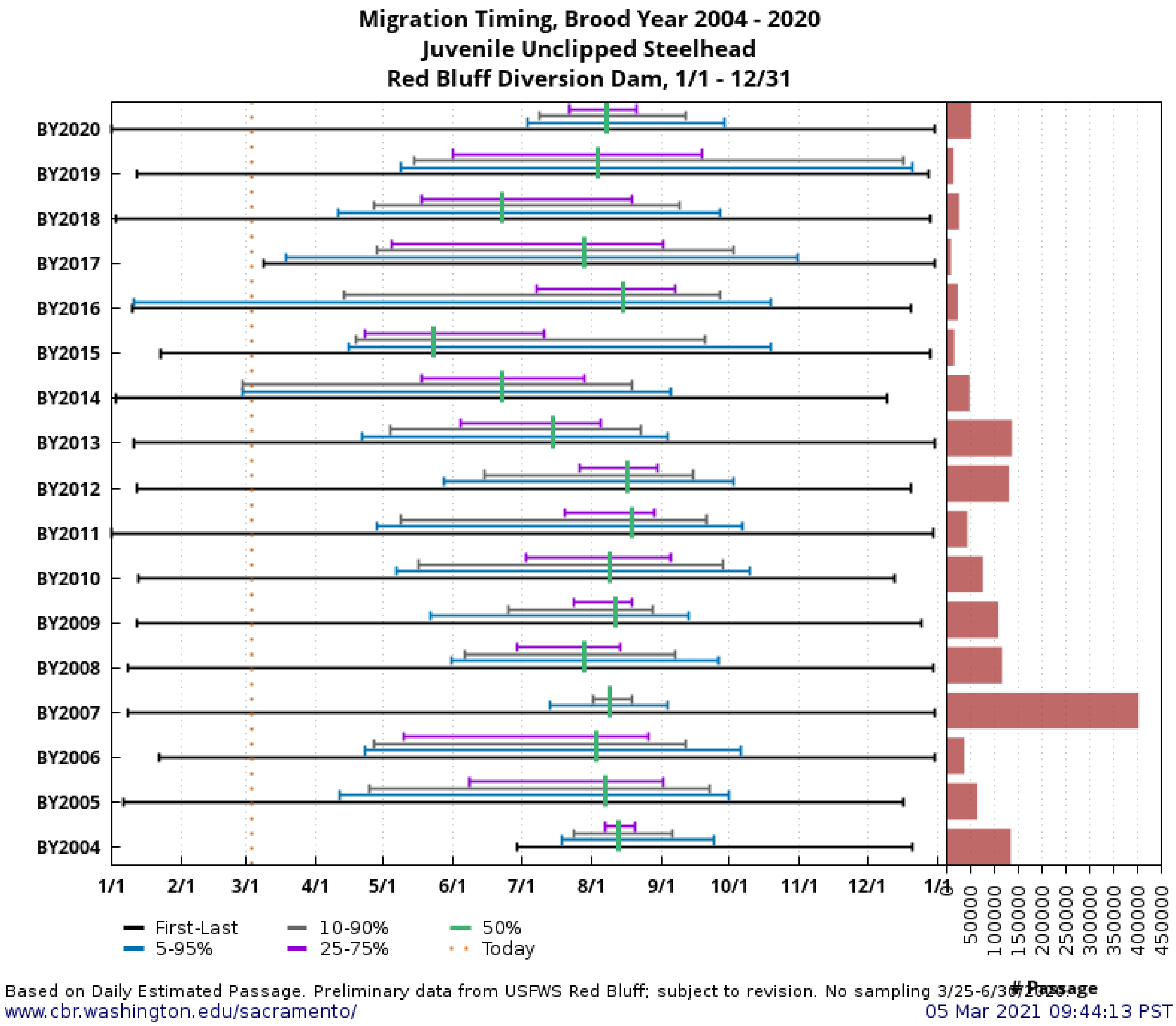


Figure 11A-Att1-37. Timing and Number of Juvenile Steelhead in Red Bluff Diversion Dam Rotary Screw Traps.

1.6.2 Steelhead: Tisdale Weir Rotary Screw Traps

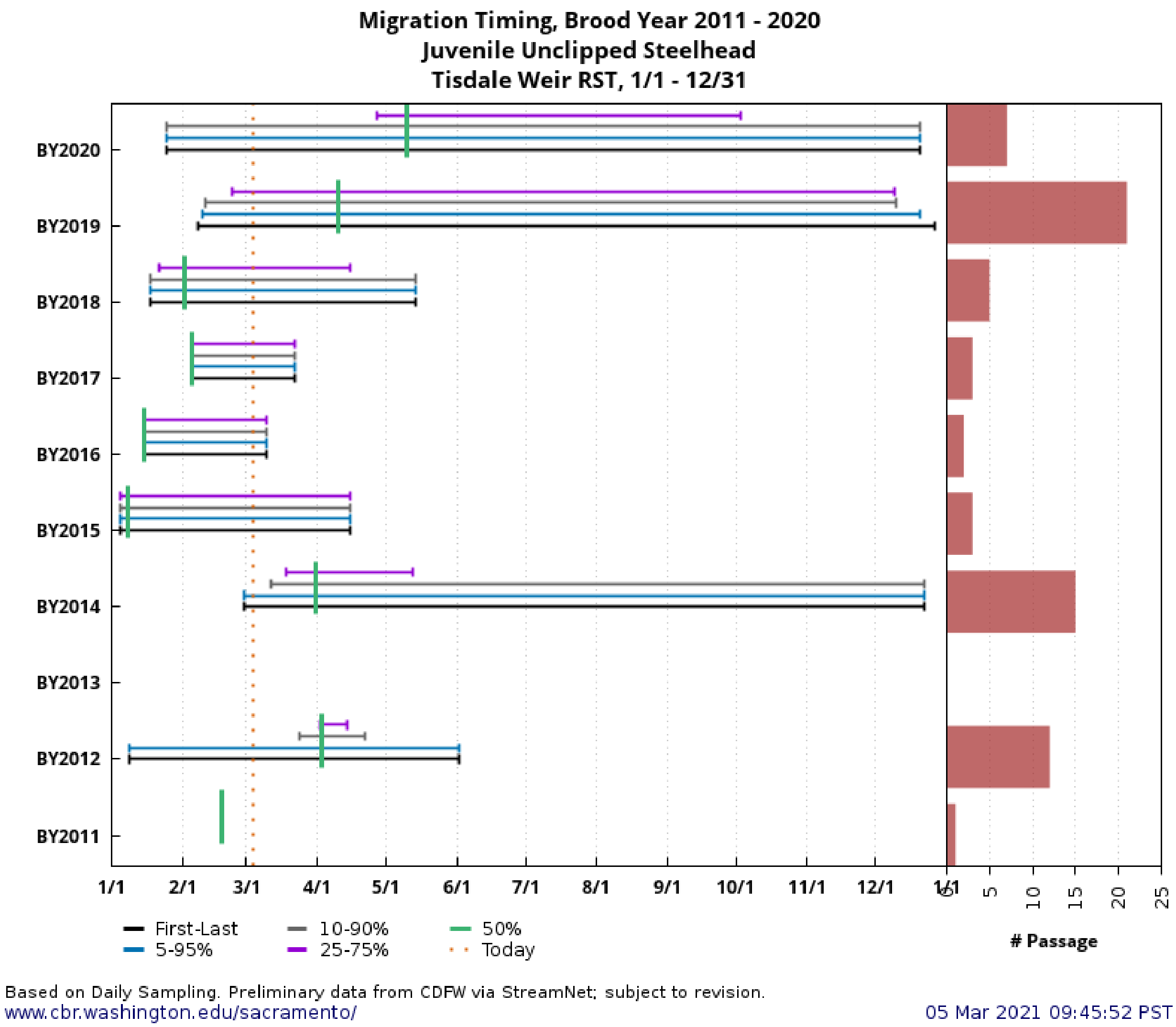


Figure 11A-Att1-38. Timing and Number of Juvenile Steelhead in Tisdale Weir Rotary Screw Traps.

1.6.3 Steelhead: Knights Landing Rotary Screw Traps

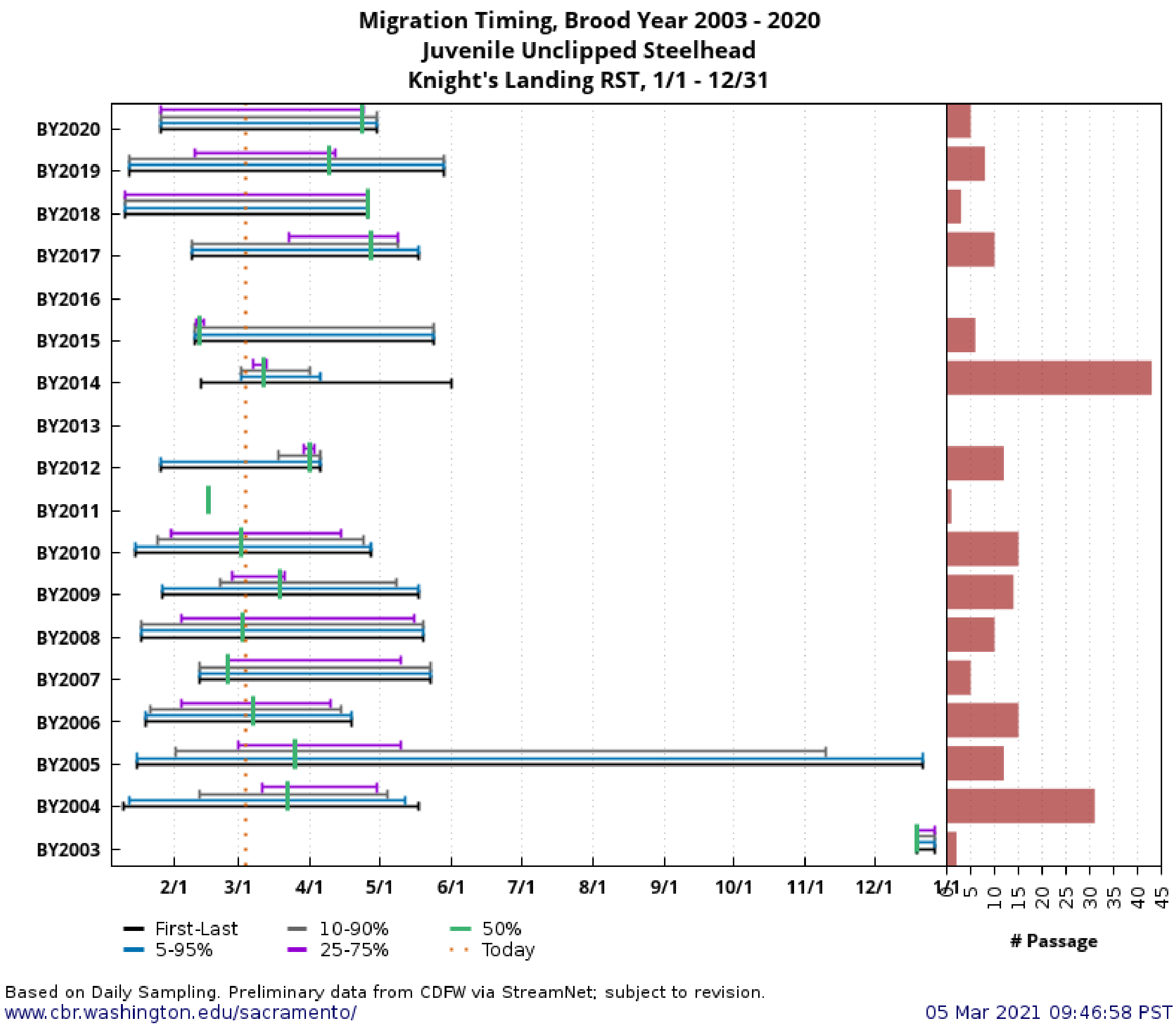


Figure 11A-Att1-39. Timing and Number of Juvenile Steelhead in Knights Landing Rotary Screw Traps.

1.6.4 Steelhead: Sacramento Beach Seines Combined

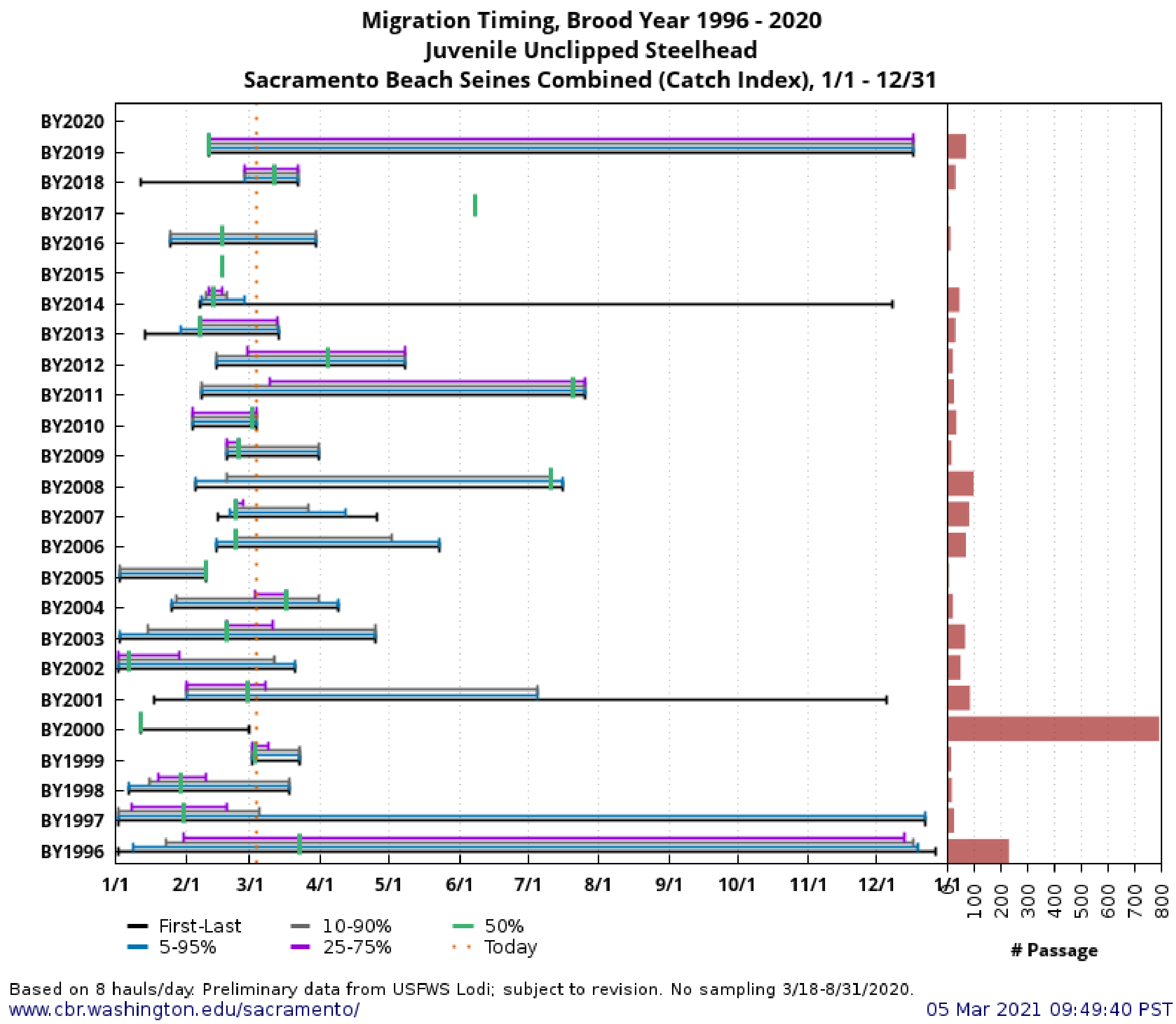


Figure 11A-Att1-40. Catch Index Timing and Number of Juvenile Steelhead in Sacramento Beach Seines.

1.6.5 Steelhead: Sacramento Trawls (Sherwood Harbor)

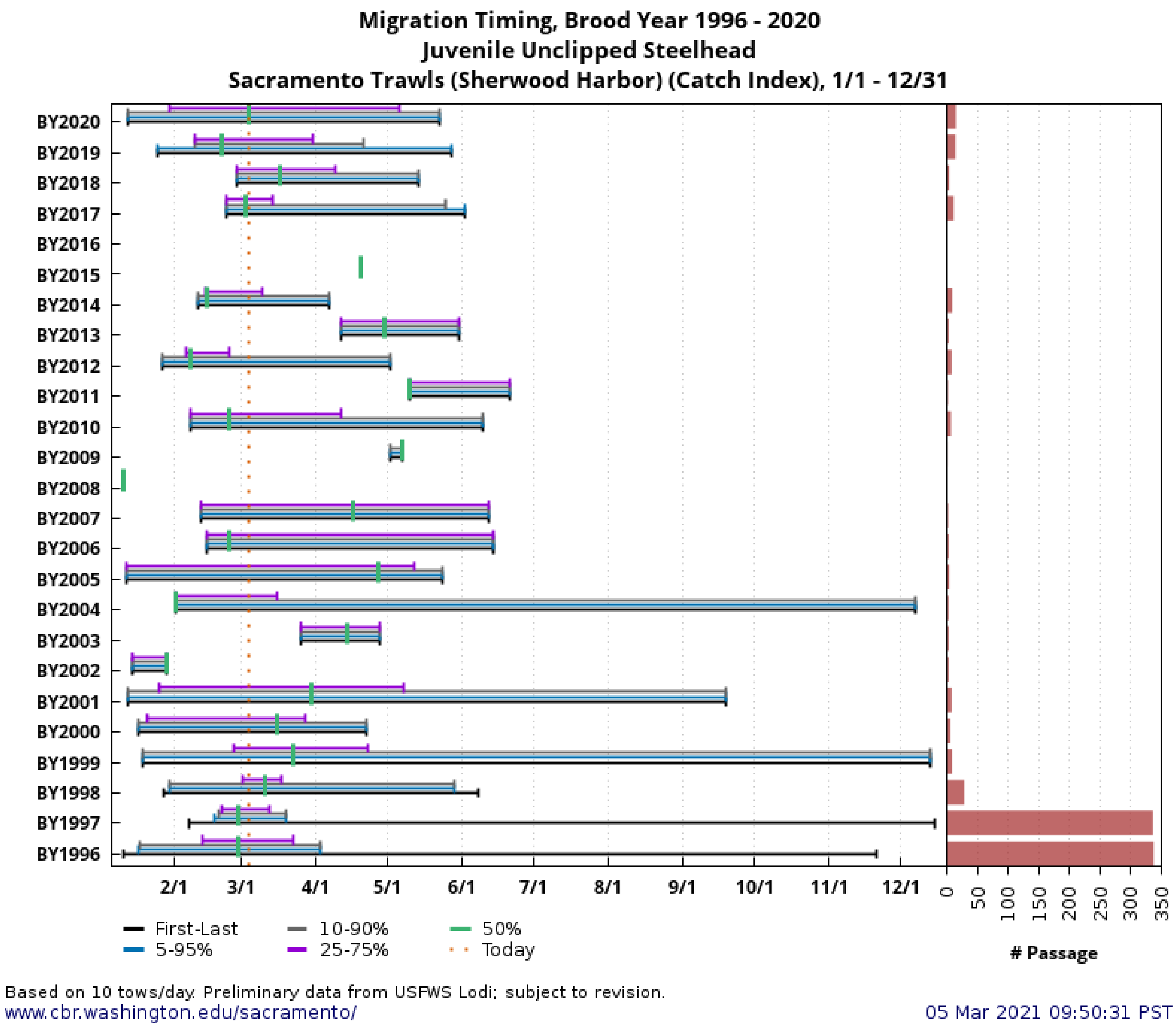


Figure 11A-Att1-41. Catch Index Timing and Number of Juvenile Steelhead in Sacramento Trawls at Sherwood Harbor.

1.6.6 Steelhead: Chipps Island Trawls

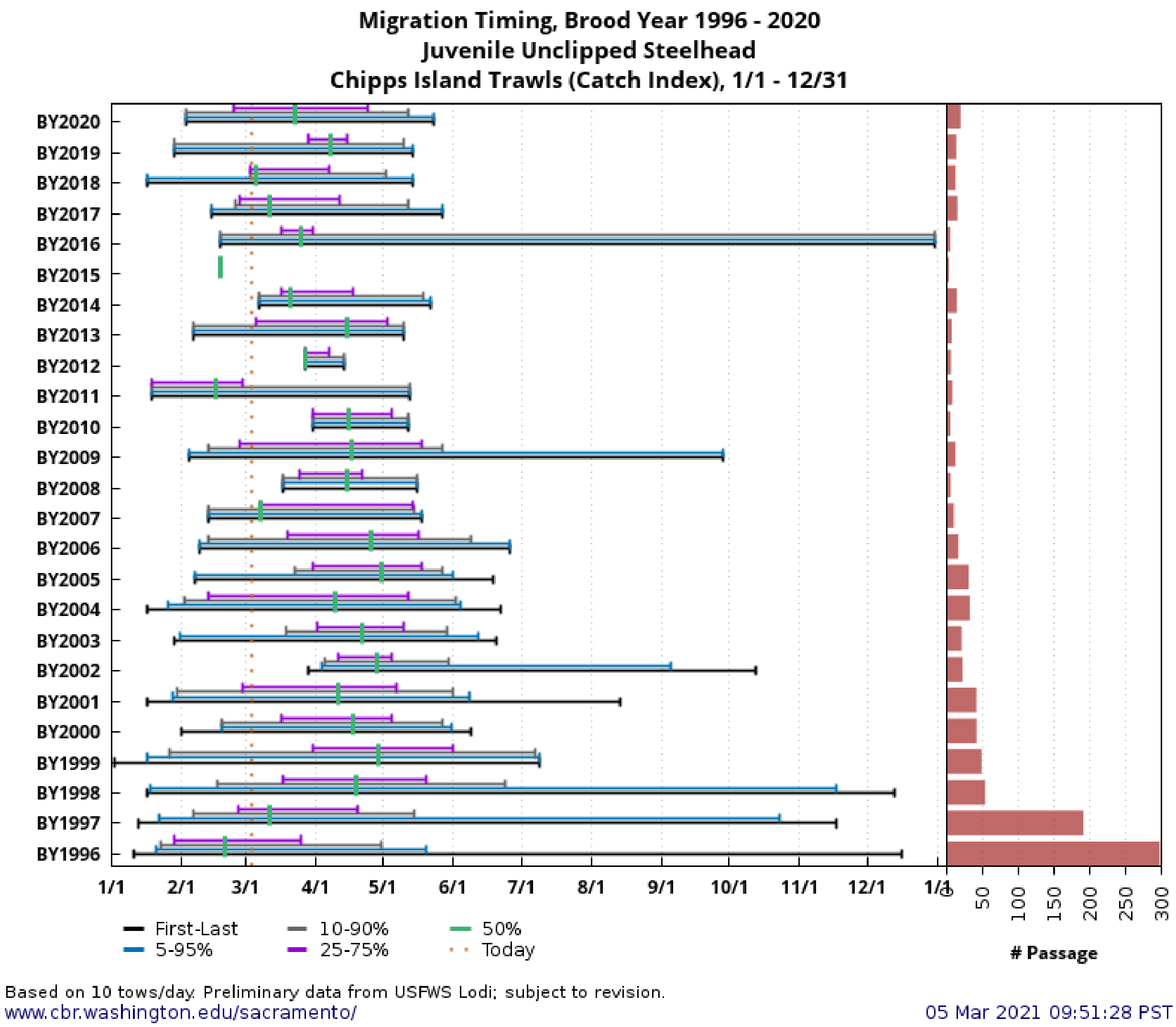


Figure 11A-Att1-42. Catch Index Timing and Number of Juvenile Steelhead in Chipps Island Trawls.

1.6.7 Steelhead Salvage: Unclipped

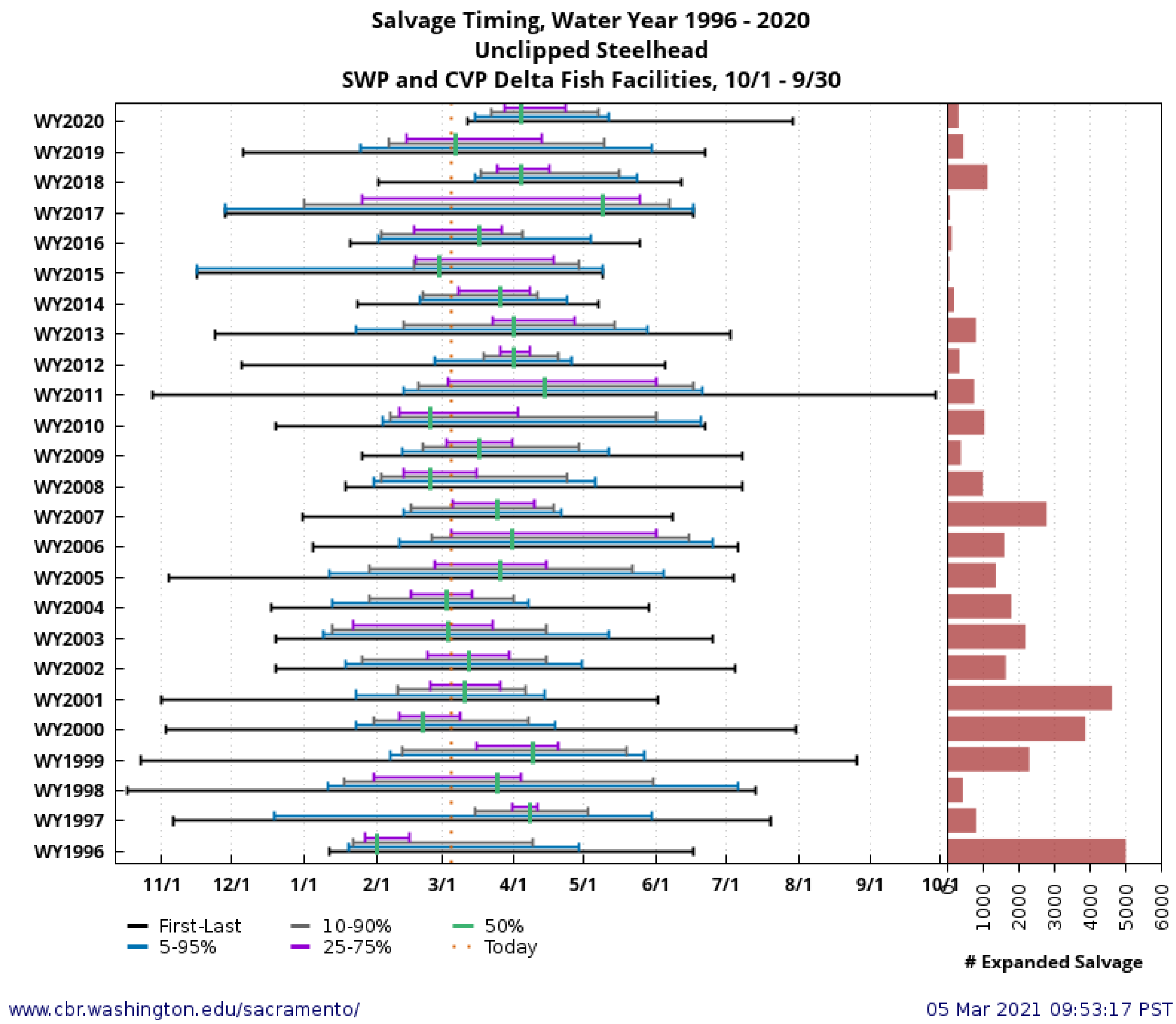


Figure 11A-Att1-43. Timing and Number of Unclipped Juvenile Steelhead at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.

1.6.8 Steelhead Salvage: Clipped

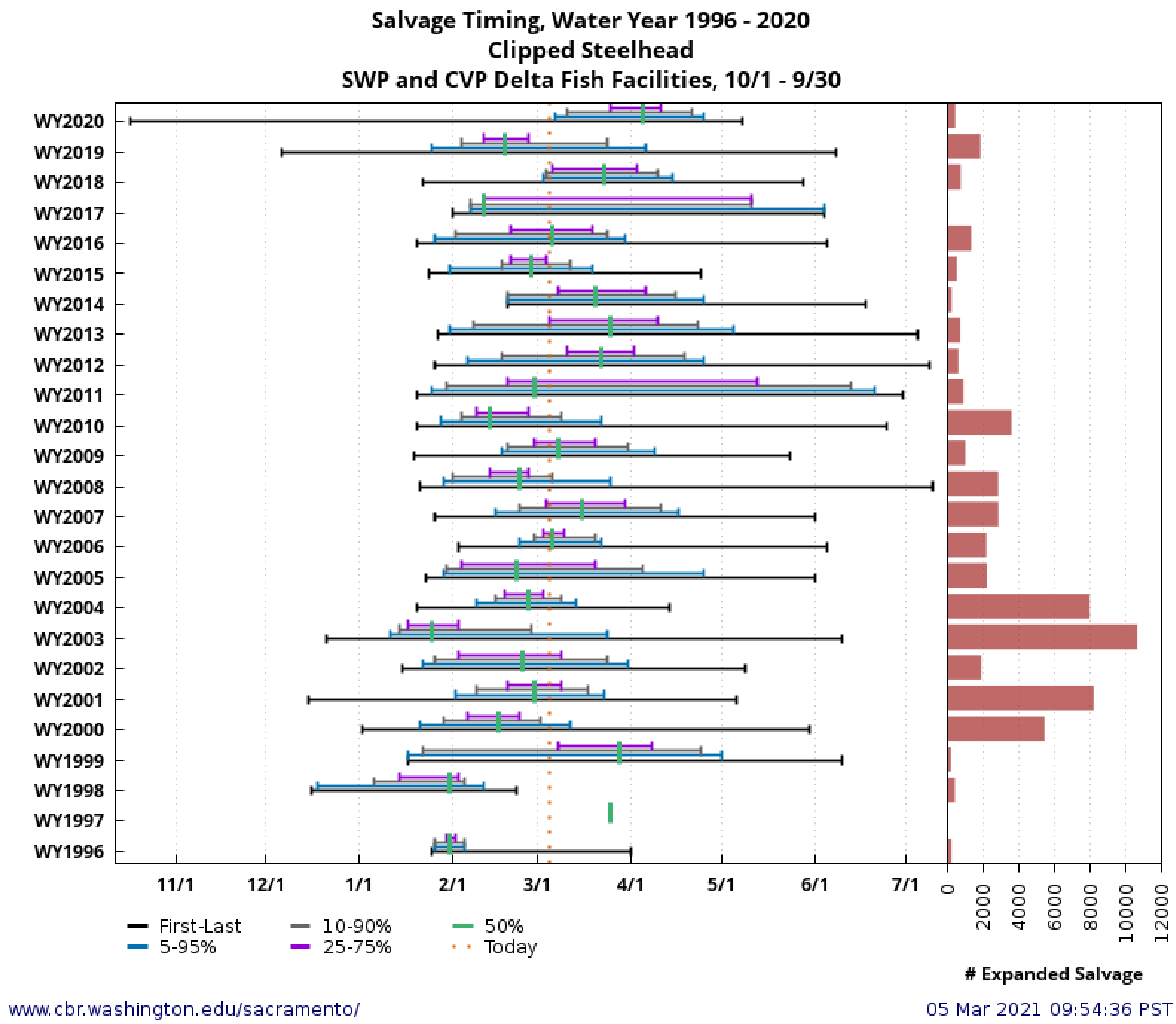


Figure 11A-Att1-44. Timing and Number of Clipped Juvenile Steelhead at the State Water Project and Central Valley Project South Delta Fish Salvage Facilities.