Long-Term Operation – Biological Assessment

Appendix AB-C – Species Spatial-Temporal Domains

July 2024

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Appendix C Species Spatial-Temporal Domains

C.1 Introduction

This document describes the presence of listed species by life stage and geographic region to inform whether individuals may experience stressors that require evaluation due to the Long-Term Operation of the Central Valley Project (CVP) and State Water Project (SWP). Sources of data in existing species timing tables were reviewed or aggregated to evaluate each species in different locations.

Variability in the timing of species present requires consideration of a broader window than conditions on average or in any single year. For example, if fish may start migrating as early as November or as late as January, then the analyses considered the migration as potentially starting in November so that the potential stressors would be evaluated. Differences in abundance were categorized, as described below, with approximate percentages based on the National Marine Fisheries Service (NMFS) 2019 Biological Opinion (National Marine Fisheries Service 2019):

- Low – no specific consideration of stressors: ~1% of the population may be present
- Medium – some considerations needed: ~>5% of the population may be present
- High – considerations needed: ~>10% of the population may be present

These analyses inform the risks and potential benefits of calendar-based versus real-time strategies. To illustrate spatiotemporal occurrence, tables in this document are presented in terms of "First" occurrence, percent passing (from the monitoring location), and "Last" occurrence.

Additionally, this document described the observed demographics of listed species by life stage and geographic region to inform life cycle analyses completed during the evaluations of the Long-Term Operation of the CVP and SWP. Sources of species data were reviewed and aggregated to assess long term status and trend and inform comparisons with evaluations under alternatives.

C.2 Winter-Run Chinook Salmon

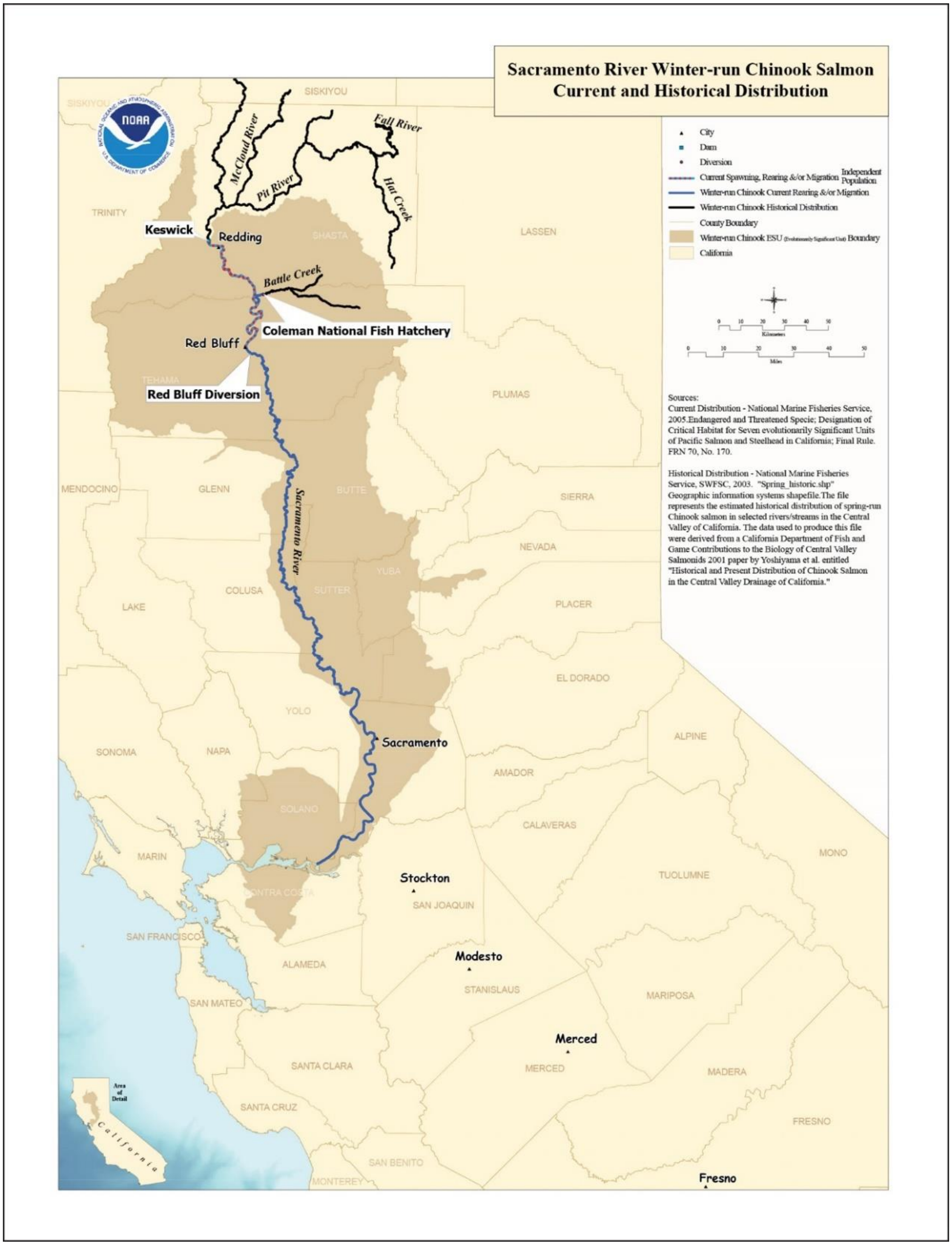
Windell et al. (2017) describes life stages and geographic locations for winter-run Chinook salmon.

During the winter months, adults return from the ocean through San Francisco Bay to the Sacramento River and travel to the extent of their current range, below Keswick Dam (Figure C-1). All known winter-run Chinook salmon production occurs either in the mainstem

Sacramento River or Livingston Stone National Fish Hatchery, 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, and below Keswick Dam during the summer months (National Marine Fisheries Service 2014). Access to historical habitat in upper Sacramento River tributaries is no longer available (Figure C-1). Following spawning, fry and juvenile downstream movement begins in July/August, as shown by monitoring at Red Bluff Diversion Dam (Table C-4). 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 Sacramento–San Joaquin Delta (Delta) before emigrating to the ocean (Phillis et al. 2018).

Summaries of the temporal life-history domains for winter-run Chinook salmon can be found below on Figure C-2.



Source: National Marine Fisheries Service 2014.

Figure C-1. Current and Historical Sacramento River Winter-Run Chinook Salmon Distribution

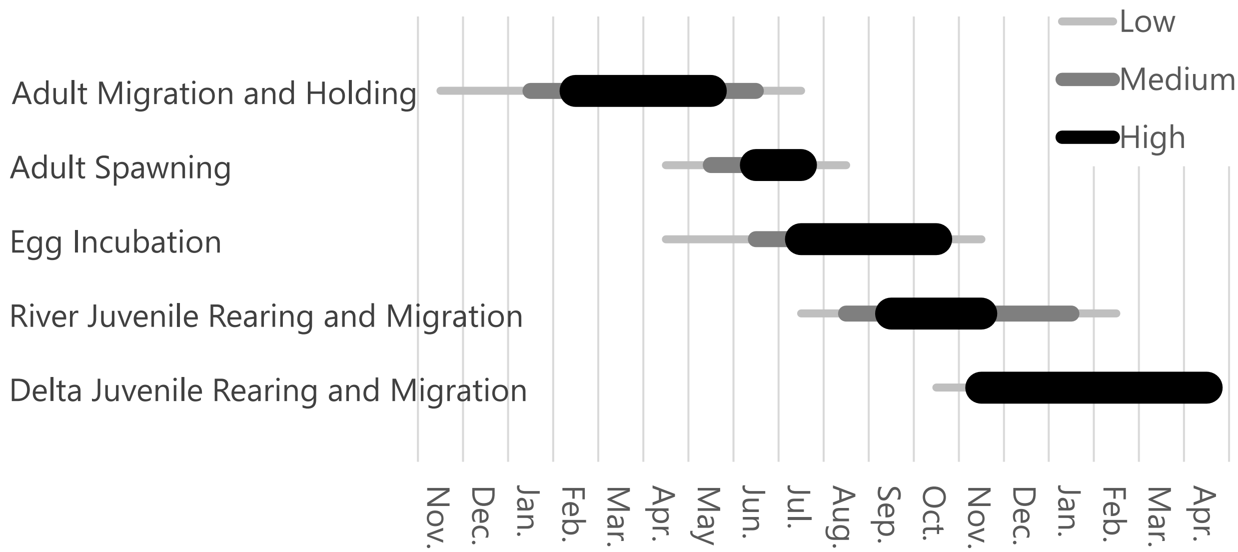


Figure C-2. Summary of Temporal Life Stage Domains for Winter-Run Chinook Salmon

C.2.1 Adult Migration and Holding

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 July to the extent of anadromy at the base of Keswick Dam (Figure C-2). Hallock and Fisher (1985) observed winter-run Chinook salmon adult fish passage at Red Bluff Diversion Dam during November through July. Holding occurs in the upper 10 to 15 river miles of the Sacramento River below Keswick Dam for up to 8 months (Windell et al. 2017; National Marine Fisheries Service 2011; Table C-1). Winter-run Chinook salmon employ a different life-history strategy than fall-run Chinook salmon because they typically enter the system with undeveloped gametes and move into the upper Sacramento River, where they hold until ready to spawn (Windell et al. 2017). Historically, Fisher (1994) and the U.S. Fish and Wildlife Service (USFWS) (U.S. Fish and Wildlife Service 1995) described adult immigration between December and July, with a peak in spawning during March. Fisher (1994) and USFWS (1995) do not cite any data or personal communication; it is assumed this periodicity is based on the timing of adult passage through Red Bluff Diversion Dam.

Table C-1. Summary Winter-Run Chinook Salmon Passage at Red Bluff Diversion Dam, 1982–1986

First	5% Passing	10% Passing	90% Passing	95% Passing
NA	January Week 2	February Week 1	June Week 1	June Week 3

Source: U.S. Fish and Wildlife Service Red Bluff Diversion Dam fish ladder passage.

C.2.2 Adult Spawning and Egg Incubation

Hallock and Fisher (1985) observed winter-run Chinook salmon spawning in the Sacramento River, upstream of Red Bluff Diversion Dam, between mid-April and mid-August, with the bulk of spawning occurring in May and June. Fisher (1994) described spawning between late April and early August, with a peak in spawning activity during early June. USFWS (1995) described spawning occurring between April and July, with peak spawning in May and June. Fisher (1994) and USFWS (1995) do not cite any data or personal communication; it is assumed this periodicity is based on biologist observations of spawning and carcasses. USFWS (2006) summarized 5 years of carcass surveys before Red Bluff Diversion Dam was removed. In some years, peak abundance of hatchery-origin carcasses was delayed, relative to natural-origin carcasses, although the spatial distribution of hatchery and natural-origin carcasses were nearly identical and consistent across years.

The California Department of Fish and Wildlife (CDFW) provides summaries of redd and carcass surveys, which are available on the CalFish website (https://www.calfish.org). Table C-2 shows carcass survey data for winter-run Chinook salmon spawning in the upper Sacramento River between 2004–2020 (CalFish 2020). CDFW biologists estimate that it takes approximately 10–14 days for a carcass to be observed after spawning, so spawning timing is estimated to occur 10–14 days prior to carcass observations (Killam pers. comm.). The first carcass is detected in May, peak spawning occurs throughout June and July, by August 95% of the carcasses have been observed, and the last of the carcasses have been observed in September. Spawning was proxied by the 10–14 day estimate by CDFW biologists, and follows a similar trajectory as the carcass data, but with a slight temporal shift for the 5% passing and 90% passing (Table C-2). USFWS (1995) described winter-run Chinook salmon egg incubation as occurring between April and October, with peak incubation between July and October (Table C-2). Carcass and redd surveys on the upper Sacramento River start in May, so it is likely that spawning occurs in April, before the first survey, along with egg incubation as noted by USFWS (1995). Yoshiyama et al. (1998) described winter-run Chinook salmon juvenile emergence between July and October.

Table C-2. Winter-Run Chinook Salmon Carcass Survey Detections and Median Estimates of Spawning and Incubation Based on Carcass Distributions, 2004–2020

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	May 15	Jun 14	Jun 23	Aug 4	Aug 11	Sep 3
2019	May 13	Jun 9	Jun 15	Aug 2	Aug 8	Sep 1
2018	May 8	Jun 13	Jun 28	Aug 12	Aug 20	Sep 5
2017	May 2	Jun 1	Jun 5	Aug 15	Aug 19	Sep 2
2016	May 4	May 22	Jun 6	Aug 5	Aug 11	Aug 26
2015	May 12	Jun 3	Jun 14	Aug 4	Aug 10	Aug 25
2014	May 17	Jun 12	Jun 21	Aug 5	Aug 8	Aug 20
2013	May 22	Jun 12	Jul 1	Aug 9	Aug 15	Aug 30
2012	May 11	Jun 16	Jun 25	Aug 6	Aug 12	Aug 24

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2011	May 6	Jun 15	Jun 24	Aug 8	Aug 11	Aug 26
2010	May 5	May 22	Jun 3	Jul 28	Aug 3	Aug 21
2009	May 18	Jun 8	Jun 14	Jul 22	Jul 26	Aug 10
2008	May 7	Jun 2	Jun 11	Jul 23	Jul 29	Aug 13
2007	May 8	May 25	Jun 8	Jul 29	Aug 3	Aug 18
2006	May 10	Jun 2	Jun 9	Jul 25	Aug 1	Aug 16
2005	May 15	Jun 10	Jun 17	Aug 1	Aug 6	Aug 22
2004	May 3	Jun 5	Jun 18	Jul 30	Aug 5	Aug 20
Carcass Median	May	June	June	August	August	August
Spawning Median	May	May	June	July	August	August
Incubation Median	April	June	July	October	October	October

Source: CalFish 2020.

Winter-run emerge from the gravel 9 to 10 weeks after spawning depending upon water temperatures during incubation.

C.2.3 River Juvenile Rearing and Migration

Winter-run Chinook salmon juvenile rearing and migration can be described based on observations in the upper Sacramento River at the Red Bluff Diversion Dam rotary screw trap and in the lower Sacramento River at the Knights Landing rotary screw trap. Hallock and Fisher (1985) observed fry migration past Red Bluff Diversion Dam in early August and continuing through October. The peak was reported between mid-September to mid-October. Fisher (1994) described juvenile emergence between July and October and ocean entry between November and May. USFWS (1995) describe winter-run Chinook salmon rearing in freshwater between July and May, with smolt emigration from January through May. Martin et al. (2001) summarized Red Bluff Diversion Dam rotary screw trap total passage and found that winter-run Chinook salmon fry were predominantly captured in July through October, which aligns with recent catch data available in the Sacramento Prediction and Assessment of Salmon (SacPAS) online database (Table C-4). According to Martin et al. (2001), fry passage through August was observed to be low, with most fry passing by September, and all passing by November. Pre-smolt/smolt winter-run Chinook salmon passage was greatest in November. The data available on SacPAS combine all juvenile stages and shows the last passage in June, and the median last passage in May (Figure C-3, Table C-3 and Table C-4). At Knights Landing, first passage occurs in October, peaks in December and January, and ends by April (Figure C-4, Table C-5, and Table C-3).

In addition to the mainstem Sacramento River, juvenile winter-run Chinook salmon have also been found to rear in Sacramento River tributaries, such as the lower American River, Battle Creek, and in the Delta (Phillis et al. 2018). The population of winter-run Chinook salmon in

Battle Creek varied between 127 and 942 fish in the last three years (Dec 2019 – Aug 2022; June 2023 GrandTab, available on https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=84381). Lower American River catch data is readily available through the Pacific States Marine Fisheries Commission (PSMFC) on http://CalFish.org. At the rotary screw traps located near the Watt Ave Bridge, PSMFC reports small numbers of winter-run Chinook salmon passage, suggesting use of the area as rearing habitat. All Chinook salmon are assigned a run at the time of capture, using length-at-date criteria for the Sacramento River that Greene (1992; PSMFC 2013–2022) developed. Detections start in January and end in March, with 90% of juvenile passage by March (Table C-6).

Table C-3. Summary of Juvenile Winter-Run Chinook Salmon Passage in the Sacramento River by Median Month from USFWS Raw Catch Data, 2003–2021

Station	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
RBDD	July	August	September	November	December	May
KNL	October	October	October	January	February	April

Source: University of Washington, School of Aquatic and Fishery Science 2022.
RBDD = Red Bluff Diversion Dam; KNL = Knights Landing

Table C-4. Red Bluff Diversion Dam Rotary Screw Trap Winter-Run Chinook Salmon Juvenile Passage, 2004–2021

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2021	Jul 2	Aug 27	Sept 6	Nov 7	Nov 12	May 25
2020	Jul 5	Sep 6	Sep 13	Nov 23	Dec 28	Apr 28
2019	Jul 6	Aug 23	Aug 29	Nov 3	Nov 28	Mar 23
2018	Jul 18	Sep 14	Sep 22	Dec 1	Dec 2	May 15
2017	Jul 12	Aug 28	Sep 9	Nov 19	Jan 20	May 1
2016	Jul 2	Aug 24	Sep 1	Nov 2	Nov 22	Apr 3
2015	Jul 6	Sep 4	Sep 11	Dec 11	Dec 15	Apr 28
2014	Jul 7	Aug 27	Aug 30	Nov 19	Dec 2	May 21
2013	Jul 9	Sep 9	Sep 16	Dec 28	Feb 10	May 8
2012	Jul 16	Sep 11	Sep 17	Nov 22	Dec 13	May 4
2011	Aug 3	Sep 15	Sep 19	Dec 1	Dec 13	Apr 18
2010	Jul 13	Aug 27	Sep 5	Nov 16	Dec 13	Apr 27
2009	Jul 6	Aug 20	Aug 25	Oct 17	Oct 20	May 4
2008	Jul 15	Aug 22	Aug 24	Nov 4	Dec 3	May 14
2007	Jul 17	Aug 21	Sep 3	Nov 20	Dec 8	Apr 20
2006	Jul 4	Aug 19	Aug 26	Nov 15	Dec 2	Jun 7
2005	Jul 11	Sep 3	Sep 9	Oct 21	Nov 8	Apr 22

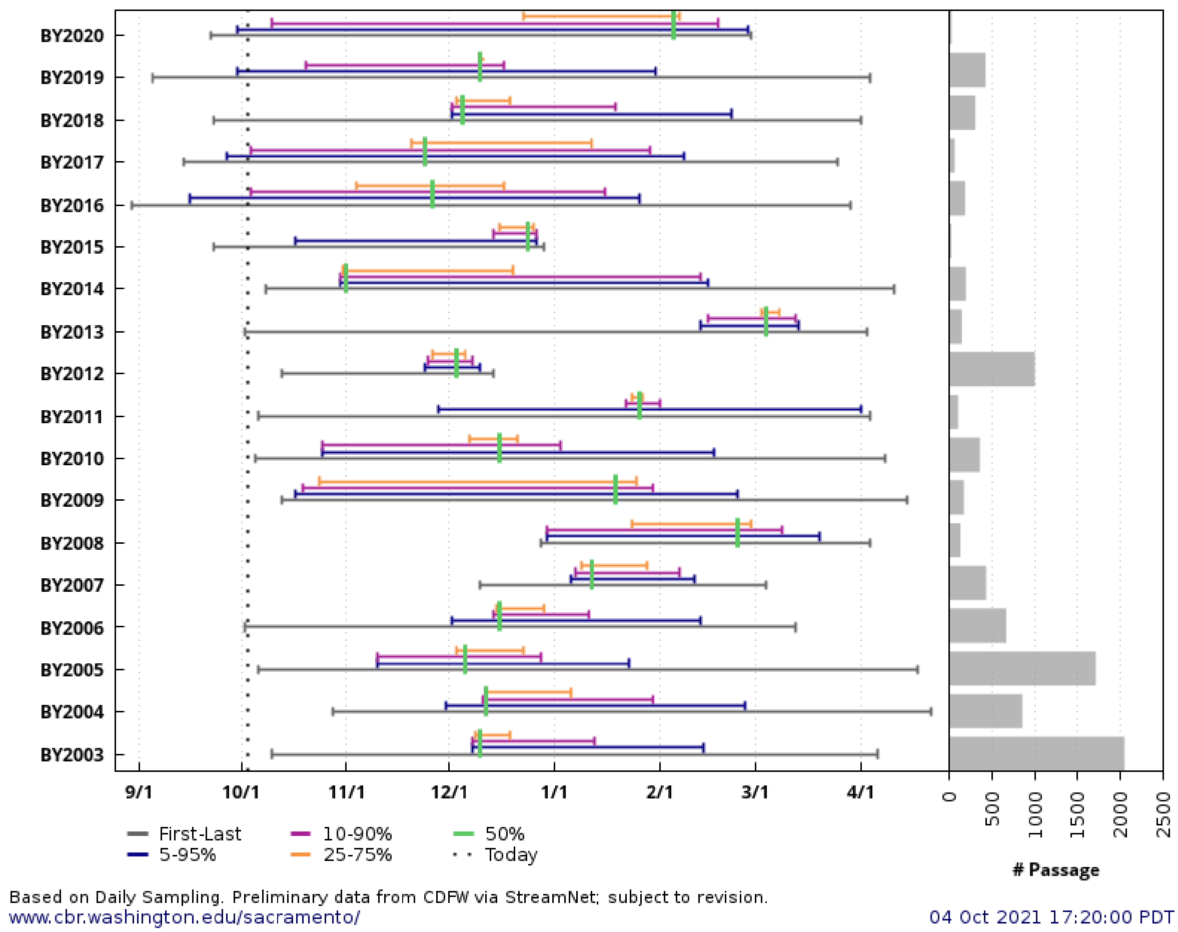
Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2004	Jul 10	Aug 23	Sep 1	Oct 21	Oct 31	May 11
Median	July	August	September	November	December	May

Source: University of Washington, School of Aquatic and Fishery Science 2022

Table C-5. Winter-Run Chinook Salmon Migration Timing Passing Knights Landing, 2003–2020

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	Sep 21	Sep 29	Oct 9	Feb 17	Feb 26	Feb 27
2019	Sep 5	Sep 30	Oct 20	Dec 17	Jan 30	Apr 2
2018	Sep 23	Dec 2	Dec 2	Jan 18	Feb 21	Mar 31
2017	Sep 14	Sep 27	Oct 4	Jan 28	Feb 7	Mar 24
2016	Aug 29	Sep 15	Oct 3	Jan 15	Jan 25	Mar 28
2015	Sep 23	Oct 17	Dec 14	Dec 27	Dec 27	Dec 29
2014	Oct 8	Oct 30	Oct 30	Feb 12	Feb 14	Apr 10
2013	Oct 2	Feb 12	Feb 14	Mar 12	Mar 13	Apr 2
2012	Oct 12	Nov 23	Nov 24	Dec 7	Dec 9	Dec 13
2011	Oct 6	Nov 28	Jan 21	Jan 31	Mar 30	Apr 2
2010	Oct 5	Oct 25	Oct 25	Jan 2	Feb 16	Apr 7
2009	Oct 13	Oct 17	Oct 19	Jan 29	Feb 23	Apr 14
2008	Dec 27	Dec 29	Dec 29	Mar 8	Mar 19	Apr 3
2007	Dec 10	Jan 5	Jan 6	Feb 6	Feb 10	Mar 2
2006	Oct 2	Dec 2	Dec 14	Jan 10	Feb 12	Mar 12
2005	Oct 6	Nov 10	Nov 10	Dec 28	Jan 22	Apr 17
2004	Oct 27	Nov 29	Dec 10	Jan 29	Feb 25	Apr 21
Median Month	October	October	October	January	February	April

Source: University of Washington, School of Aquatic and Fishery Science 2022.



Source: University of Washington, School of Aquatic and Fishery Science 2022.

Figure C-3. Winter-Run Chinook Salmon Migration Timing Passing Knights Landing, 2003–2020

Table C-6. Summary of Juvenile Winter-Run Chinook Salmons Catch, Passage in the Lower American River Screw Trap, 2013–2021

Observation Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2022	No winter-run detected at screw trap.					
2021	Feb 4	Feb 4	Feb 4	Mar 26	Mar 26	Mar 26
2020	Jan 16	Jan 31	Feb 3	Mar 21	Mar 23	Mar 26
2019	Jan 14	Jan 14	Jan 14	Jan 31	Feb 1	Feb 1
2018	Jan 15	Jan 15	Jan 16	Mar 5	Mar 13	Mar 13
2017	No winter-run detected at screw trap.					
2016	One winter-run detected March 3, 2016.					

Observation Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2015	Jan 11	Jan 14	Jan 16	Mar 2	Mar 8	Mar 26
2014	Feb 17	Feb 17	Feb 17	Mar 16	Apr 8	Apr 8
2013	Jan 26	Jan 28	Jan 30	Mar 28	Mar 28	Mar 30
Median Month	January	January	January	March	March	March

Source: CalFish 2022a.

C.2.4 Delta Juvenile Rearing and Migration

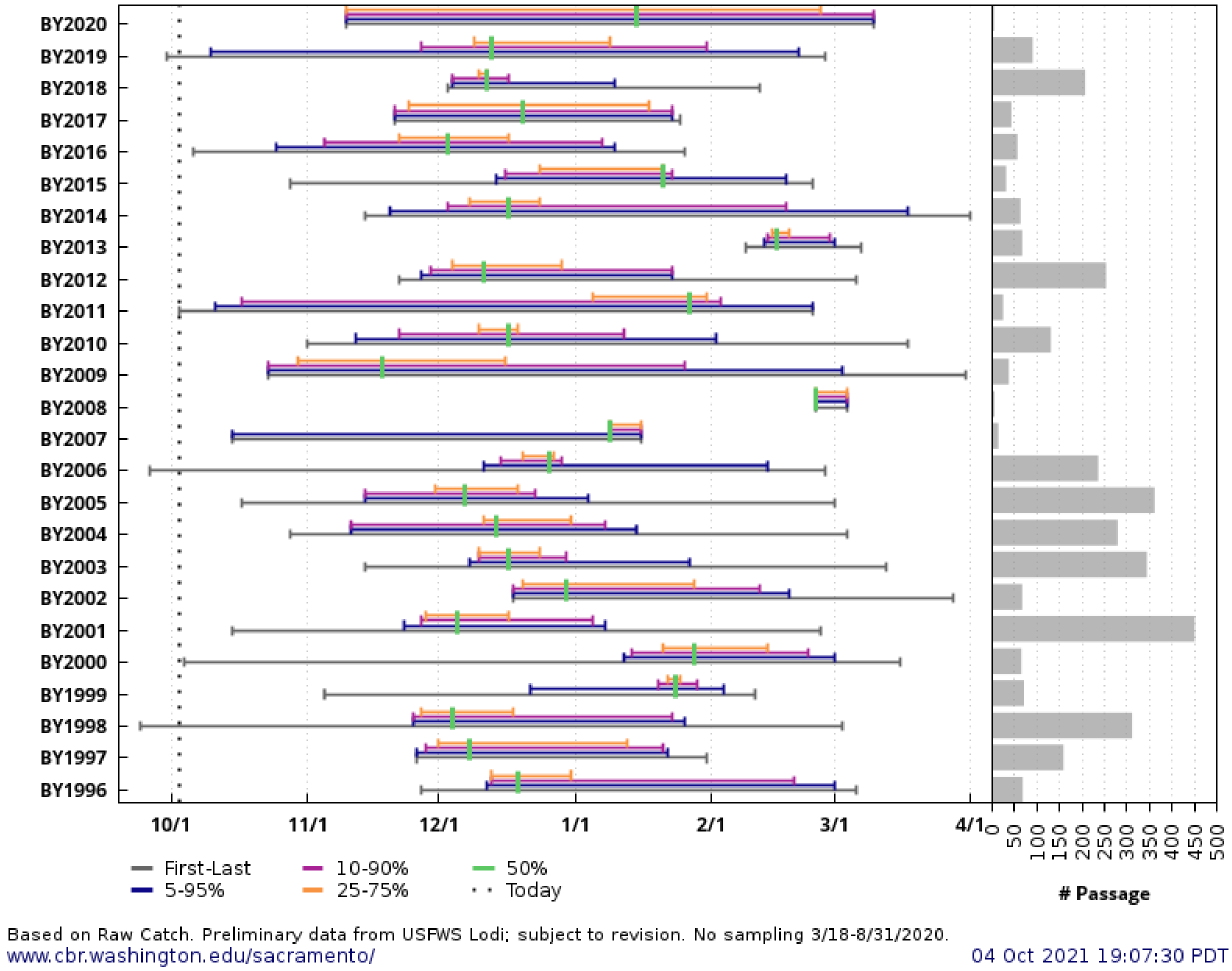
The lower reaches of the Sacramento River, the Delta, and San Francisco Bay serve as migration corridors for both smolts and adults and are thought to serve as juvenile rearing habitat. Juvenile winter-run Chinook salmon begin to enter the Delta in October, and smolt outmigration continues until April. 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; Hassrick et al. 2022). In addition to monitoring salvage of winter-run Chinook salmon at the Tracy Fish Collection Facility and the John E. Skinner Delta Fish Protective 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 Golden Gate Bridge (e.g., Klimley et al. 2017). USFWS-conducted long-term fish monitoring surveys provide observations of when juvenile winter-run Chinook salmon enter and exit the Delta. Entrance can be inferred from data collected by the Sacramento Beach Seine and Trawl surveys, and Delta exit can be inferred from data collected by the Chipps Island trawl survey. Catch data are compiled on the SacPAS database. Based on catch data from USFWS, passage in the Delta starts in October, peaks in December through April, and individuals exit the Delta by May (Table C-7 through Table C-10, Figure C-5 through Figure C-7). Salvage data from the CVP facilities show a similar temporal pattern as the Chipps Island trawl, with the first occurrence in December and last occurrence in May (Table C-11 and Figure C-8).

Table C-7. Summary of Juvenile Winter-Run Chinook Passage in the Delta by Median Month from USFWS Raw Catch, 1996–2020

Station	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
Sacramento Seine	October	October	November	February	February	March
Sacramento Trawl	November	November	December	April	April	April
Chipps Trawl	December	February	February	April	April	May

USFWS = U.S. Fish and Wildlife Service.

C.2.4.1 Delta – Sacramento Beach Seines



Source: University of Washington, School of Aquatic and Fishery Science 2022.

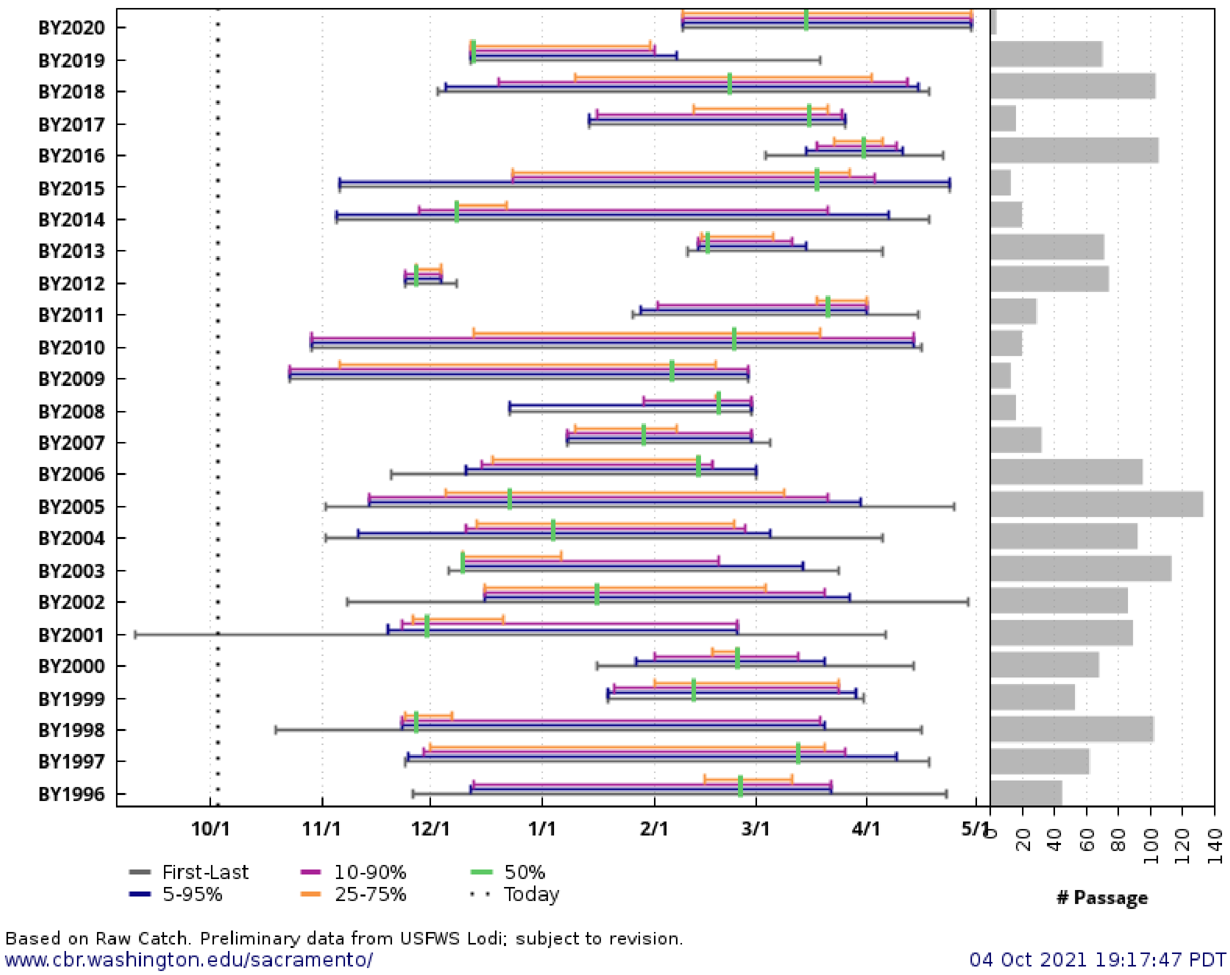
Figure C-4. Winter-Run Chinook Juvenile Migrating Timing, Sacramento Beach Seines, 1996–2020

Table C-8. Winter-Run Chinook Salmon Juvenile Migrating Timing, Sacramento Beach Seines, 1996–2020

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	Nov 9	Nov 9	Nov 9	Mar 9	Mar 9	Mar 9
2019	Sep 30	Oct 10	Nov 27	Jan 30	Feb 20	Feb 26
2018	Dec 3	Dec 4	Dec 4	Dec 17	Jan 9	Feb 11
2017	Nov 21	Nov 21	Nov 21	Jan 22	Jan 22	Jan 24
2016	Oct 5	Oct 24	Nov 4	Jan 6	Jan 9	Jan 25
2015	Oct 28	Dec 14	Dec 16	Jan 22	Feb 17	Feb 23

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2014	Nov 14	Nov 20	Dec 3	Feb 17	Mar 17	Mar 31
2013	Feb 8	Feb 12	Feb 13	Feb 27	Feb 28	Mar 6
2012	Nov 21	Nov 26	Nov 28	Jan 22	Jan 22	Mar 5
2011	Oct 3	Oct 11	Oct 17	Feb 2	Feb 23	Feb 23
2010	Nov 1	Nov 12	Nov 22	Jan 11	Feb 1	Mar 17
2009	Oct 23	Oct 23	Oct 23	Jan 25	Mar 2	Mar 30
2008	Feb 24	Feb 24	Feb 24	Mar 3	Mar 3	Mar 3
2007	Oct 15	Oct 15	Jan 8	Jan 15	Jan 15	Jan 15
2006	Sep 26	Dec 11	Dec 15	Dec 29	Feb 13	Feb 26
2005	Oct 17	Nov 14	Nov 14	Dec 23	Jan 3	Feb 28
2004	Oct 27	Nov 10	Nov 10	Jan 7	Jan 14	Mar 3
2003	Nov 14	Dec 8	Dec 10	Dec 30	Jan 26	Mar 11
2002	Dec 18	Dec 18	Dec 18	Feb 11	Feb 18	Mar 27
2001	Oct 15	Nov 23	Nov 27	Jan 4	Jan 7	Feb 25
2000	Oct 3	Jan 11	Jan 13	Feb 22	Feb 28	Mar 15
1999	Nov 5	Dec 22	Jan 19	Jan 28	Feb 3	Feb 10
1998	Sep 24	Nov 25	Nov 25	Jan 22	Jan 25	Mar 2
1997	Nov 26	Nov 26	Nov 28	Jan 20	Jan 21	Jan 30
1996	Nov 26	Dec 11	Dec 12	Feb 19	Feb 28	Mar 5
Median Month	October	October	November	February	February	March

Source: University of Washington, School of Aquatic and Fishery Science 2022.



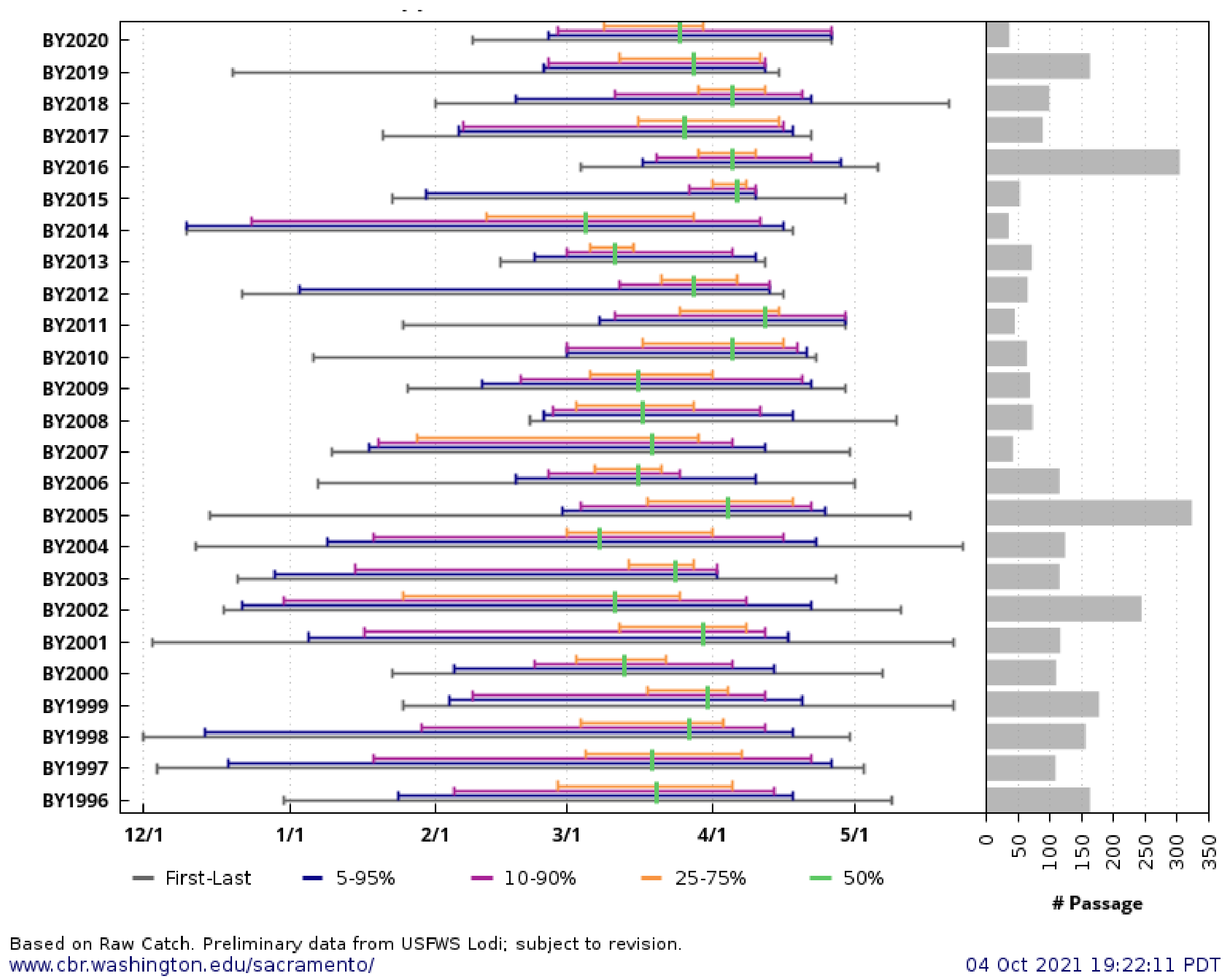
Source: University of Washington, School of Aquatic and Fishery Science 2022.

Figure C-5. Winter-Run Chinook Salmon Juvenile Migrating Timing, Sacramento Trawl at Sherwood Harbor, 1996–2020

Table C-9. Winter-Run Chinook Salmon Juvenile Migrating Timing, Sacramento Trawl at Sherwood Harbor, 1996–2020

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	Feb 8	Feb 8	Feb 8	Apr 29	Apr 29	Apr 29
2019	Dec 12	Dec 12	Dec 12	Jan 31	Feb 6	Mar 17
2018	Dec 3	Dec 5	Dec 20	Apr 11	Apr 14	Apr 17
2017	Jan 13	Jan 13	Jan 15	Mar 24	Mar 25	Mar 25
2016	Mar 3	Mar 14	Mar 17	Apr 8	Apr 10	Apr 21
2015	Nov 6	Nov 6	Dec 24	Apr 1	Apr 22	Apr 22
2014	Nov 5	Nov 5	Nov 28	Mar 20	Apr 6	Apr 17
2013	Feb 9	Feb 12	Feb 12	Mar 10	Mar 14	Apr 4
2012	Nov 23	Nov 23	Nov 23	Dec 3	Dec 3	Dec 7
2011	Jan 25	Jan 27	Feb 1	Mar 30	Mar 30	Apr 13
2010	Oct 29	Oct 29	Oct 29	Apr 13	Apr 13	Apr 15
2009	Oct 23	Oct 23	Oct 23	Feb 26	Feb 26	Feb 26
2008	Dec 22	Dec 22	Jan 28	Feb 27	Feb 27	Feb 27
2007	Jan 7	Jan 7	Jan 7	Feb 27	Feb 27	Mar 3
2006	Nov 20	Dec 11	Dec 15	Feb 16	Feb 28	Feb 28
2005	Nov 2	Nov 14	Nov 14	Mar 20	Mar 29	Apr 24
2004	Nov 1	Nov 10	Dec 10	Feb 25	Mar 4	Apr 4
2003	Dec 6	Dec 10	Dec 10	Feb 18	Mar 12	Mar 22
2002	Nov 8	Dec 16	Dec 16	Mar 19	Mar 26	Apr 28
2001	Sep 10	Nov 19	Nov 23	Feb 23	Feb 23	Apr 5
2000	Jan 15	Jan 26	Jan 31	Mar 12	Mar 19	Apr 13
1999	Jan 18	Jan 18	Jan 20	Mar 22	Mar 27	Mar 29
1998	Oct 19	Nov 23	Nov 23	Mar 18	Mar 19	Apr 15
1997	Nov 24	Nov 25	Nov 29	Mar 25	Apr 8	Apr 17
1996	Nov 25	Dec 11	Dec 12	Mar 21	Mar 21	Apr 22
Median Month	October	November	November	April	April	April

Source: University of Washington, School of Aquatic and Fishery Science 2022.



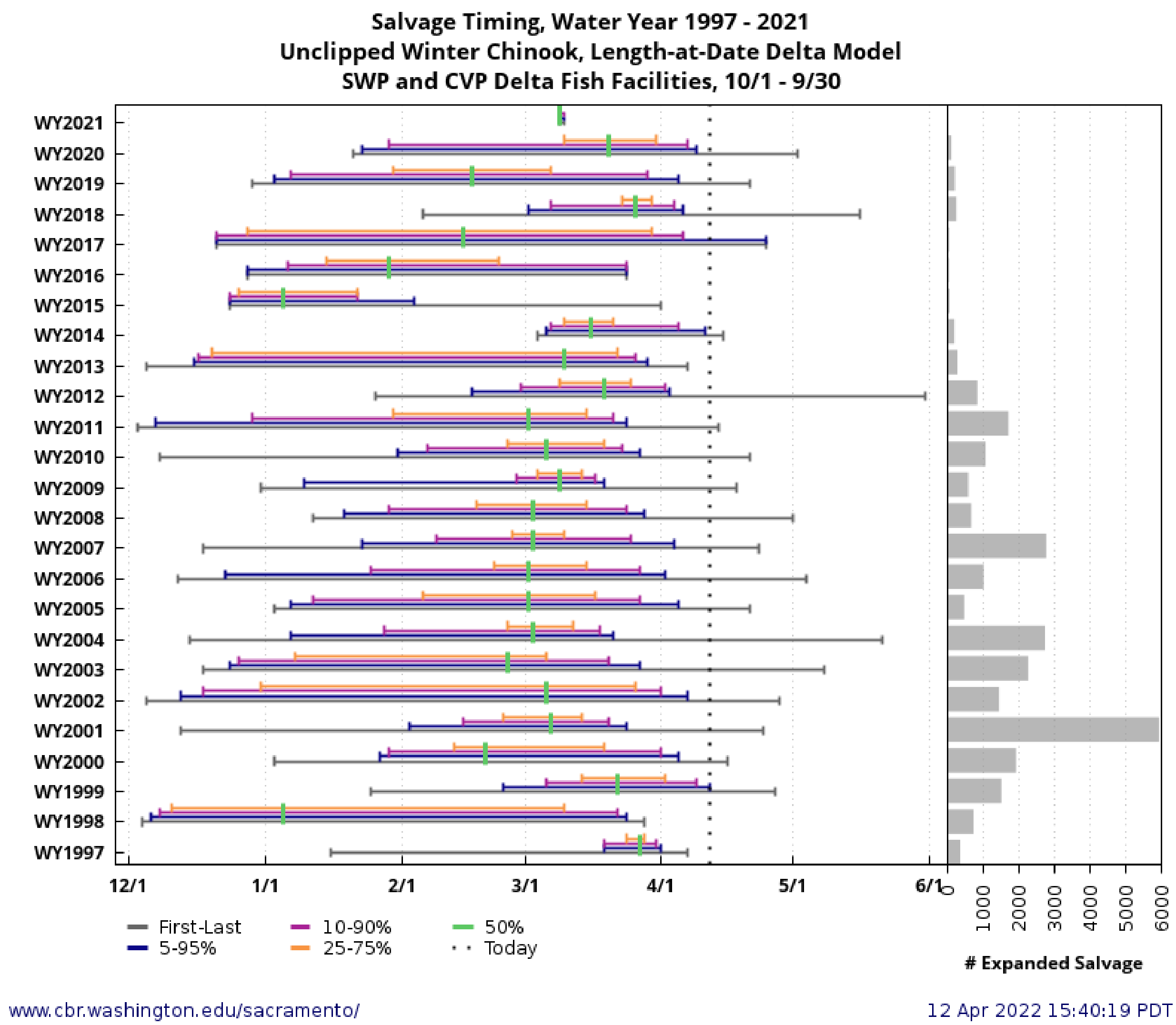
Source: University of Washington, School of Aquatic and Fishery Science 2022.

Figure C-6. Winter-Run Chinook Salmon Juvenile Migrating Timing, Chipps Island Trawl, 1996–2020

Table C-10. Winter-Run Chinook Salmon Juvenile Migrating Timing, Chipps Island Trawl, 1996–2020

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	Feb 8	Feb 24	Feb 26	Apr 25	Apr 25	Apr 25
2019	Dec 20	Feb 23	Feb 24	Apr 10	Apr 10	Apr 13
2018	Jan 31	Feb 17	Mar 10	Apr 19	Apr 21	May 20
2017	Jan 20	Feb 5	Feb 6	Apr 15	Apr 17	Apr 21
2016	Mar 3	Mar 16	Mar 19	Apr 21	Apr 27	May 5
2015	Jan 22	Jan 29	Mar 25	Apr 8	Apr 8	Apr 27
2014	Dec 10	Dec 10	Dec 24	Apr 10	Apr 15	Apr 17
2013	Feb 14	Feb 21	Feb 28	Apr 4	Apr 9	Apr 11
2012	Dec 21	Jan 2	Mar 11	Apr 12	Apr 12	Apr 15
2011	Jan 24	Mar 6	Mar 9	Apr 27	Apr 27	Apr 27
2010	Jan 5	Feb 28	Feb 28	Apr 18	Apr 20	Apr 22
2009	Jan 25	Feb 10	Feb 18	Apr 19	Apr 21	Apr 28
2008	Feb 20	Feb 23	Feb 25	Apr 10	Apr 17	May 9
2007	Jan 9	Jan 17	Jan 19	Apr 3	Apr 10	Apr 28
2006	Jan 6	Feb 17	Feb 24	Mar 24	Apr 9	Apr 30
2005	Dec 15	Feb 27	Mar 3	Apr 21	Apr 24	May 12
2004	Dec 11	Jan 8	Jan 18	Apr 15	Apr 22	May 23
2003	Dec 21	Dec 29	Jan 14	Mar 31	Mar 31	Apr 25
2002	Dec 18	Dec 22	Dec 31	Apr 7	Apr 21	May 10
2001	Dec 3	Jan 4	Jan 16	Apr 11	Apr 16	May 21
2000	Jan 22	Feb 4	Feb 21	Apr 4	Apr 13	May 6
1999	Jan 24	Feb 3	Feb 8	Apr 10	Apr 18	May 20
1998	Dec 1	Dec 14	Jan 28	Apr 11	Apr 17	Apr 29
1997	Dec 4	Dec 19	Jan 18	Apr 21	Apr 25	May 2
1996	Dec 30	Jan 23	Feb 4	Apr 13	Apr 17	May 8
Median Month	December	February	February	April	April	April

Source: University of Washington, School of Aquatic and Fishery Science 2022.



Source: University of Washington, School of Aquatic and Fishery Science 2022.

Figure C-7. Unclipped Winter-Run Chinook Salmon Juvenile Migration Timing, Salvage at CVP and SWP Fish Facilities, 1997–2021

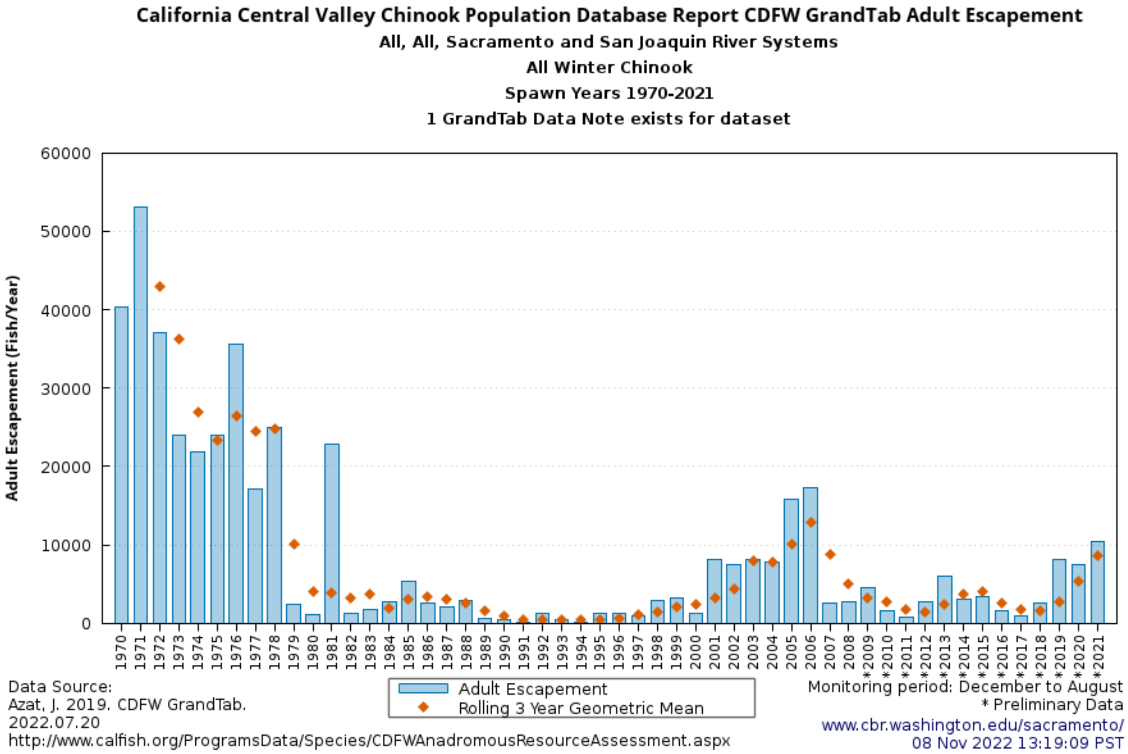
Table C-11. Unclipped Winter-Run Chinook Salmon Juvenile Migration Timing, Salvage at CVP and SWP Fish Facilities, 1997–2021

Water Year	First	5%	10%	90%	95%	Last
2021	3/8/2021	3/8/2021	3/8/2021	3/9/2021	3/9/2021	3/9/2021
2020	1/20/2020	1/22/2020	1/28/2020	4/5/2020	4/7/2020	4/30/2020
2019	12/29/2018	1/2/2019	1/6/2019	3/28/2019	4/4/2019	4/20/2019
2018	2/5/2018	3/1/2018	3/6/2018	4/3/2018	4/5/2018	5/15/2018
2017	12/20/2016	12/20/2016	12/20/2016	4/5/2017	4/24/2017	4/24/2017

Water Year	First	5%	10%	90%	95%	Last
2016	12/28/2015	12/28/2015	1/5/2016	3/22/2016	3/22/2016	3/22/2016
2015	12/24/2014	12/24/2014	12/24/2014	1/21/2015	2/3/2015	3/31/2015
2014	3/3/2014	3/5/2014	3/6/2014	4/4/2014	4/10/2014	4/14/2014
2013	12/4/2012	12/15/2012	12/16/2012	3/25/2013	3/28/2013	4/6/2013
2012	1/25/2012	2/16/2012	2/27/2012	3/31/2012	4/1/2012	5/29/2012
2011	12/3/2010	12/7/2010	12/29/2010	3/20/2011	3/23/2011	4/13/2011
2010	12/8/2009	1/30/2010	2/6/2010	3/22/2010	3/26/2010	4/20/2010
2009	12/30/2008	1/9/2009	2/26/2009	3/16/2009	3/18/2009	4/17/2009
2008	1/11/2008	1/18/2008	1/28/2008	3/22/2008	3/26/2008	4/29/2008
2007	12/18/2006	1/22/2007	2/8/2007	3/24/2007	4/3/2007	4/22/2007
2006	12/12/2005	12/23/2005	1/24/2006	3/26/2006	4/1/2006	5/3/2006
2005	1/2/2005	1/6/2005	1/11/2005	3/26/2005	4/4/2005	4/20/2005
2004	12/15/2003	1/6/2004	1/27/2004	3/16/2004	3/19/2004	5/19/2004
2003	12/18/2002	12/24/2002	12/26/2002	3/19/2003	3/26/2003	5/7/2003
2002	12/5/2001	12/13/2001	12/18/2001	3/31/2002	4/6/2002	4/27/2002
2001	12/12/2000	2/2/2001	2/14/2001	3/19/2001	3/23/2001	4/23/2001
2000	1/2/2000	1/26/2000	1/28/2000	3/30/2000	4/3/2000	4/14/2000
1999	1/24/1999	2/23/1999	3/5/1999	4/8/1999	4/11/1999	4/26/1999
1998	12/4/1997	12/6/1997	12/8/1997	3/21/1998	3/23/1998	3/27/1998
1997	1/15/1997	3/18/1997	3/18/1997	3/30/1997	3/31/1997	4/6/1997
Median	December	January	January	March	March	April

Source: University of Washington, School of Aquatic and Fishery Science 2022.
CVP = Central Valley Project; SWP = State Water Project.

C.2.5 Spawner Adult Abundance



Source: https://www.cbr.washington.edu/sacramento/.

Figure C-8. California Central Valley Chinook population adult winter-run escapement and rolling 3-year geometric mean (red diamonds), Sacramento and San Joaquin river systems, spawn years 1970 – 2021

Table C-12. Winter Chinook (in-river plus hatchery return) 1970-2021 (December to August). Asterisks denote preliminary data

Year	Annual	3 Year Rolling Geometric Mean
2021 *	10494	8588
2020 *	7428	5421
2019 *	8128	2758
2018 *	2639	1587
2017 *	979	1734
2016 *	1549	2523
2015 *	3440	3981
2014 *	3015	3659
2013 *	6086	2377
2012 *	2671	1521

Year	Annual	3 Year Rolling Geometric Mean
2011 *	827	1815
2010 *	1596	2736
2009 *	4537	3195
2008	2830	4991
2007	2541	8862
2006	17296	12918
2005	15839	10080
2004	7869	7836
2003	8218	7952
2002	7441	4357
2001	8224	3318
2000	1352	2369
1999	3288	2053
1998	2992	1521
1997	880	1151
1996	1337	685
1995	1297	453
1994	186	446
1993	387	466
1992	1240	482
1991	211	398
1990	430	951
1989	696	1635
1988	2878	2536
1987	2185	3130
1986	2596	3384
1985	5407	3013
1984	2763	1864
1983	1831	3767
1982	1281	3231
1981	22797	3964
1980	1156	4088
1979	2364	10059
1978	25012	24839

Year	Annual	3 Year Rolling Geometric Mean
1977	17214	24476
1976	35596	26520
1975	23930	23280
1974	21897	26952
1973	24079	36207
1972	37133	43027
1971	53089	-
1970	40409	-

Source: Azat 2022.

C.2.6 Fecundity

Table C-13. Winter-run Chinook salmon fecundity (eggs per female) 2002 – 2022. N/A denotes information not available

Year	Eggs/Female
2002	4,820
2003	4,854
2004	5,200
2005	5,251
2006	5,382
2007	5,056
2008	5,424
2009	5,231
2010	5,161
2011	4,776
2012	4,364
2013	4,596
2014	5,191
2015	4,819
2016	N/A
2017	N/A
2018	N/A
2019	N/A
2020	5,424
2021	N/A
2022	N/A

Source: 2002-2015 Data: USFWS 2016 Memo to File. Documentation of a change in the methodology of estimating winter-run Chinook salmon egg-to-fry survival for brood year 2016. 2019: National Marine Fisheries Service 2020.

Table C-14. Winter Chinook fry-equivalent juvenile production indices (JPIs), lower and upper 90% confidence intervals (CI), estimated adult female spawners above Red Bluff Diversion Dam (Estimated Females), estimates of female fecundity, calculated juveniles per estimated female (Estimated Recruits / Female) and egg-to-fry survival estimates (ETF) with associated lower and upper 90% confidence intervals (L90 CI:U90 CI) by brood year (BY) for Red Bluff Diversion Dam (river kilometer [RKM] 391) rotary traps between July 2002 and June 2020

BY	Fry Equivalent JPI	Lower 90% CI	Upper 90% CI	Estimated Females	Fecundity	Estimated Recruits/ Female	ETF Survival Rate (%)
2002	7,635,469	2,811,132	13,144,325	5,670	4,923	1,347	27.4
2003	5,781,519	3,525,098	8,073,129	5,179	4,854	1,116	23
2004	3,677,989	2,129,297	5,232,037	3,185	5,515	1,155	20.9
2005	8,943,194	4,791,726	13,277,637	8,807	5,500	1,015	18.5
2006	7,298,838	4,150,323	10,453,765	8,626	5,484	846	15.4
2007	1,637,804	1,062,780	2,218,745	1,517	5,112	1,080	21.1
2008	1,371,739	858,933	1,885,141	1,443	5,424	951	17.5
2009	4,972,954	2,790,092	7,160,098	2,702	5,519	1,840	33.5
2010	1,572,628	969,016	2,181,572	813	5,161	1,934	37.5
2011	996,621	671,779	1,321,708	424	4,832	2,351	48.6
2012	1,814,244	1,227,386	2,401,102	1,491	4,518	1,217	26.9
2013	2,481,324	1,539,193	3,423,456	3,577	4,596	694	15.1
2014	523,872	301,197	746,546	1,681	5,308	312	5.9
2015	440,951	288,911	592,992	2,022	4,819	218	4.5
2016	640,149	429,876	850,422	653	4,131	980	23.7
2017	734,432	471,292	997,572	367	4,109	2,001	48.7
2018	1,477,529	824,706	2,130,352	1,080	5,141	1,368	26.6
2019	4,691,764	2,630,095	6,753,433	4,884	5,424	961	17.7

Source: Voss and Poytress 2022.

C.2.7 Redds

Table C-15. Annual number of redds per reach and total number of redds, 2007 - 2022. Reaches are defined by their downstream reach boundary

Year	ACID	HW44	Airport Road	Balls Ferry	Battle	Jelly's Ferry	Bend	Red Bluff	Total
2007	149	90	32	6	5	4	2	0	288
2008	226	180	34	1	0	0	0	0	441
2009	14	72	0	0	0	0	0	0	86
2010	107	107	9	0	0	0	0	0	223
2011	1	13	4	0	0	0	0	0	18
2012	173	87	1	0	0	0	0	0	261
2013	432	128	8	0	0	1	0	0	569
2014	71	47	9	0	0	0	0	0	127
2015	74	120	2	0	0	0	0	0	196
2016	0	12	6	0	0	0	0	0	18
2017	0	23	3	0	0	0	0	0	26
2018	54	130	14	0	0	0	0	0	198
2019	9	256	213	36	0	0	1	0	515
2020	229	226	36	0	0	0	0	0	491
2021	331	246	1	0	0	0	0	0	578
2022	215	182	9	0	0	0	0	0	406

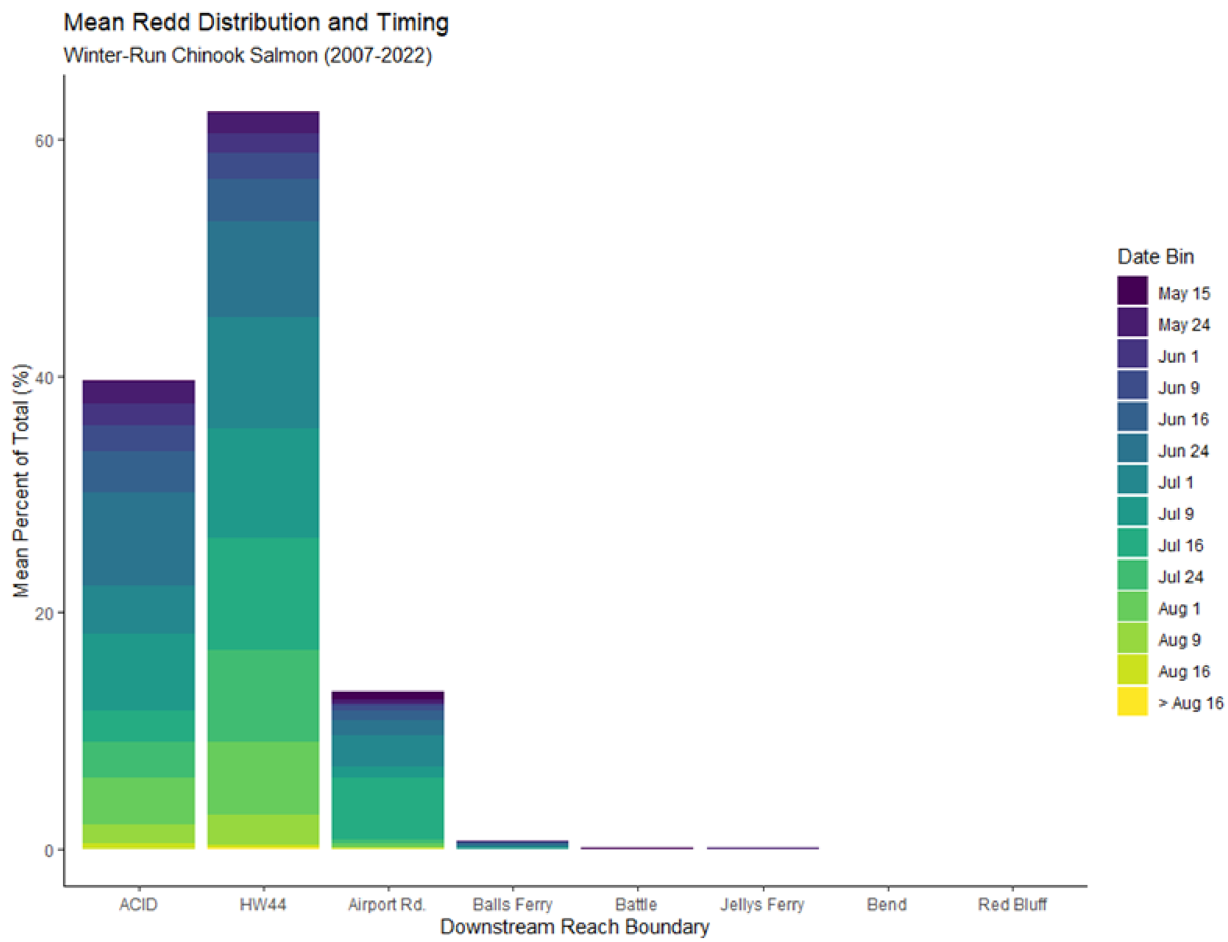


Figure C-9. Mean timing and distribution of winter run Chinook salmon in the upper reaches of the Sacramento River. This includes data from 2007-2021

C.2.8 Survival of Eggs

Table C-16. Egg survival for Livingston Stone National Fish Hatchery (LSNFH) winter-run Chinook salmon based on a 2-year average (2006-2007) that does not include captive broodstock crosses

	Green Egg to Eyed Egg	Eyed Egg to Ponding	Ponding to Release	Overall Egg to Release
LSNFH Winter-Run Chinook Salmon	0.92	0.78	0.8	0.58

Source: California Hatchery Review Project 2012

Table C-17. Livingston Stone National Fish Hatchery winter-run Chinook salmon 2000 – 2010

Release Year	Egg Take	Eyed Eggs	Eggs Culled	Fish Ponded	Smolts Released	Egg to Release Survival
2000	216,075	197,511	-	179,399	166,556	77.08%
2001	236,864	225,845	-	214,954	190,732	80.52%
2002	231,375	220,189	-	176,882	164,806	71.23%
2003	223,269	195,689	-	180,205	152,011	68.08%
2004	192,387	177,507	-	165,878	148,385	77.13%
2005	267,803	243,525	-	196,211	160,212	59.82%
2006	279,853	259,348	-	189,881	161,212	57.61%
2007	121,341	111,686	-	100,909	71,883	59.24%
2008	260,370	235,279	-	200,696	146,211	56.16%
2009	324,321	302,544	-	267,819	198,582	61.23%
2010	139,349	129,512	-	125,153	123,857	88.88%
Average	226,637	208,967	-	181,635	153,132	68.82%

Source: California Hatchery Review Project 2012:Appendix A-2 Table 2.

Table C-18. Egg-to-fry survival based on estimated female spawner abundance, fecundity, and passage of fry-equivalents past Red Bluff Diversion Dam: 2002 - 2021

Year	Percent egg-to-fry survival rate (90% confidence intervals)
2021	2.6
2020	11.5
2019	17.5 (9.8, 25.2)
2018	26.6 (14.9, 38.4)
2017	48.7 (31.3, 66.2)
2016	23.7 (15.9, 31.5)
2015	4.5 (3.0, 6.1)
2014	5.9 (3.4, 8.4)
2013	15.1 (9.4, 20.8)
2012	26.9 (18.2, 35.6)
2011	48.6 (32.8, 64.5)
2010	37.5 (23.1, 52.0)
2009	33.5 (18.7, 48.0)

Year	Percent egg-to-fry survival rate (90% confidence intervals)
2008	17.5 (11.0, 24.1)
2007	21.1 (13.7, 28.6)
2006	15.4 (8.8, 22.1)
2005	18.5 (9.9, 27.4)
2004	20.9 (12.1, 29.8)
2003	23.0 (14.0, 32.1)
2002	27.4 (10.1, 47.1)

Source: Estimates 2002-2018 were obtained from Voss and Poytress 2020. Estimates 2019-2021 were obtained from Marcinkevage 2022 and National Marine Fisheries Service 2021.

C.2.9 Fry Existing Natal Stream Abundance

Table C-19. Winter-run Chinook salmon run-size and fry equivalent juvenile production index (JPI) for brood years 2007 - 2021. Data are available in Appendix AB-L (*Shasta Coldwater Pool Management*)

Brood Year	Run Size	Fry Equivalent JPI (90% CI)
Average (2007 – 2021)	1,279,139	-
2021	557,652	-
2020	2,078,101	-
2019	3,666,516	-
2018	1,084,961	1,477,529 (824,706, 2,130,352)
2017	591,066	734,432 (471,292, 997,572)
2016	498,386	640,149 (429,876, 850,422)
2015	324,246	440,951 (288,911, 592,992)
2014	270,279	523,872 (301,197, 746,546)
2013	1,392,950	2,481,324 (1,539,193, 3,423,456)
2012	1,186,248	1,814,244 (1,227,386, 2,401,102)
2011	742,344	996,621 (671,779, 1,321,708)
2010	1,228,975	1,572,628 (969,016, 2,181,572)
2009	3,274,893	4,972,954 (2,790,092, 7,160,098)
2008	953,310	1,371,739 (858,933, 1,885,141)
2007	1,337,160	1,637,804 (1,062,780, 2,218,745)

Source: Fry equivalent JPI were obtained from Voss and Poytress (2020).

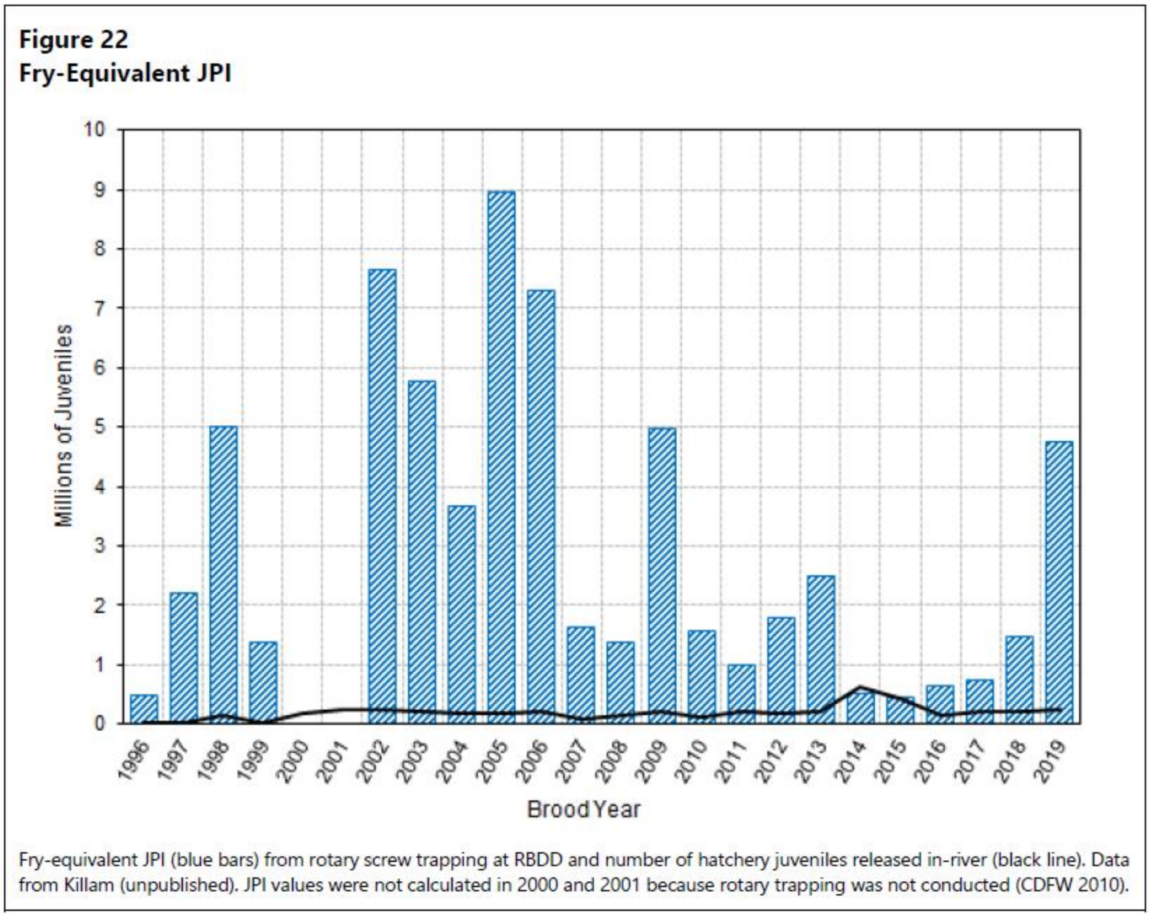
Table C-20. Red Bluff Diversion Dam RST juvenile anadromous fish abundance estimated passage of winter-run Chinook salmon fry, pre-smolt/smolts, total, and fry-equivalent JPI (90% CI low and high) (brood years 2013 – 2019)

Period	BY	Estimated Fry	Estimated Pre-Smolt / Smolts	Estimated Total	Fry-Equivalent JPI
7/1/2019 – 6/30/2020	2019	3,050,004 low 1,734,019 high 4,365,990	763,584 low 400,423 high 1,126,745	3,813,589 low 2,152,984 high 5,474,193	4,691,764 low 2,630,095 high 6,753,422
7/1/2018 – 6/30/2019	2018	726,455 low 486,673 high 966,237	441,808 low 193,106 high 690, 510	1,168,263 low 683,866 high 1,652,660	1,477,529 low 824,706 high 2,130,352
7/1/2017 – 6/30/2018	2017	412,028 low 299,049 high 525,007	189,649 low 97,172 high 282,127	601,677 low 399,435 high 803,919	734,432 low 471,292 high 997,572
7/1/2016 – 6/30/2017	2016	390,899 low 291,208 high 490,590	146,618 low 77,365 high 215,870	537,517 low 371,480 high 703,554	640,149 low 429,876 high 850,422
7/1/2015 – 6/30/2016	2015	193,115 low 147,323 high 238,907	145,786 low 80,032 high 211,540	338,901 low 229,316 high 448,486	440,951 low 288,911 high 592,992
7/1/2014 – 6/30/2015	2014	250,536	160,786	411,322	523,872
7/1/2013 – 6/30/2014	2013	763,240	1,010,638	1,773,878	2,481,324

Sources: For BY 2019, Voss and Poytress 2022. For BY 2018, Voss and Poytress 2020. For BY 2017, Voss and Poytress 2019. For BY 2016, Voss and Poytress 2018. For BY 2015, Voss and Poytress 2017. For BY 2014, Poytress 2016. For BY 2013, Poytress, and Gruber 2015.

C.2.10 Survival of Fry

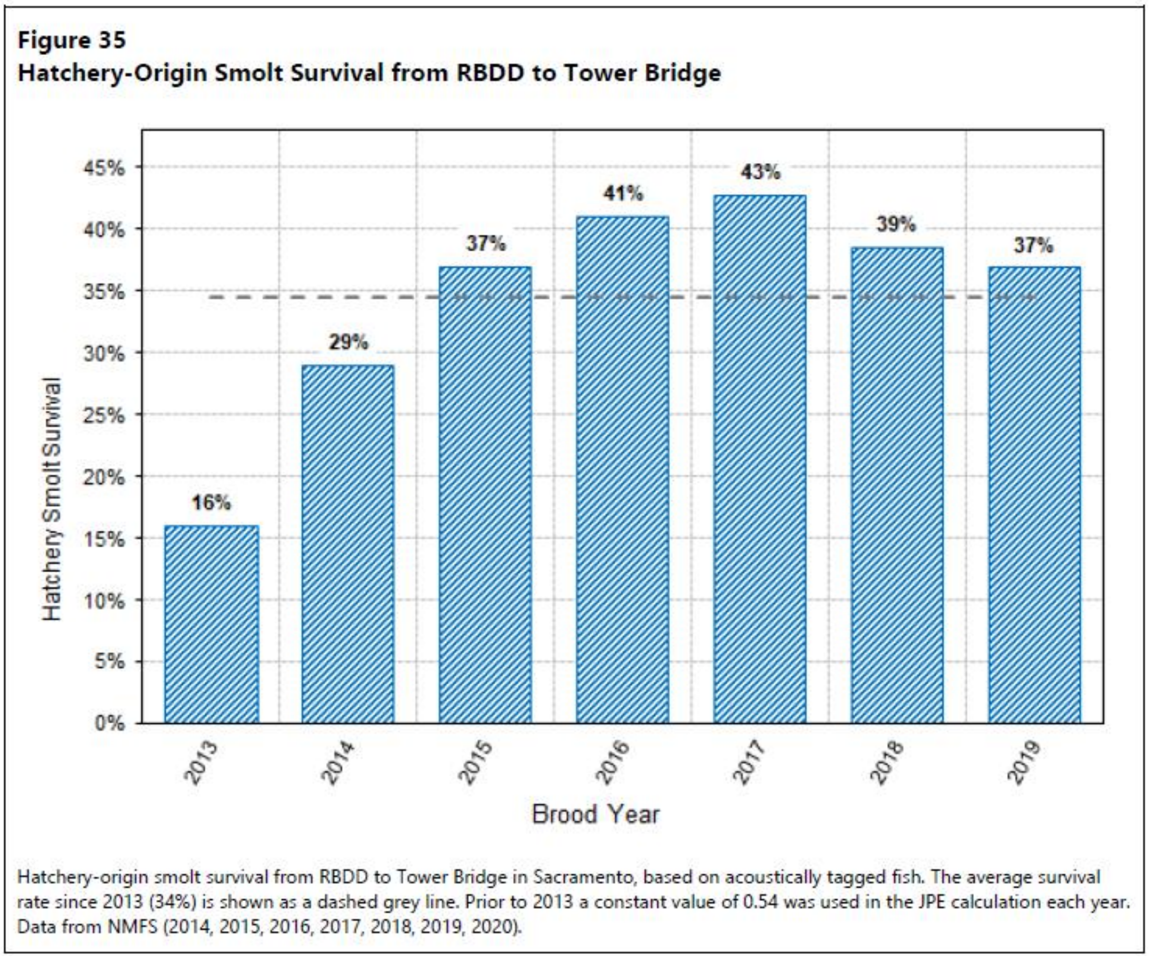
Preliminary results shared by NMFS indicate that mean estimated fry survival associated with thiamine deficiency for 2020, 2021, and 2022 was 77%, 56%, and 55% (National Marine Fisheries Service 2022).



Source: BY2019 Sacramento WCS Chinook Cohort Report.

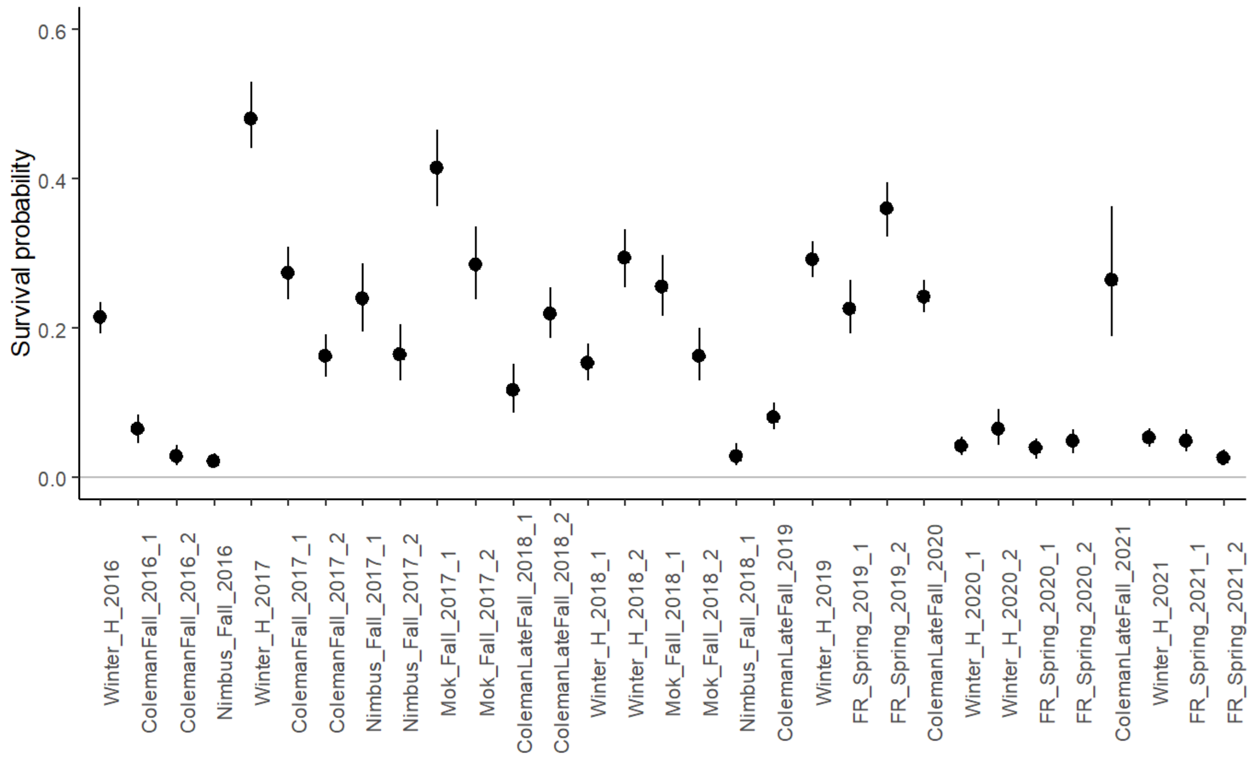
Figure C-10. Winter-run Chinook salmon fry-equivalent juvenile production index (JPI) from Red Bluff Diversion Dam rotary screw trapping and released hatchery juveniles (black line) brood years 1996 – 2019

C.2.11 Survival of Smolts



Source: BY2019 Sacramento WCS Chinook Cohort Report.
RBDD = Red Bluff Diversion Dam

Figure C-11. Hatchery-origin winter-run Chinook salmon smolt survival from Red Bluff Diversion Dam to Tower Bridge for brood years 2013 – 2019. Average survival rate since 2013 (34%) denoted by a grey dashed line



Source: https://oceanview.pfeg.noaa.gov/CalFishTrack/index.html

Figure C-12. Preliminary probability of survival to Chipps Island using acoustic telemetry groups for various runs of tagged Chinook salmon (2016-2021)

C.2.12 Juveniles Entering Delta Abundance

Table C-21. NMFS WR Juvenile Production Estimate (JPE) and Sacramento Valley Index (WYT) 2008 – 2021

WR BY	NMFS WR JPE	WYT
2008	617,783	D
2009	1,179,633	BN
2010	332,012	W
2011	162,051	BN
2012	532,809	D
2013	1,196,387	C
2014	124,521	C
2015	101,716	BN
2016	166,189	W

WR BY	NMFS WR JPE	WYT
2017	201,409	BN
2018	433,176	W
2019	854,941	D
2020	330,130	C
2021	125,038	C

Source: National Marine Fisheries Service JPE letters 2008 – 2021.

C.2.13 Survival of Juveniles in Delta

Table C-22. Estimated survival of juvenile winter-run Chinook salmon and total river kilometers (RKM) from the start (release site of hatchery fish) to I80-50 bridge (RKM 170.74) or Tower Bridge (RKM 172)

Group	Data Source	Year	Start	End	Total RKM	Survival Estimate
Livingston Stone NFH	EAT	2019	Caldwell Park	Tower Bridge	379.29	0.233
Livingston Stone NFH	EAT	2019	Tower Bridge	I80-50	1.26	0.976
Livingston Stone NFH	EAT	2019	Caldwell Park	Benicia Bridge	499.05	0.256
Coleman NFH	EAT	2019	North Fork Battle Creek	Tower Bridge	364.23	0.233
Coleman NFH	EAT	2019	Tower Bridge	I80 – 50	1.26	0.924
Coleman NFH	EAT	2019	North Fork Battle Creek	Benicia Bridge	483.99	0.14
Livingston Stone NFH	EAT	2020	Caldwell Park	Tower Bridge	379.29	0.132
Livingston Stone NFH	EAT	2020	Tower Bridge	I80-50	1.26	1
Livingston Stone NFH	EAT	2020	Caldwell Park	Benicia Bridge	499.05	0.035
Coleman NFH	EAT	2020, Mar	North Fork Battle Creek	Tower Bridge	364.23	0.064
Coleman NFH	EAT	2020, Mar	Tower Bridge	I80 – 50	1.26	Not Reported
Coleman NFH	EAT	2020, Mar	North Fork Battle Creek	Benicia Bridge	483.99	Not Reported
Coleman NFH	EAT	2020, May	North Fork Battle Creek	Tower Bridge	364.23	0.156
Coleman NFH	EAT	2020, May	Tower Bridge	I80 – 50	1.26	Not Reported
Coleman NFH	EAT	2020, May	North Fork Battle Creek	Benicia Bridge	483.99	Not Reported

Group	Data Source	Year	Start	End	Total RKM	Survival Estimate
Livingston Stone NFH	EAT	2021	Caldwell Park	Tower Bridge	379.29	0.101
Livingston Stone NFH	EAT	2021	Tower Bridge	I80-50	1.26	1
Livingston Stone NFH	EAT	2021	Caldwell Park	Benicia Bridge	499.05	0.036
Coleman NFH	EAT	2021	North Fork Battle Creek	Tower Bridge	364.23	0.033
Coleman NFH	EAT	2021	Tower Bridge	I80 – 50	1.26	0.893
Coleman NFH	EAT	2021	North Fork Battle Creek	Benicia Bridge	483.99	0.002
Livingston Stone NFH	EAT	2022	Caldwell Park	Tower Bridge	379.29	0.134
Livingston Stone NFH	EAT	2022	Tower Bridge	I80-50	1.26	Not Reported
Livingston Stone NFH	EAT	2022	Caldwell Park	Benicia Bridge	499.05	0.058
Coleman NFH	EAT	2022	North Fork Battle Creek	Tower Bridge	364.23	0.011
Coleman NFH	EAT	2022	Tower Bridge	I80 – 50	1.26	Not Reported
Coleman NFH	EAT	2022	North Fork Battle Creek	Benicia Bridge	483.99	0.001

Source: https://oceanview.pfeg.noaa.gov/CalFishTrack/index.html

C.2.14 Juveniles Exiting the Delta Abundance

Table C-23. Preliminary genetic winter-run abundance estimates (in the thousands) for 2017 to 2021 for juveniles exiting the delta

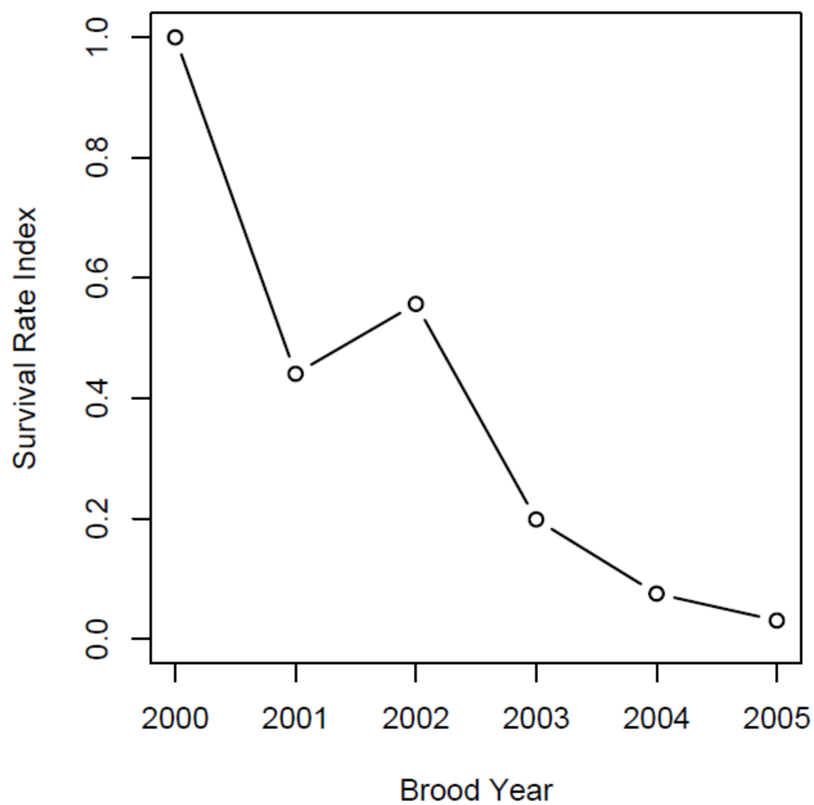
Year	Median	10th Percentile	90th Percentile
2017	54.3	35.6	84.5
2018	49.0	36.1	67.1
2019	85.5	60.5	121.4
2020	92.2	69.3	126.5
2021	31.8	22.5	47.7

Source: Perry pers. comm.

C.2.15 Survival of Juveniles in Ocean

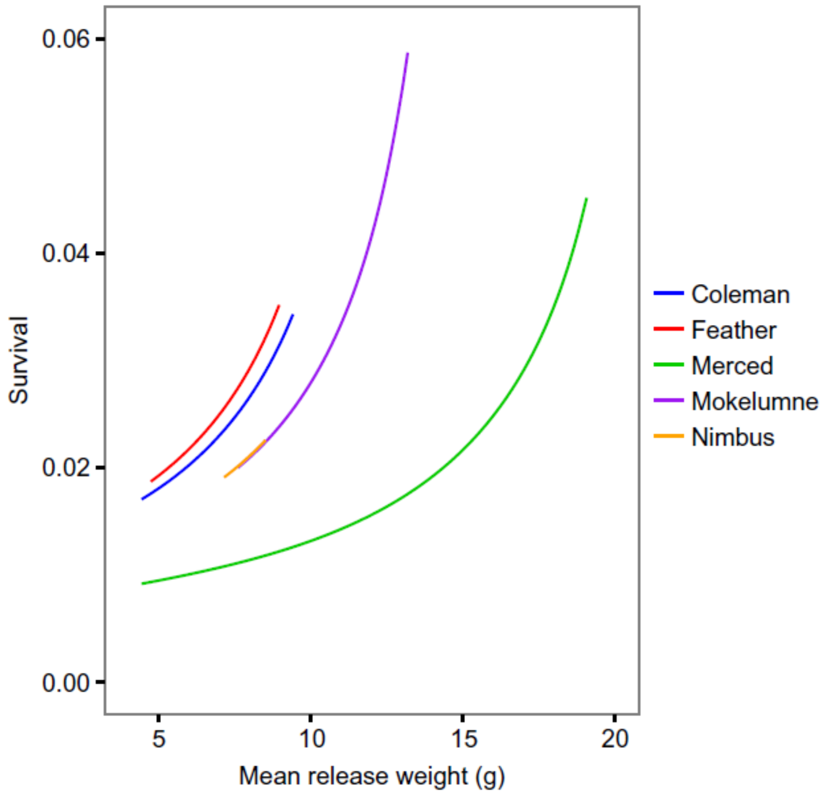
Cohort reconstructions for winter-run Chinook salmon have applied an assumed annual 50% survival of juveniles (i.e., age-2 fish) in the ocean, based on similar cohort analyses for Pacific salmon (O'Farrell et al. 2012). There are no empirical estimates of survival of juveniles in the ocean for winter-run Chinook salmon available.

Analyses of relative recovery rates of CWTs associated with hatchery-origin fall-run Chinook salmon indicated the role of upwelling indices (i.e., initiation of net upwelling) and hatchery release characteristics on survival (Satterthwaite et al. 2014). Similar analyses of relative survival rate have been conducted for fall-run Chinook salmon in the Central Valley using CWTs (Lindley et al. 2009; Sabal et al. 2016). The survival rate index was calculated from coded wire tag recoveries, released coded wire tags, and fishing effort (Lindley et al. 2009). These estimates may provide additional juvenile survival rates in the ocean for winter-run Chinook salmon.



Source: Lindley et al. 2009 National Marine Fisheries Service SWFSC Tech Memo (Figure 9).

Figure C-13. Feather River Hatchery fall-run Chinook survival rate index between release in San Francisco Bay and age two in the San Francisco major port area



Source: Sabal et al. 2016 (Figure 5).

Figure C-14. Modeled fall-run Chinook salmon survival by hatchery across a range of mean release weights holding other covariates constant

C.2.16 Ocean Abundance

Estimates of hatchery release abundances in the ocean for brood years 1998-2007 on a monthly timestep are available in Appendix C of the report summarizing cohort reconstructions of winter-run Chinook salmon (National Marine Fisheries Service 2022: Appendix C):10 tables from O’Farrell et al. 2012 are found below.

BY	CY	Age	Month	Ocean N	Ocean I_{com}	Ocean I_{rec}	Ocean V	River H_r	River E_{hat}	River E_{nat}
1998	1999	2	3	1528.38	0.00	0.00	85.78	0.00	0.00	0.00
1998	1999	2	4	1442.60	0.00	0.00	80.97	0.00	0.00	0.00
1998	1999	2	5	1361.63	0.00	0.00	76.42	0.00	0.00	0.00
1998	1999	2	6	1285.21	0.00	0.00	72.13	0.00	0.00	0.00
1998	1999	2	7	1213.08	0.00	0.00	68.08	0.00	0.00	0.00
1998	1999	2	8	1144.99	0.00	8.68	63.78	0.00	0.00	0.00
1998	1999	2	9	1072.53	0.00	0.00	60.20	0.00	0.00	0.00
1998	1999	2	10	1012.34	0.00	0.00	56.82	0.00	0.00	0.00
1998	1999	2	11	955.52	0.00	0.00	53.63	0.00	0.00	0.00
1998	1999	2	12	901.89	0.00	0.00	50.62	0.00	0.00	0.00
1998	2000	2	1	851.27	0.00	0.00	47.78	0.00	0.00	0.00
1998	2000	2	2	803.49	0.00	0.00	45.10	23.48	8.29	0.00
1998	2000	3	3	726.63	0.00	0.00	13.39	0.00	0.00	0.00
1998	2000	3	4	713.24	0.00	8.37	12.99	0.00	0.00	0.00
1998	2000	3	5	691.88	0.00	0.00	12.75	0.00	0.00	0.00
1998	2000	3	6	679.14	28.93	43.65	11.17	0.00	0.00	0.00
1998	2000	3	7	595.38	6.52	53.84	9.86	0.00	0.00	0.00
1998	2000	3	8	525.16	0.00	14.14	9.41	0.00	0.00	0.00
1998	2000	3	9	501.60	0.00	4.73	9.15	0.00	0.00	0.00
1998	2000	3	10	487.72	0.00	9.71	8.81	0.00	0.00	0.00
1998	2000	3	11	469.20	0.00	0.00	8.64	0.00	0.00	0.00
1998	2000	3	12	460.56	0.00	0.00	8.49	0.00	0.00	0.00
1998	2001	3	1	452.07	0.00	0.00	8.33	0.00	0.00	0.00
1998	2001	3	2	443.74	0.00	0.00	8.18	90.83	13.18	268.04
1998	2001	4	3	63.52	0.00	0.00	1.17	0.00	0.00	0.00
1998	2001	4	4	62.35	0.00	0.00	1.15	0.00	0.00	0.00
1998	2001	4	5	61.20	5.21	0.00	1.03	0.00	0.00	0.00
1998	2001	4	6	54.96	0.00	0.00	1.01	0.00	0.00	0.00
1998	2001	4	7	53.95	0.00	0.00	0.99	0.00	0.00	0.00
1998	2001	4	8	52.95	0.00	0.00	0.98	0.00	0.00	0.00
1998	2001	4	9	51.98	2.71	0.00	0.91	0.00	0.00	0.00
1998	2001	4	10	48.36	0.00	0.00	0.89	0.00	0.00	0.00
1998	2001	4	11	47.47	0.00	0.00	0.87	0.00	0.00	0.00
1998	2001	4	12	46.59	0.00	0.00	0.86	0.00	0.00	0.00
1998	2002	4	1	45.74	0.00	0.00	0.84	0.00	0.00	0.00
1998	2002	4	2	44.89	0.00	0.00	0.83	31.54	0.00	4.92
1998	2002	5	3	7.61	0.00	0.00	0.14	0.00	0.00	0.00
1998	2002	5	4	7.47	0.00	0.00	0.14	0.00	0.00	0.00
1998	2002	5	5	7.33	7.33	0.00	0.00	0.00	0.00	0.00
1998	2002	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2002	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2002	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2002	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2002	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2002	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2002	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2003	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2003	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: O'Farrell et al. 2012 National Marine Fisheries Service SWFSC Tech Memo (Appendix C, p 63 – 73, tables C1 – C10).

Figure C-15. Reconstructed cohort: 1998 brood

BY	CY	Age	Month	Ocean N	Ocean I_{com}	Ocean I_{rec}	Ocean V	River H_r	River E_{hat}	River E_{nat}
1999	2000	2	3	1162.47	0.00	0.00	65.24	0.00	0.00	0.00
1999	2000	2	4	1097.23	0.00	0.00	61.58	0.00	0.00	0.00
1999	2000	2	5	1035.65	0.00	0.00	58.13	0.00	0.00	0.00
1999	2000	2	6	977.52	0.00	0.00	54.86	0.00	0.00	0.00
1999	2000	2	7	922.65	0.00	0.00	51.78	0.00	0.00	0.00
1999	2000	2	8	870.87	0.00	0.00	48.88	0.00	0.00	0.00
1999	2000	2	9	821.99	0.00	0.00	46.13	0.00	0.00	0.00
1999	2000	2	10	775.86	0.00	0.00	43.55	0.00	0.00	0.00
1999	2000	2	11	732.31	0.00	0.00	41.10	0.00	0.00	0.00
1999	2000	2	12	691.21	0.00	0.00	38.79	0.00	0.00	0.00
1999	2001	2	1	652.42	0.00	0.00	36.62	0.00	0.00	0.00
1999	2001	2	2	615.80	0.00	0.00	34.56	0.00	0.00	95.27
1999	2001	3	3	485.97	0.00	13.19	8.71	0.00	0.00	0.00
1999	2001	3	4	464.07	0.00	37.31	7.86	0.00	0.00	0.00
1999	2001	3	5	418.89	0.00	9.25	7.55	0.00	0.00	0.00
1999	2001	3	6	402.10	0.00	5.03	7.32	0.00	0.00	0.00
1999	2001	3	7	389.76	14.15	34.44	6.29	0.00	0.00	0.00
1999	2001	3	8	334.89	0.00	8.74	6.01	0.00	0.00	0.00
1999	2001	3	9	320.14	0.00	0.00	5.90	0.00	0.00	0.00
1999	2001	3	10	314.24	0.00	0.00	5.79	0.00	0.00	0.00
1999	2001	3	11	308.45	0.00	0.00	5.68	0.00	0.00	0.00
1999	2001	3	12	302.77	0.00	0.00	5.58	0.00	0.00	0.00
1999	2002	3	1	297.19	0.00	0.00	5.48	0.00	0.00	0.00
1999	2002	3	2	291.72	0.00	0.00	5.37	0.00	5.06	268.24
1999	2002	4	3	13.04	0.00	0.00	0.24	0.00	0.00	0.00
1999	2002	4	4	12.80	0.00	0.00	0.24	0.00	0.00	0.00
1999	2002	4	5	12.56	0.00	0.00	0.23	0.00	0.00	0.00
1999	2002	4	6	12.33	5.49	0.00	0.13	0.00	0.00	0.00
1999	2002	4	7	6.72	0.00	3.85	0.05	0.00	0.00	0.00
1999	2002	4	8	2.81	0.00	0.00	0.05	0.00	0.00	0.00
1999	2002	4	9	2.76	0.00	0.00	0.05	0.00	0.00	0.00
1999	2002	4	10	2.71	0.00	0.00	0.05	0.00	0.00	0.00
1999	2002	4	11	2.66	0.00	0.00	0.05	0.00	0.00	0.00
1999	2002	4	12	2.61	0.00	0.00	0.05	0.00	0.00	0.00
1999	2003	4	1	2.56	0.00	0.00	0.05	0.00	0.00	0.00
1999	2003	4	2	2.52	0.00	0.00	0.05	0.00	0.00	2.47
1999	2003	5	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2004	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2004	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: O'Farrell et al. 2012 National Marine Fisheries Service SWFSC Tech Memo (Appendix C, p 63 – 73, tables C1 – C10).

Figure C-16. Reconstructed cohort: 1999 brood

BY	CY	Age	Month	Ocean				River		
				N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2000	2001	2	3	1063.81	0.00	0.00	59.71	0.00	0.00	0.00
2000	2001	2	4	1004.11	0.00	0.00	56.36	0.00	0.00	0.00
2000	2001	2	5	947.75	0.00	0.00	53.19	0.00	0.00	0.00
2000	2001	2	6	894.56	0.00	0.00	50.21	0.00	0.00	0.00
2000	2001	2	7	844.35	0.00	0.00	47.39	0.00	0.00	0.00
2000	2001	2	8	796.96	0.00	0.00	44.73	0.00	0.00	0.00
2000	2001	2	9	752.23	0.00	0.00	42.22	0.00	0.00	0.00
2000	2001	2	10	710.01	0.00	0.00	39.85	0.00	0.00	0.00
2000	2001	2	11	670.16	0.00	0.00	37.61	0.00	0.00	0.00
2000	2001	2	12	632.55	0.00	0.00	35.50	0.00	0.00	0.00
2000	2002	2	1	597.05	0.00	0.00	33.51	0.00	0.00	0.00
2000	2002	2	2	563.54	0.00	0.00	31.63	0.00	3.11	30.50
2000	2002	3	3	498.30	0.00	0.00	9.18	0.00	0.00	0.00
2000	2002	3	4	489.12	0.00	0.00	9.01	0.00	0.00	0.00
2000	2002	3	5	480.11	0.00	19.81	8.48	0.00	0.00	0.00
2000	2002	3	6	451.82	14.33	16.81	7.75	0.00	0.00	0.00
2000	2002	3	7	412.93	17.30	22.86	6.87	0.00	0.00	0.00
2000	2002	3	8	365.91	9.01	8.66	6.42	0.00	0.00	0.00
2000	2002	3	9	341.82	0.00	0.00	6.30	0.00	0.00	0.00
2000	2002	3	10	335.53	0.00	0.00	6.18	0.00	0.00	0.00
2000	2002	3	11	329.35	0.00	0.00	6.07	0.00	0.00	0.00
2000	2002	3	12	323.28	0.00	0.00	5.96	0.00	0.00	0.00
2000	2003	3	1	317.32	0.00	0.00	5.85	0.00	0.00	0.00
2000	2003	3	2	311.48	0.00	0.00	5.74	0.00	6.13	282.88
2000	2003	4	3	16.73	0.00	5.65	0.20	0.00	0.00	0.00
2000	2003	4	4	10.88	0.00	0.00	0.20	0.00	0.00	0.00
2000	2003	4	5	10.68	0.00	0.00	0.20	0.00	0.00	0.00
2000	2003	4	6	10.48	3.50	0.00	0.13	0.00	0.00	0.00
2000	2003	4	7	6.85	0.00	0.00	0.13	0.00	0.00	0.00
2000	2003	4	8	6.72	0.00	0.00	0.12	0.00	0.00	0.00
2000	2003	4	9	6.60	0.00	0.00	0.12	0.00	0.00	0.00
2000	2003	4	10	6.47	0.00	0.00	0.12	0.00	0.00	0.00
2000	2003	4	11	6.36	0.00	0.00	0.12	0.00	0.00	0.00
2000	2003	4	12	6.24	0.00	0.00	0.11	0.00	0.00	0.00
2000	2004	4	1	6.12	0.00	0.00	0.11	0.00	0.00	0.00
2000	2004	4	2	6.01	0.00	0.00	0.11	0.00	0.00	5.90
2000	2004	5	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2005	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2005	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: O'Farrell et al. 2012 National Marine Fisheries Service SWFSC Tech Memo (Appendix C, p 63 – 73, tables C1 – C10).

Figure C-17. Reconstructed cohort: 2000 brood

BY	CY	Age	Month	Ocean				River		
				N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2001	2002	2	3	954.19	0.00	0.00	53.55	0.00	0.00	0.00
2001	2002	2	4	900.63	0.00	0.00	50.55	0.00	0.00	0.00
2001	2002	2	5	850.09	0.00	0.00	47.71	0.00	0.00	0.00
2001	2002	2	6	802.37	0.00	0.00	45.03	0.00	0.00	0.00
2001	2002	2	7	757.34	0.00	0.00	42.51	0.00	0.00	0.00
2001	2002	2	8	714.83	0.00	0.00	40.12	0.00	0.00	0.00
2001	2002	2	9	674.71	0.00	0.00	37.87	0.00	0.00	0.00
2001	2002	2	10	636.84	0.00	0.00	35.74	0.00	0.00	0.00
2001	2002	2	11	601.10	0.00	0.00	33.74	0.00	0.00	0.00
2001	2002	2	12	567.36	0.00	0.00	31.84	0.00	0.00	0.00
2001	2003	2	1	535.52	0.00	0.00	30.06	0.00	0.00	0.00
2001	2003	2	2	505.46	0.00	0.00	28.37	0.00	1.09	27.76
2001	2003	3	3	448.24	0.00	0.00	8.26	0.00	0.00	0.00
2001	2003	3	4	439.99	0.00	0.00	8.11	0.00	0.00	0.00
2001	2003	3	5	431.88	0.00	13.19	7.71	0.00	0.00	0.00
2001	2003	3	6	410.98	0.00	17.51	7.25	0.00	0.00	0.00
2001	2003	3	7	386.22	0.00	15.64	6.83	0.00	0.00	0.00
2001	2003	3	8	363.75	0.00	0.00	6.70	0.00	0.00	0.00
2001	2003	3	9	357.05	0.00	0.00	6.58	0.00	0.00	0.00
2001	2003	3	10	350.47	0.00	0.00	6.46	0.00	0.00	0.00
2001	2003	3	11	344.01	0.00	0.00	6.34	0.00	0.00	0.00
2001	2003	3	12	337.68	0.00	0.00	6.22	0.00	0.00	0.00
2001	2004	3	1	331.46	0.00	0.00	6.11	0.00	0.00	0.00
2001	2004	3	2	325.35	0.00	0.00	5.99	0.00	8.21	302.82
2001	2004	4	3	8.32	0.00	0.00	0.15	0.00	0.00	0.00
2001	2004	4	4	8.17	0.00	5.59	0.05	0.00	0.00	0.00
2001	2004	4	5	2.53	0.00	0.00	0.05	0.00	0.00	0.00
2001	2004	4	6	2.48	0.00	0.00	0.05	0.00	0.00	0.00
2001	2004	4	7	2.44	0.00	0.00	0.04	0.00	0.00	0.00
2001	2004	4	8	2.39	0.00	0.00	0.04	0.00	0.00	0.00
2001	2004	4	9	2.35	0.00	0.00	0.04	0.00	0.00	0.00
2001	2004	4	10	2.30	0.00	0.00	0.04	0.00	0.00	0.00
2001	2004	4	11	2.26	0.00	0.00	0.04	0.00	0.00	0.00
2001	2004	4	12	2.22	0.00	0.00	0.04	0.00	0.00	0.00
2001	2005	4	1	2.18	0.00	0.00	0.04	0.00	0.00	0.00
2001	2005	4	2	2.14	0.00	0.00	0.04	0.00	0.00	2.10
2001	2005	5	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2006	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2006	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: O’Farrell et al. 2012 National Marine Fisheries Service SWFSC Tech Memo (Appendix C, p 63 – 73, tables C1 – C10).

Figure C-18. Reconstructed cohort: 2001 brood

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2002	2003	2	3	10345.83	0.00	0.00	580.67	0.00	0.00	0.00
2002	2003	2	4	9765.16	0.00	0.00	548.08	0.00	0.00	0.00
2002	2003	2	5	9217.09	0.00	0.00	517.32	0.00	0.00	0.00
2002	2003	2	6	8699.77	0.00	0.00	488.28	0.00	0.00	0.00
2002	2003	2	7	8211.49	0.00	0.00	460.88	0.00	0.00	0.00
2002	2003	2	8	7750.61	0.00	0.00	435.01	0.00	0.00	0.00
2002	2003	2	9	7315.61	0.00	0.00	410.59	0.00	0.00	0.00
2002	2003	2	10	6905.01	0.00	0.00	387.55	0.00	0.00	0.00
2002	2003	2	11	6517.46	0.00	0.00	365.80	0.00	0.00	0.00
2002	2003	2	12	6151.67	0.00	0.00	345.27	0.00	0.00	0.00
2002	2004	2	1	5806.40	0.00	0.00	325.89	0.00	0.00	0.00
2002	2004	2	2	5480.51	0.00	0.00	307.60	0.00	0.00	178.45
2002	2004	3	3	4994.46	0.00	0.00	92.02	0.00	0.00	0.00
2002	2004	3	4	4902.45	0.00	81.23	88.82	0.00	0.00	0.00
2002	2004	3	5	4732.39	110.61	190.31	81.64	0.00	0.00	0.00
2002	2004	3	6	4349.84	189.42	145.65	73.97	0.00	0.00	0.00
2002	2004	3	7	3940.81	156.66	316.65	63.88	0.00	0.00	0.00
2002	2004	3	8	3403.61	10.42	53.77	61.52	0.00	0.00	0.00
2002	2004	3	9	3277.89	0.00	7.04	60.26	0.00	0.00	0.00
2002	2004	3	10	3210.59	0.00	2.58	59.10	0.00	0.00	0.00
2002	2004	3	11	3148.90	0.00	13.49	57.77	0.00	0.00	0.00
2002	2004	3	12	3077.65	0.00	0.00	56.70	0.00	0.00	0.00
2002	2005	3	1	3020.95	0.00	0.00	55.66	0.00	0.00	0.00
2002	2005	3	2	2965.29	0.00	0.00	54.63	0.00	3.12	2705.25
2002	2005	4	3	202.29	0.00	0.00	3.73	0.00	0.00	0.00
2002	2005	4	4	198.56	0.00	15.06	3.38	0.00	0.00	0.00
2002	2005	4	5	180.12	8.20	0.00	3.17	0.00	0.00	0.00
2002	2005	4	6	168.76	13.28	0.00	2.86	0.00	0.00	0.00
2002	2005	4	7	152.61	19.05	0.00	2.46	0.00	0.00	0.00
2002	2005	4	8	131.10	8.71	0.00	2.25	0.00	0.00	0.00
2002	2005	4	9	120.13	8.75	0.00	2.05	0.00	0.00	0.00
2002	2005	4	10	109.33	0.00	0.00	2.01	0.00	0.00	0.00
2002	2005	4	11	107.32	0.00	4.37	1.90	0.00	0.00	0.00
2002	2005	4	12	101.05	0.00	0.00	1.86	0.00	0.00	0.00
2002	2006	4	1	99.19	0.00	0.00	1.83	0.00	0.00	0.00
2002	2006	4	2	97.36	0.00	0.00	1.79	0.00	1.03	94.54
2002	2006	5	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2007	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2007	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: O'Farrell et al. 2012 National Marine Fisheries Service SWFSC Tech Memo (Appendix C, p 63 – 73, tables C1 – C10).

Figure C-19. Reconstructed cohort: 2002 brood

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2003	2004	2	3	7026.64	0.00	0.00	394.37	0.00	0.00	0.00
2003	2004	2	4	6632.26	0.00	0.00	372.24	0.00	0.00	0.00
2003	2004	2	5	6260.02	0.00	0.00	351.35	0.00	0.00	0.00
2003	2004	2	6	5908.67	0.00	0.00	331.63	0.00	0.00	0.00
2003	2004	2	7	5577.05	0.00	0.00	313.02	0.00	0.00	0.00
2003	2004	2	8	5264.03	0.00	0.00	295.45	0.00	0.00	0.00
2003	2004	2	9	4968.58	0.00	0.00	278.87	0.00	0.00	0.00
2003	2004	2	10	4689.72	0.00	0.00	263.21	0.00	0.00	0.00
2003	2004	2	11	4426.50	0.00	0.00	248.44	0.00	0.00	0.00
2003	2004	2	12	4178.06	0.00	0.00	234.50	0.00	0.00	0.00
2003	2005	2	1	3943.57	0.00	0.00	221.34	0.00	0.00	0.00
2003	2005	2	2	3722.23	0.00	0.00	208.91	0.00	0.00	141.67
2003	2005	3	3	3371.65	0.00	0.00	62.12	0.00	0.00	0.00
2003	2005	3	4	3309.53	0.00	81.20	59.48	0.00	0.00	0.00
2003	2005	3	5	3168.86	0.00	99.43	56.55	0.00	0.00	0.00
2003	2005	3	6	3012.88	33.68	157.09	51.99	0.00	0.00	0.00
2003	2005	3	7	2770.12	76.05	77.48	48.21	0.00	0.00	0.00
2003	2005	3	8	2568.38	34.15	12.01	46.47	0.00	0.00	0.00
2003	2005	3	9	2475.76	2.28	3.59	45.50	0.00	0.00	0.00
2003	2005	3	10	2424.38	0.00	0.00	44.67	0.00	0.00	0.00
2003	2005	3	11	2379.72	0.00	2.01	43.81	0.00	0.00	0.00
2003	2005	3	12	2333.91	0.00	0.00	43.00	0.00	0.00	0.00
2003	2006	3	1	2290.91	0.00	0.00	42.21	0.00	0.00	0.00
2003	2006	3	2	2248.70	0.00	0.00	41.43	0.00	2.02	2092.10
2003	2006	4	3	113.15	0.00	0.00	2.08	0.00	0.00	0.00
2003	2006	4	4	111.07	0.00	5.33	1.95	0.00	0.00	0.00
2003	2006	4	5	103.79	3.11	0.00	1.85	0.00	0.00	0.00
2003	2006	4	6	98.82	0.00	5.52	1.72	0.00	0.00	0.00
2003	2006	4	7	91.57	0.00	10.51	1.49	0.00	0.00	0.00
2003	2006	4	8	79.57	0.00	0.00	1.47	0.00	0.00	0.00
2003	2006	4	9	78.10	1.61	0.00	1.41	0.00	0.00	0.00
2003	2006	4	10	75.09	0.00	0.00	1.38	0.00	0.00	0.00
2003	2006	4	11	73.70	0.00	0.00	1.36	0.00	0.00	0.00
2003	2006	4	12	72.35	0.00	0.00	1.33	0.00	0.00	0.00
2003	2007	4	1	71.01	0.00	0.00	1.31	0.00	0.00	0.00
2003	2007	4	2	69.70	0.00	0.00	1.28	0.00	2.18	62.59
2003	2007	5	3	3.65	0.00	0.00	0.07	0.00	0.00	0.00
2003	2007	5	4	3.58	0.00	0.00	0.07	0.00	0.00	0.00
2003	2007	5	5	3.52	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	6	3.45	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	7	3.39	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	8	3.33	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	9	3.26	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	10	3.20	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	11	3.15	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	12	3.09	0.00	0.00	0.06	0.00	0.00	0.00
2003	2008	5	1	3.03	0.00	0.00	0.06	0.00	0.00	0.00
2003	2008	5	2	2.97	0.00	0.00	0.05	0.00	0.00	2.92

Source: O’Farrell et al. 2012 National Marine Fisheries Service SWFSC Tech Memo (Appendix C, p 63 – 73, tables C1 – C10).

Figure C-20. Reconstructed cohort: 2003 brood

BY	CY	Age	Month	Ocean				River		
				N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2004	2005	2	3	291.71	0.00	0.00	16.37	0.00	0.00	0.00
2004	2005	2	4	275.34	0.00	0.00	15.45	0.00	0.00	0.00
2004	2005	2	5	259.88	0.00	0.00	14.59	0.00	0.00	0.00
2004	2005	2	6	245.30	0.00	0.00	13.77	0.00	0.00	0.00
2004	2005	2	7	231.53	0.00	0.00	12.99	0.00	0.00	0.00
2004	2005	2	8	218.54	0.00	0.00	12.27	0.00	0.00	0.00
2004	2005	2	9	206.27	0.00	0.00	11.58	0.00	0.00	0.00
2004	2005	2	10	194.69	0.00	0.00	10.93	0.00	0.00	0.00
2004	2005	2	11	183.77	0.00	0.00	10.31	0.00	0.00	0.00
2004	2005	2	12	173.45	0.00	0.00	9.74	0.00	0.00	0.00
2004	2006	2	1	163.72	0.00	0.00	9.19	0.00	0.00	0.00
2004	2006	2	2	154.53	0.00	0.00	8.67	0.00	0.00	3.31
2004	2006	3	3	142.55	0.00	0.00	2.63	0.00	0.00	0.00
2004	2006	3	4	139.92	0.00	8.04	2.43	0.00	0.00	0.00
2004	2006	3	5	129.45	0.00	0.00	2.38	0.00	0.00	0.00
2004	2006	3	6	127.06	0.00	4.12	2.27	0.00	0.00	0.00
2004	2006	3	7	120.68	0.00	9.29	2.05	0.00	0.00	0.00
2004	2006	3	8	109.33	0.00	0.00	2.01	0.00	0.00	0.00
2004	2006	3	9	107.32	0.00	0.00	1.98	0.00	0.00	0.00
2004	2006	3	10	105.34	0.00	0.00	1.94	0.00	0.00	0.00
2004	2006	3	11	103.40	0.00	0.00	1.90	0.00	0.00	0.00
2004	2006	3	12	101.49	0.00	0.00	1.87	0.00	0.00	0.00
2004	2007	3	1	99.62	0.00	0.00	1.84	0.00	0.00	0.00
2004	2007	3	2	97.79	0.00	0.00	1.80	0.00	7.62	84.43
2004	2007	4	3	3.94	0.00	0.00	0.07	0.00	0.00	0.00
2004	2007	4	4	3.86	0.00	0.00	0.07	0.00	0.00	0.00
2004	2007	4	5	3.79	0.00	0.00	0.07	0.00	0.00	0.00
2004	2007	4	6	3.72	0.00	0.00	0.07	0.00	0.00	0.00
2004	2007	4	7	3.66	0.00	0.00	0.07	0.00	0.00	0.00
2004	2007	4	8	3.59	0.00	0.00	0.07	0.00	0.00	0.00
2004	2007	4	9	3.52	0.00	0.00	0.06	0.00	0.00	0.00
2004	2007	4	10	3.46	0.00	0.00	0.06	0.00	0.00	0.00
2004	2007	4	11	3.39	0.00	0.00	0.06	0.00	0.00	0.00
2004	2007	4	12	3.33	0.00	0.00	0.06	0.00	0.00	0.00
2004	2008	4	1	3.27	0.00	0.00	0.06	0.00	0.00	0.00
2004	2008	4	2	3.21	0.00	0.00	0.06	0.00	0.00	3.15
2004	2008	5	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2009	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2009	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: O'Farrell et al. 2012 National Marine Fisheries Service SWFSC Tech Memo (Appendix C, p 63 – 73, tables C1 – C10).

Figure C-21. Reconstructed cohort: 2004 brood

BY	CY	Age	Month	Ocean N	Ocean I_{com}	Ocean I_{rec}	Ocean V	River H_r	River E_{hat}	River E_{nat}
2005	2006	2	3	364.07	0.00	0.00	20.43	0.00	0.00	0.00
2005	2006	2	4	343.64	0.00	0.00	19.29	0.00	0.00	0.00
2005	2006	2	5	324.35	0.00	0.00	18.20	0.00	0.00	0.00
2005	2006	2	6	306.14	0.00	0.00	17.18	0.00	0.00	0.00
2005	2006	2	7	288.96	0.00	0.00	16.22	0.00	0.00	0.00
2005	2006	2	8	272.74	0.00	0.00	15.31	0.00	0.00	0.00
2005	2006	2	9	257.44	0.00	0.00	14.45	0.00	0.00	0.00
2005	2006	2	10	242.99	0.00	0.00	13.64	0.00	0.00	0.00
2005	2006	2	11	229.35	0.00	0.00	12.87	0.00	0.00	0.00
2005	2006	2	12	216.48	0.00	0.00	12.15	0.00	0.00	0.00
2005	2007	2	1	204.33	0.00	0.00	11.47	0.00	0.00	0.00
2005	2007	2	2	192.86	0.00	0.00	10.82	0.00	0.00	1.83
2005	2007	3	3	180.20	0.00	0.00	3.32	0.00	0.00	0.00
2005	2007	3	4	176.88	0.00	0.00	3.26	0.00	0.00	0.00
2005	2007	3	5	173.63	0.00	10.12	3.01	0.00	0.00	0.00
2005	2007	3	6	160.50	0.00	7.50	2.82	0.00	0.00	0.00
2005	2007	3	7	150.18	0.00	14.43	2.50	0.00	0.00	0.00
2005	2007	3	8	133.25	0.00	0.00	2.45	0.00	0.00	0.00
2005	2007	3	9	130.80	0.00	0.00	2.41	0.00	0.00	0.00
2005	2007	3	10	128.39	0.00	0.00	2.37	0.00	0.00	0.00
2005	2007	3	11	126.02	0.00	0.00	2.32	0.00	0.00	0.00
2005	2007	3	12	123.70	0.00	0.00	2.28	0.00	0.00	0.00
2005	2008	3	1	121.42	0.00	0.00	2.24	0.00	0.00	0.00
2005	2008	3	2	119.19	0.00	0.00	2.20	0.00	4.29	112.70
2005	2008	4	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	4	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	4	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2010	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2010	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: O'Farrell et al. 2012 National Marine Fisheries Service SWFSC Tech Memo (Appendix C, p 63 – 73, tables C1 – C10).

Figure C-22. Reconstructed cohort: 2005 brood

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2006	2007	2	3	1228.82	0.00	0.00	68.97	0.00	0.00	0.00
2006	2007	2	4	1159.85	0.00	0.00	65.10	0.00	0.00	0.00
2006	2007	2	5	1094.75	0.00	0.00	61.44	0.00	0.00	0.00
2006	2007	2	6	1033.31	0.00	0.00	58.00	0.00	0.00	0.00
2006	2007	2	7	975.31	0.00	0.00	54.74	0.00	0.00	0.00
2006	2007	2	8	920.57	0.00	0.00	51.67	0.00	0.00	0.00
2006	2007	2	9	868.90	0.00	0.00	48.77	0.00	0.00	0.00
2006	2007	2	10	820.14	0.00	0.00	46.03	0.00	0.00	0.00
2006	2007	2	11	774.11	0.00	0.00	43.45	0.00	0.00	0.00
2006	2007	2	12	730.66	0.00	0.00	41.01	0.00	0.00	0.00
2006	2008	2	1	689.65	0.00	0.00	38.71	0.00	0.00	0.00
2006	2008	2	2	650.94	0.00	0.00	36.53	8.70	3.35	22.35
2006	2008	3	3	580.01	0.00	0.00	10.69	0.00	0.00	0.00
2006	2008	3	4	569.32	0.00	0.00	10.49	0.00	0.00	0.00
2006	2008	3	5	558.83	0.00	0.00	10.30	0.00	0.00	0.00
2006	2008	3	6	548.54	0.00	0.00	10.11	0.00	0.00	0.00
2006	2008	3	7	538.43	0.00	0.00	9.92	0.00	0.00	0.00
2006	2008	3	8	528.51	0.00	0.00	9.74	0.00	0.00	0.00
2006	2008	3	9	518.77	0.00	0.00	9.56	0.00	0.00	0.00
2006	2008	3	10	509.22	0.00	0.00	9.38	0.00	0.00	0.00
2006	2008	3	11	499.84	0.00	0.00	9.21	0.00	0.00	0.00
2006	2008	3	12	490.63	0.00	0.00	9.04	0.00	0.00	0.00
2006	2009	3	1	481.59	0.00	0.00	8.87	0.00	0.00	0.00
2006	2009	3	2	472.72	0.00	0.00	8.71	0.00	6.23	423.12
2006	2009	4	3	34.66	0.00	0.00	0.64	0.00	0.00	0.00
2006	2009	4	4	34.02	0.00	0.00	0.63	0.00	0.00	0.00
2006	2009	4	5	33.39	0.00	0.00	0.62	0.00	0.00	0.00
2006	2009	4	6	32.78	0.00	0.00	0.60	0.00	0.00	0.00
2006	2009	4	7	32.17	0.00	0.00	0.59	0.00	0.00	0.00
2006	2009	4	8	31.58	0.00	0.00	0.58	0.00	0.00	0.00
2006	2009	4	9	31.00	0.00	0.00	0.57	0.00	0.00	0.00
2006	2009	4	10	30.43	0.00	0.00	0.56	0.00	0.00	0.00
2006	2009	4	11	29.87	0.00	0.00	0.55	0.00	0.00	0.00
2006	2009	4	12	29.32	0.00	0.00	0.54	0.00	0.00	0.00
2006	2010	4	1	28.78	0.00	0.00	0.53	0.00	0.00	0.00
2006	2010	4	2	28.25	0.00	0.00	0.52	0.00	0.00	26.83
2006	2010	5	3	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	4	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	5	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	6	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	7	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	8	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	9	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	10	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	11	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	12	NA	NA	NA	NA	NA	NA	NA
2006	2011	5	1	NA	NA	NA	NA	NA	NA	NA
2006	2011	5	2	NA	NA	NA	NA	NA	NA	NA

Source: O'Farrell et al. 2012 National Marine Fisheries Service SWFSC Tech Memo (Appendix C, p 63 – 73, tables C1 – C10).

Figure C-23. Reconstructed cohort: 2006 brood

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2007	2008	2	3	464.03	0.00	0.00	26.04	0.00	0.00	0.00
2007	2008	2	4	437.99	0.00	0.00	24.58	0.00	0.00	0.00
2007	2008	2	5	413.40	0.00	0.00	23.20	0.00	0.00	0.00
2007	2008	2	6	390.20	0.00	0.00	21.90	0.00	0.00	0.00
2007	2008	2	7	368.30	0.00	0.00	20.67	0.00	0.00	0.00
2007	2008	2	8	347.63	0.00	0.00	19.51	0.00	0.00	0.00
2007	2008	2	9	328.12	0.00	0.00	18.42	0.00	0.00	0.00
2007	2008	2	10	309.70	0.00	0.00	17.38	0.00	0.00	0.00
2007	2008	2	11	292.32	0.00	0.00	16.41	0.00	0.00	0.00
2007	2008	2	12	275.91	0.00	0.00	15.49	0.00	0.00	0.00
2007	2009	2	1	260.43	0.00	0.00	14.62	0.00	0.00	0.00
2007	2009	2	2	245.81	0.00	0.00	13.80	15.72	0.00	0.00
2007	2009	3	3	216.29	0.00	0.00	3.98	0.00	0.00	0.00
2007	2009	3	4	212.31	0.00	0.00	3.91	0.00	0.00	0.00
2007	2009	3	5	208.40	0.00	0.00	3.84	0.00	0.00	0.00
2007	2009	3	6	204.56	0.00	0.00	3.77	0.00	0.00	0.00
2007	2009	3	7	200.79	0.00	0.00	3.70	0.00	0.00	0.00
2007	2009	3	8	197.09	0.00	0.00	3.63	0.00	0.00	0.00
2007	2009	3	9	193.46	0.00	0.00	3.56	0.00	0.00	0.00
2007	2009	3	10	189.90	0.00	0.00	3.50	0.00	0.00	0.00
2007	2009	3	11	186.40	0.00	0.00	3.43	0.00	0.00	0.00
2007	2009	3	12	182.96	0.00	0.00	3.37	0.00	0.00	0.00
2007	2010	3	1	179.59	0.00	0.00	3.31	0.00	0.00	0.00
2007	2010	3	2	176.28	0.00	0.00	3.25	0.00	0.00	163.65
2007	2010	4	3	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	4	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	5	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	6	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	7	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	8	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	9	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	10	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	11	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	12	NA	NA	NA	NA	NA	NA	NA
2007	2011	4	1	NA	NA	NA	NA	NA	NA	NA
2007	2011	4	2	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	3	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	4	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	5	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	6	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	7	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	8	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	9	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	10	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	11	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	12	NA	NA	NA	NA	NA	NA	NA
2007	2012	5	1	NA	NA	NA	NA	NA	NA	NA
2007	2012	5	2	NA	NA	NA	NA	NA	NA	NA

Source: O'Farrell et al. 2012 National Marine Fisheries Service SWFSC Tech Memo (Appendix C, p 63 – 73, tables C1 – C10).

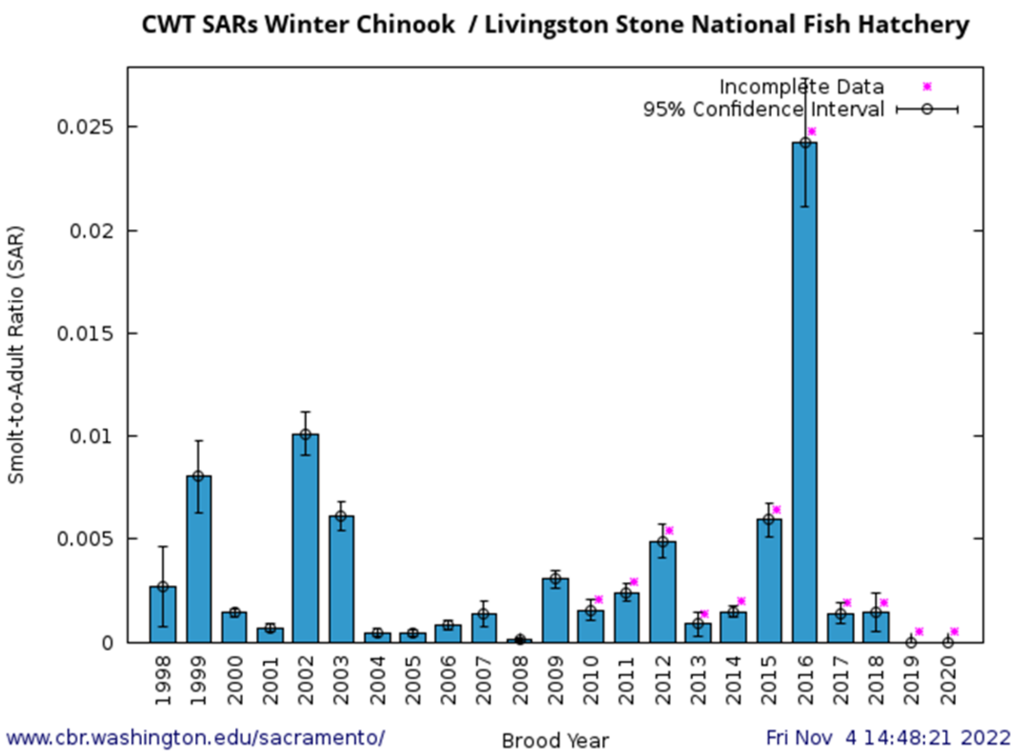
Figure C-24. Reconstructed cohort: 2007 brood

C.2.17 Subadult Ocean Survival

Cohort reconstructions for winter-run Chinook salmon specified annual natural mortality rates of 20% based on past cohort analyses (O'Farrell et al. 2012). This annual natural mortality rate is applied to ages 3, 4, and 5 and has been used since in management strategy evaluation and life cycle models (Winship et al. 2012; Hendrix et al. 2019).

Cohort reconstructions have also provided estimates of fishery impact rates for 1978 through 2012 (O'Farrell and Satterthwaite 2015). Since approximately 2000, fishery impact (i.e., mortality) rates have been around or below 20%. Combined estimates of impact rates and natural mortality yield estimates of total annual survival.

Estimates of smolt-to-adult ratios (SARs) for CWT tagged winter-run Chinook salmon from LSNFH are available for 1998-2020 from SacPAS (www.cbr.washington.edu/sacramento/). These are calculated only based on the number of released smolts with CWTs and the estimated number of adult returns.



Source: SacPAS (www.cbr.washington.edu/sacramento/).

Figure C-25. Smolt-to-adult ratio for CWT tagged winter-run Chinook salmon

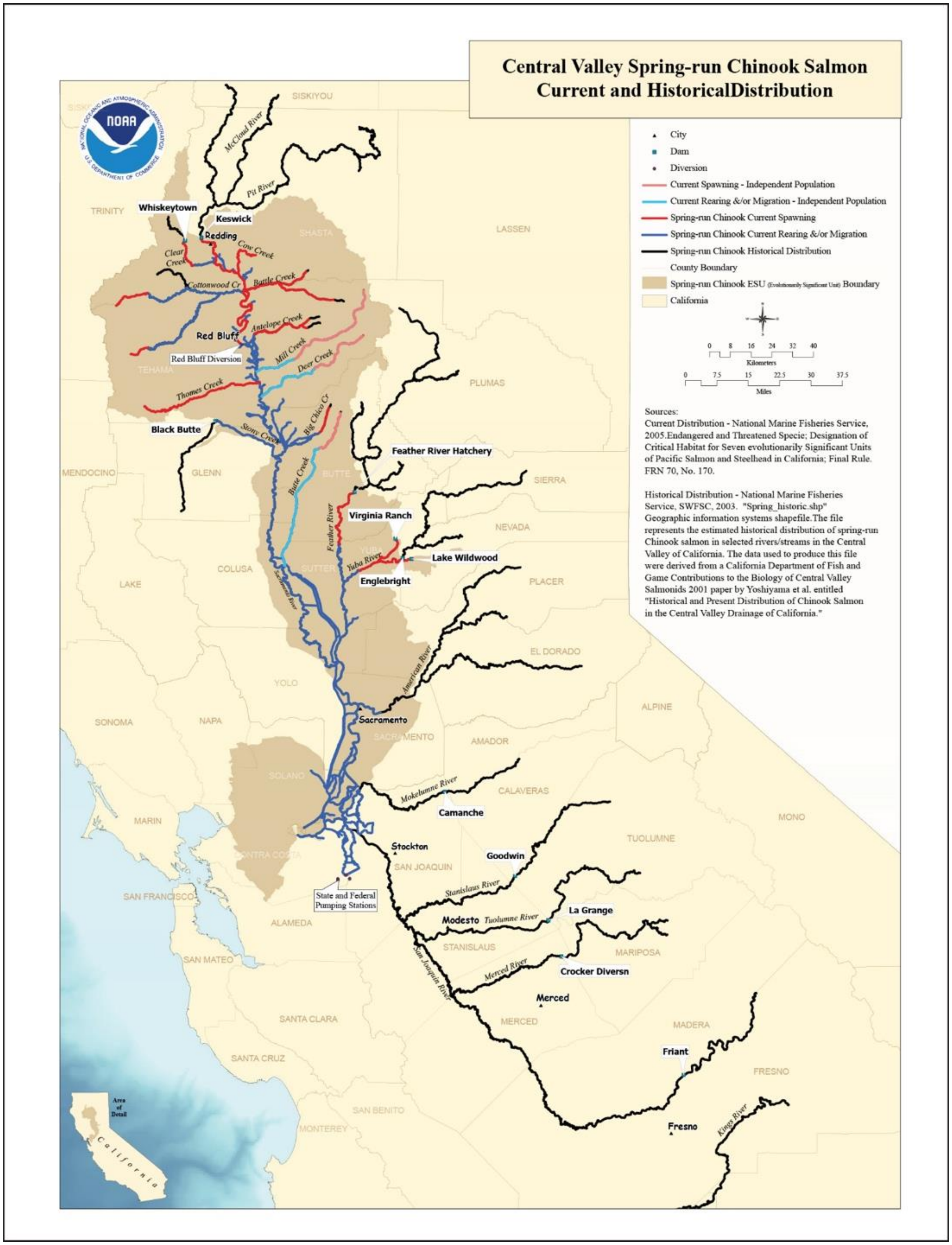
Analyses of late fall-run Chinook salmon using estimates of in-river survival from acoustic telemetry studies and overall smolt-to-adult survival from CWTs also observed total marine survival rates varying between 4.2% and 22.8% (Michel 2019). These survival rates encompass both juvenile and subadult ocean survival periods. Similar estimates of marine survival for winter-run Chinook salmon are not available, but this analysis provides a convenient reference point.

C.3 Spring-Run Chinook Salmon

Central Valley spring-run Chinook salmon have independent populations in Butte Creek, Mill Creek, and Deer Creek, with repopulation of a historically independent population in Battle Creek occurring; dependent populations occur in Antelope Creek, Big Chico Creek, Clear Creek, and Cottonwood/Beegum Creek (National Marine Fisheries Service 2016; Goertler et al. 2020). Of the tributaries of the Sacramento River, CVP uses Clear Creek and Battle Creek, which have monitoring efforts that can elucidate their spatiotemporal occurrences. Native spring-run Chinook salmon have been extirpated from the San Joaquin River watershed, which represented a large portion of their historical range. There are, however, San Joaquin River spring-run Chinook salmon as a result of reintroduction efforts, and spring-run Chinook salmon in San Joaquin River tributaries. Phenotypically spring-running Chinook salmon observed in the Tuolumne and Stanislaus Rivers in the last decade may represent strays from the Feather River hatchery (fall- or spring-run) or spring-run Chinook salmon produced in the Sacramento River Basin for reintroduction efforts in the San Joaquin River (National Marine Fisheries Service 2019:7).

Life history and habitat requirements are largely the same as those described for winter-run Chinook salmon, with differences primarily in the duration and time of year that spring-run adults and juveniles occupy freshwater habitat. Typically, adult spring-run Chinook salmon enter fresh water as sexually immature fish in the springtime, oversummer, 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.

Summaries of the temporal life-history domains for spring-run Chinook salmon can be found below, on Figure C-26.



Source: National Marine Fisheries Service 2003.

Figure C-26. Current and Historical Central Valley Spring-Run Chinook Salmon Distribution

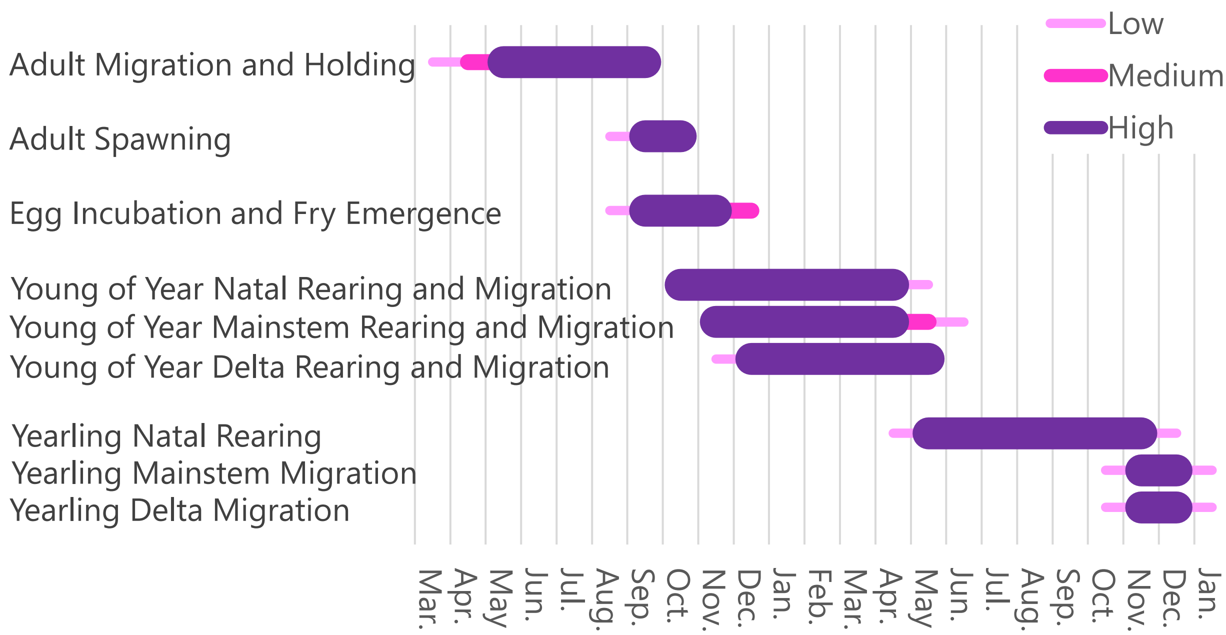


Figure C-27. Summary of Temporal Life Stage Domains for Spring-Run Chinook Salmon

C.3.1 Adult Migration and Holding

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). Adult passage data are limited, but 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. Historical timing from Baird Hatchery aligns with passage data collected at Red Bluff Diversion Dam from 1970–1988, showing the first occurrence in March and last passage by September (Table C-24).

Passage data is limited in the San Joaquin River basin, but unpublished data in the NMFS 5-year review (2016) revealed that adults began to return to tributaries, including the Mokelumne, Stanislaus, and Tuolumne Rivers, in February through June (Franks 2014; Workman 2003; FishBio 2015).

Table C-24. Summary of Spring-Run Chinook Salmon Adult Passage at Red Bluff Diversion Dam, 1970–1988

First	5% Passage	10% Passage	90% Passage	95% Passage	Last
March	April	May	September	September	September

C.3.2 Adult Spawning and Egg Incubation

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 are dependent on cold water temperatures (Myrick and Cech 2004). Data on spring-run specific spawning are limited due to the temporal and spatial overlap of spawning with fall-run Chinook salmon. Williams (2006) reports first occurrence of spawning in late August, peaking from mid-September to early October, and finishing by October (Table C-25). Fry emerge from gravels from November to March (Williams 2006). Post-emergent fry inhabit calm, shallow waters with fine substrates; fry depend on fallen trees, undercut banks, and overhanging riparian vegetation for refuge (Healey 1991).

Table C-25. Summary of Spring-Run Chinook Salmon Spawning in the Sacramento River Basin

River or Tributary	5% Passage	Peak	95% Passage
Butte Creek	–	September–October	–
Deer Creek	August	September	October
Sacramento River[a]	August–September	September–October	October

Source: Williams 2006.
[a] Killam pers. comm.

C.3.3 River Juvenile Natal Rearing and Mainstem Migration

Identification of spring-run Chinook salmon juvenile can be challenging. The length-at-date approach used in the Central Valley has limited ability to differentiate spring-run Chinook salmon from other runs. Spring-run Chinook salmon juveniles show two rearing patterns in natal tributaries: (1) the majority of spring-run Chinook juveniles exit tributaries and emigrate through the Sacramento River and the Delta in the spring; and (2) a very small proportion of juveniles oversummer in natal habitats and exit with the first rainstorms on the fall or winter following their birth. These fish are typically called *older* or *yearling* juveniles. 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), with residency in the Delta probably lessening as the season progresses into the late-spring months (California Department of Fish and Game 1998). Peak movement of yearling spring-run Chinook salmon occurs in October–December (Goertler et al. 2020).

Rotary screw trap data on spring-run Chinook salmon outmigration from Clear Creek show fish emigrating during late October through late April (Figure C-28; Table C-26 and Table C-27; Schraml and Chamberlain 2019; Schraml et al. 2020). Peak emigration of spring-run Chinook salmon juveniles occurs in November, with few fish existing each week through the end of May (Figure C-28). Yearlings are not observed in any significant fraction of the outmigration.

Review of spring-run Chinook salmon emigration from the upper Battle Creek rotary screw trap shows fish emigrating from late October through late May (Figure C-29; Table C-28; Schraml and Earley 2021, 2019). The trap is just upstream of the CNFH barrier weir. Capture of spring-run Chinook salmon juveniles begins in late October. Typically, the peak of spring-run Chinook salmon juveniles occurs during mid-November through early December, with few fish exiting every week through the end of May. Yearlings are not observed in any significant fraction of the outmigration.

On the mainstem Sacramento River, timing of spring-run Chinook salmon juvenile rearing and migration can be estimated from rotary screw traps at Red Bluff Diversion Dam and Knights Landing. Fish emigrate during mid-October through July, with peak passage between December and April (Table C-27, Table C-28, Table C-29, Table C-30).

Table C-26. Summary of Spring-Run Chinook Salmon Juvenile Natal Rearing and Mainstem Migration

Station	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
RBDD	October	October	December	April	May	June
KNL	October	December	December	April	April	May

Source: University of Washington, School of Aquatic and Fishery Science 2022.
RBDD = Red Bluff Diversion Dam

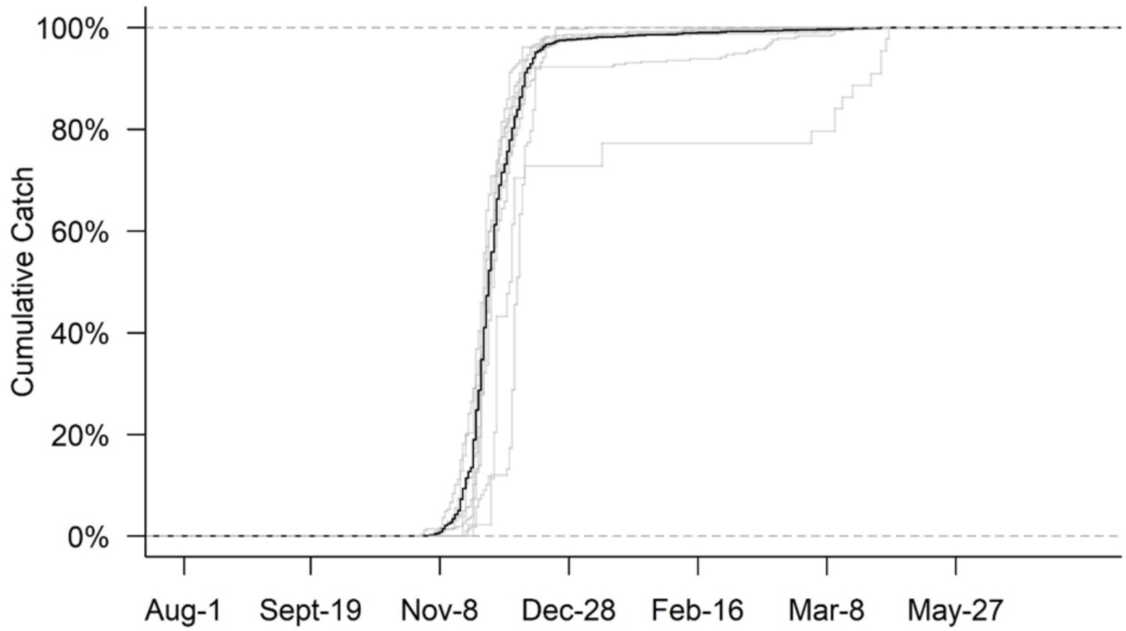


Figure C-28. Lower Clear Creek Rotary Screw Trap Spring-Run Chinook Salmon Catch Timing, 2011–2018 Brood Years

Table C-27. Lower Clear Creek Catch, USFWS Life Stage: Yolk-Sac Fry to Smolt

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2018	Nov 19	Nov 28	Nov 28	Apr 22	Apr 28	May 01
2017	Nov 21	Nov 21	Nov 21	Dec 15	Mar 04	Apr 19
2016	Oct 25	Nov 14	Nov 16	Dec 11	Dec 13	May 08
2015	Nov 03	Nov 11	Nov 14	Dec 12	Dec 16	Apr 28
2014	Nov 17	Nov 18	Nov 21	Dec 09	Dec 10	May 24
2013	Nov 05	Nov 21	Nov 22	Dec 10	Dec 16	Apr 23
2012	Nov 18	Nov 22	Nov 26	Dec 15	Dec 19	Jan 04
2011	Nov 01	Nov 18	Nov 18	Dec 05	Dec 14	Mar 16
Median Month	November	November	November	December	December	April

USFWS = U.S. Fish and Wildlife Service.

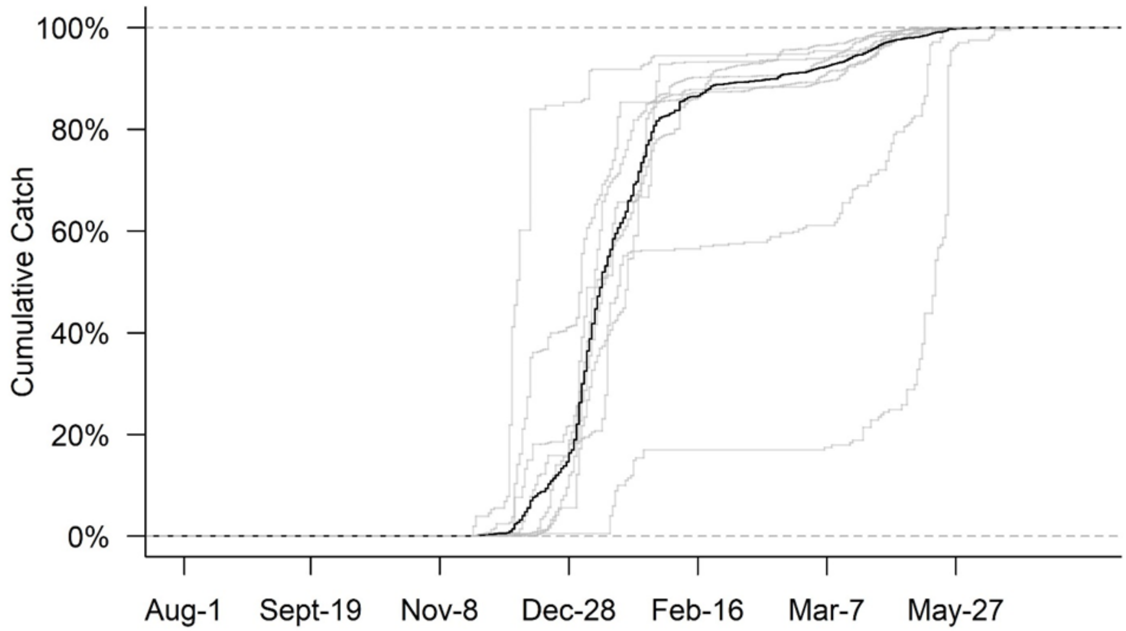


Figure C-29. Upper Battle Creek Catch, Life Stage: Yolk-Sac Fry to Smolt

Table C-28. Upper Battle Creek Spring-Run Chinook Salmon Passage Timing, 2011–2018; Life Stage: Yolk-Sac Fry to Smolt

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2018	Nov 28	Dec 07	Dec 11	Feb 01	Apr 19	May 31
2017	Dec 16	Dec 20	Dec 22	May 16	May 17	May 23
2016	Nov 21	Nov 28	Dec 05	Jan 05	Mar 25	May 09
2015	Dec 01	Dec 07	Dec 07	Apr 11	Apr 26	May 28
2014	Nov 25	Jan 14	Jan 19	May 24	May 25	Jun 17
2013	Nov 22	Dec 24	Dec 28	Feb 21	Mar 20	Jun 05
2012	Nov 15	Dec 12	Dec 15	Feb 12	Apr 12	Jun 27
2011	Dec 06	Dec 24	Dec 31	Apr 03	Apr 25	Jun 12
Median Month	November	December	December	March	April	May

USFWS = U.S. Fish and Wildlife Service.

Table C-29. Spring-Run Chinook Salmon Migration Timing Passing Red Bluff Diversion Dam

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	Nov 18	Jan 08	Mar 12	Apr 09	Apr 17	Jun 09
2019	Nov 19	Nov 27	Dec 03	Mar 19	Mar 21	Mar 23
2018	Nov 19	Mar 19	Mar 20	Apr 20	Apr 20	Jul 17
2017	Nov 19	Feb 05	Mar 15	May 08	May 13	Jun 07
2016	Oct 17	Nov 02	Mar 14	Apr 28	May 03	Jun 23
2015	Oct 16	Dec 15	Mar 17	Apr 13	Apr 14	Jun 01
2014	Oct 16	Dec 02	Dec 24	Apr 29	May 03	May 30
2013	Oct 18	Nov 02	Dec 06	Apr 17	Apr 24	Jun 17
2012	Oct 16	Oct 19	Oct 22	Apr 23	May 03	Aug 01
2011	Oct 16	Oct 18	Oct 20	Apr 16	Apr 28	Jun 01
2010	Oct 16	Oct 26	Oct 26	Apr 20	May 05	Jun 12
2009	Oct 16	Dec 04	Dec 15	Apr 22	Apr 30	May 27
2008	Oct 16	Nov 11	Nov 21	Apr 17	Apr 24	Jun 07
2007	Oct 16	Nov 23	Dec 01	Dec 26	Mar 26	Jun 20
2006	Oct 16	Oct 20	Oct 23	Apr 18	Apr 21	Jul 05
Median Month	October	October	December	April	May	June

Source: University of Washington, School of Aquatic and Fishery Science 2022.

Table C-30. Spring-Run Chinook Salmon Migration Timing Passing Knights Landing

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	Oct 25	Mar 19	Mar 23	Apr 13	Apr 16	May 03
2019	Oct 15	Dec 10	Dec 10	Apr 03	Apr 04	May 06
2018	Dec 03	Jan 13	Mar 23	Apr 16	Apr 21	May 22
2017	Oct 31	Mar 17	Apr 09	Apr 15	Apr 23	May 03
2016	Oct 21	Dec 13	Dec 19	Apr 08	Apr 14	May 09
2015	Dec 14	Dec 14	Dec 19	Dec 28	Dec 28	Dec 30
2014	Oct 23	Dec 08	Dec 08	Feb 18	Apr 09	May 05
2013	Nov 08	Mar 02	Mar 03	Apr 10	Apr 14	Apr 24
2012	Nov 24	Dec 02	Dec 03	Dec 08	Dec 09	Dec 13
2011	Oct 21	Mar 17	Mar 19	Apr 14	Apr 18	May 09
2010	Dec 07	Dec 17	Dec 19	Apr 19	Apr 20	Apr 28

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2009	Oct 20	Jan 24	Feb 16	Apr 15	Apr 15	May 09
2008	Oct 24	Feb 23	Feb 25	Apr 16	Apr 22	May 11
2007	Oct 15	Jan 06	Jan 07	Apr 28	Apr 28	May 12
2006	Dec 12	Dec 16	Dec 16	Apr 24	Apr 29	May 13
Median Month	October	December	December	April	April	May

Source: University of Washington, School of Aquatic and Fishery Science 2022.

C.3.4 Delta Juvenile Rearing and Migration

Identification of juvenile spring-run Chinook salmon can be challenging. Unlike winter-run Chinook salmon, the length-at-date approach used in the San Francisco Bay/Sacramento–San Joaquin Delta Estuary (Bay-Delta) to identify run of juvenile fish does not differentiate spring-run Chinook salmon very accurately due to the overlap of emergence with fall-run Chinook salmon.

Spring-run Chinook salmon juveniles show two migration patterns through the Delta: (1) the majority of spring-run Chinook salmon juveniles emigrate through the Sacramento River and the Delta in the spring; and (2) a proportion of juvenile oversummer in natal habitats and exit with the first rainstorms on the fall or winter following their birth. These fish are typically called *older* or *yearling* juveniles.

Delta entry is monitored at the Sacramento beach seines and trawl locations. Delta exit is monitored at the Chipps Island trawl location. Catch data was collected by USFWS and is displayed on the SacPAS database at https://www.cbr.washington.edu/sacramento/data/juv_monitoring.html. Juvenile passage in the Delta starts in November, peaks in the spring months around March, and ends by May (Table C-31, Table C-32, Table C-33, and Table C-34). Salvage data from the CVP facilities show a shift in occurrence, with the first spring-run detected in January and last in June, and peaking between April and May (Table C-35 and Figure C-30).

Table C-31. Summary of Juvenile Spring-Run Chinook Passage in the Delta by Median Month from USFWS Raw Catch Data on SacPAS

Station	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
Sacramento Beach Seine	December	December	December	April	April	April
Sacramento Trawl	January	March	March	April	April	May
Chipps Island Trawl	March	April	April	May	May	May

Source: University of Washington, School of Aquatic and Fishery Science 2022.
USFWS = U.S. Fish and Wildlife Service.

Table C-32. Juvenile Spring-Run Chinook Salmon in Sacramento Beach Seines in Sacramento Beach Seines

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	Feb 24	Feb 25	Feb 25	Apr 01	Apr 05	Apr 22
2019	Nov 08	Dec 11	Dec 16	Feb 03	Feb 26	Mar 17
2018	Dec 03	Dec 06	Dec 17	Apr 01	Apr 01	May 09
2017	Dec 06	Dec 29	Jan 22	Apr 05	Apr 05	Apr 05
2016	Nov 08	Nov 25	Dec 05	Apr 04	Apr 12	Apr 13
2015	Dec 24	Jan 13	Feb 11	Mar 29	Mar 29	Apr 13
2014	Dec 05	Dec 10	Dec 17	Mar 17	Apr 07	Apr 21
2013	Nov 14	Feb 11	Feb 12	Feb 28	Apr 03	Apr 29
2012	Nov 26	Dec 07	Dec 12	Feb 07	Feb 14	Apr 18
2011	Dec 05	Dec 12	Dec 21	Mar 29	Apr 03	Apr 18
2010	Nov 01	Dec 10	Dec 15	Mar 17	Mar 29	Apr 20
2009	Dec 28	Jan 04	Jan 04	Apr 15	Apr 15	Apr 22
2008	Jan 21	Feb 24	Feb 24	Apr 14	May 06	May 06
2007	Dec 28	Dec 28	Dec 28	Apr 08	Apr 17	Apr 24
2006	Dec 18	Dec 22	Dec 26	Feb 26	Feb 26	Mar 27
Median Month	December	December	December	April	April	April
2006	Dec 18	Dec 22	Dec 26	Feb 26	Feb 26	Mar 27
Median Month	December	December	December	April	April	April

Source: University of Washington, School of Aquatic and Fishery Science 2022.

Table C-33. Spring-Run Chinook Salmon Presence in Sacramento Trawl

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	Feb 4	Feb 25	Mar 29	Apr 11	Apr 12	Apr 22
2019	Dec 12	Mar 31	Apr 2	Apr 5	Apr 6	Apr 10
2018	Dec 3	Feb 4	Mar 1	Mar 31	Apr 9	Apr 21
2017	Feb 15	Mar 4	Mar 15	Mar 24	Apr 11	Apr 16
2016	Nov 23	Mar 28	Apr 1	Apr 5	Apr 12	May 1
2015	Jan 11	Mar 25	Mar 30	Apr 1	Apr 13	Apr 15
2014	Dec 5	Dec 8	Dec 15	Dec 24	Mar 27	Apr 17
2013	Fe 11b	Feb 15	Feb 22	Mar 7	Apr 7	Apr 11
2012	Dec 3	Apr 1	Apr 1	Apr 10	Apr 17	Apr 19

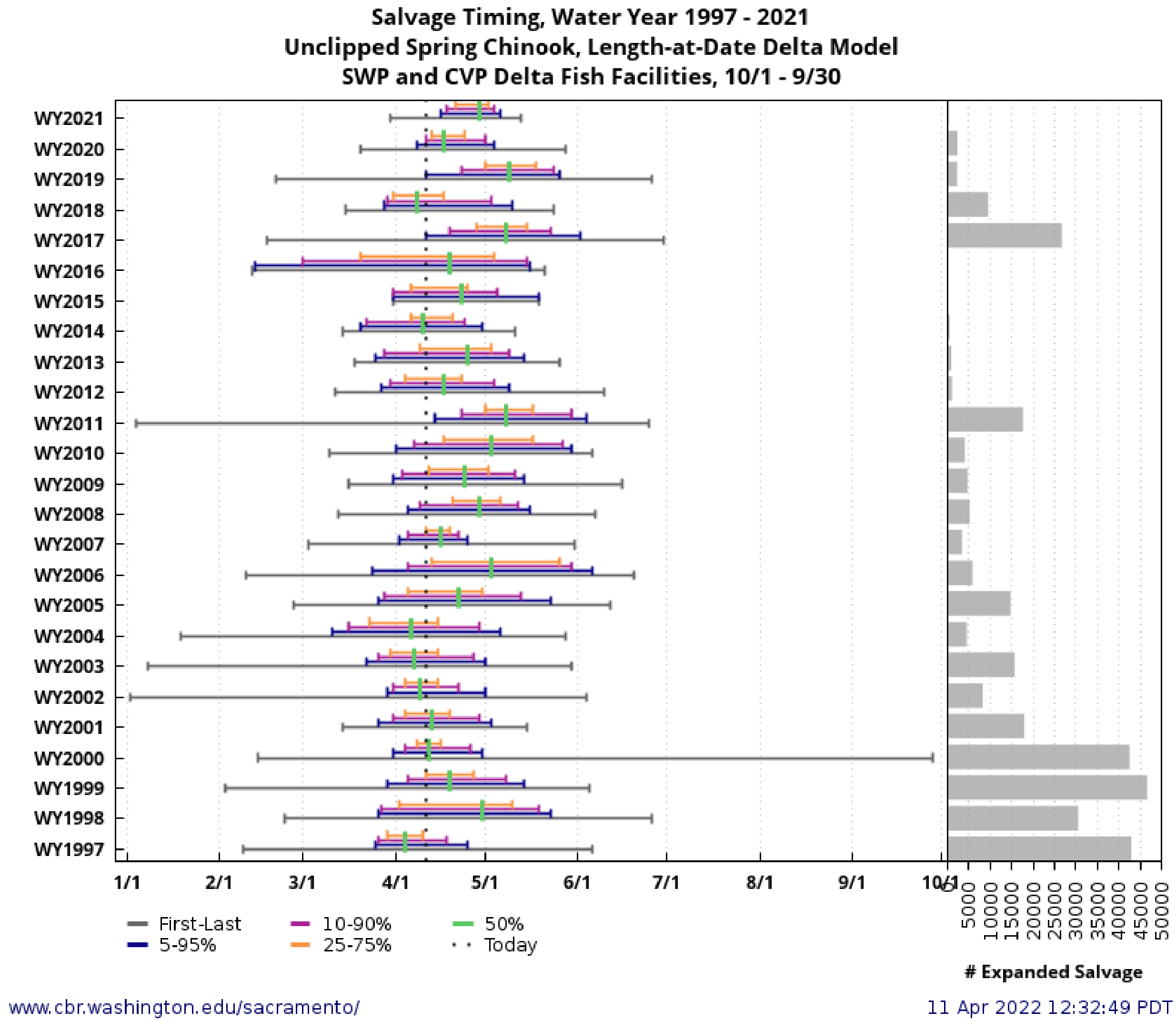
Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2011	Jan 25	Mar 16	Mar 19	Mar 30	Mar 30	Apr 18
2010	Dec 8	Dec 20	Jan 3	Apr 13	Apr 20	Apr 22
2009	Feb 3	Mar 1	Apr 9	Apr 16	Apr 16	Apr 23
2008	Feb 23	Apr 2	Apr 10	Apr 15	Apr 16	Apr 24
2007	Jan 7	Jan 7	Jan 11	Feb 27	Apr 14	Apr 25
2006	Feb 7	Feb 14	Feb 14	Apr 9	Apr 17	Apr 17
Median Month	January	March	March	April	April	May

Source: University of Washington, School of Aquatic and Fishery Science 2022.

Table C-34. Spring-Run Chinook Salmon Presence in Chipps Island Trawl

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	Mar 30	Apr 9	Apr 18	May 4	May 10	May 18
2019	Mar 23	Apr 6	Apr 6	May 1	May 8	May 15
2018	Mar 4	Apr 5	Apr 8	May 9	May 10	May 24
2017	Mar 27	Apr 10	Apr 12	Apr 27	Apr 29	May 27
2016	Feb 22	Apr 3	Apr 5	May 8	May 15	Jul 14
2015	Mar 16	Apr 4	Apr 6	Apr 29	May 2	May 31
2014	Feb 17	Mar 30	Apr 1	Apr 24	Apr 27	May 11
2013	Mar 7	Mar 28	Mar 31	May 5	May 8	May 22
2012	Mar 29	Apr 8	Apr 12	May 15	May 17	May 31
2011	Mar 23	Apr 6	Apr 13	May 11	May 14	May 18
2010	Feb 18	Apr 13	Apr 18	May 6	May 11	Jun 6
2009	Mar 29	Apr 9	Apr 16	May 14	May 14	Aug 16
2008	Mar 25	Apr 8	Apr 9	May 9	May 9	May 18
2007	Apr 3	Apr 7	Apr 14	May 5	May 8	May 30
2006	Mar 24	Apr 9	Apr 13	Apr 30	May 1	May 20
Median Month	March	April	April	May	May	May

Source: University of Washington, School of Aquatic and Fishery Science 2022.



Source: University of Washington, School of Aquatic and Fishery Science 2022.

Figure C-30. Unclipped Spring Chinook, Length-at-Date Delta Model Salvage Timing at CVP and SWP Fish Facilities

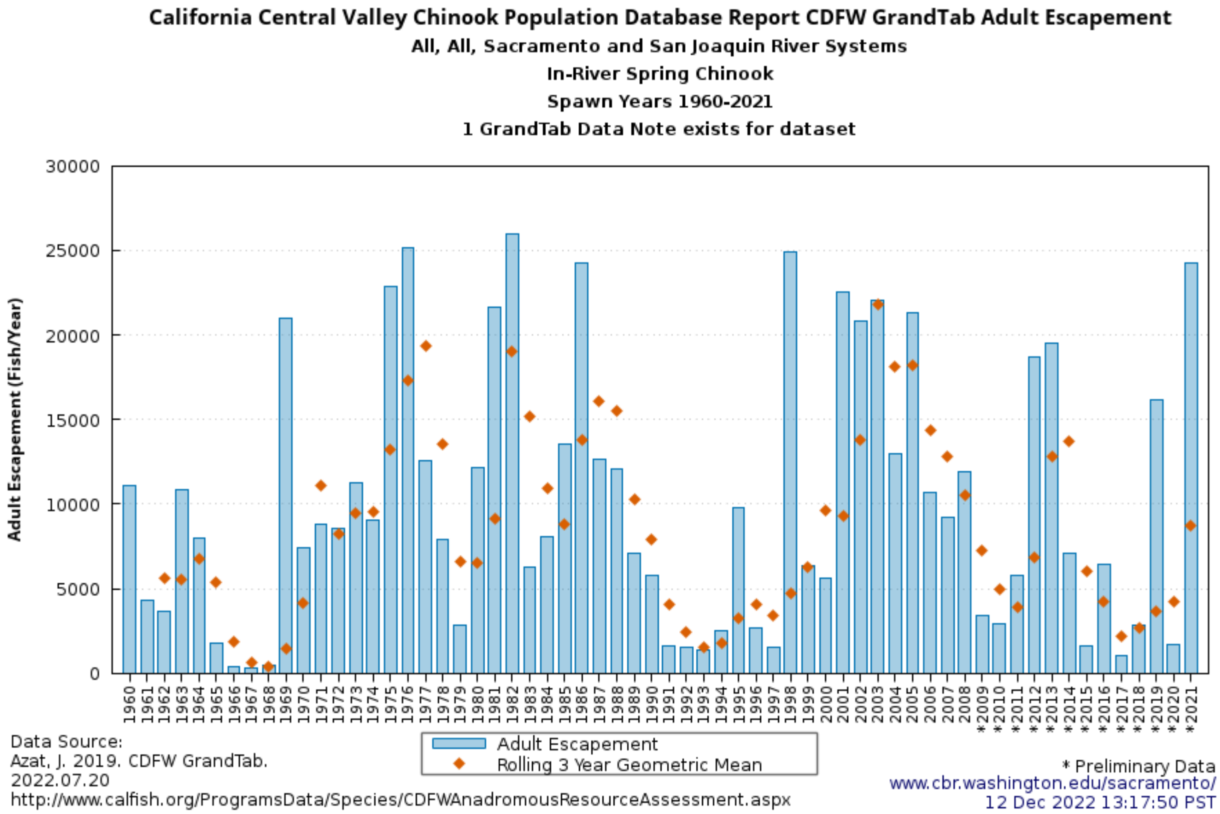
Table C-35. Unclipped Spring Chinook, Length-at-Date Delta Model Salvage Timing at CVP and SWP Fish Facilities

Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2021	3/29/2021	4/15/2021	4/17/2021	5/3/2021	5/5/2021	5/12/2021
2020	3/18/2020	4/6/2020	4/9/2020	4/29/2020	5/2/2020	5/26/2020
2019	2/19/2019	4/10/2019	4/22/2019	5/23/2019	5/25/2019	6/25/2019
2018	3/14/2018	3/27/2018	3/28/2018	5/2/2018	5/9/2018	5/23/2018
2017	2/16/2017	4/10/2017	4/18/2017	5/22/2017	6/1/2017	6/29/2017

Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2016	2/11/2016	2/12/2016	2/28/2016	5/13/2016	5/14/2016	5/19/2016
2015	3/30/2015	3/30/2015	3/30/2015	5/4/2015	5/18/2015	5/18/2015
2014	3/13/2014	3/19/2014	3/21/2014	4/23/2014	4/29/2014	5/10/2014
2013	3/17/2013	3/24/2013	3/27/2013	5/8/2013	5/13/2013	5/25/2013
2012	3/10/2012	3/25/2012	3/28/2012	5/2/2012	5/7/2012	6/8/2012
2011	1/3/2011	4/13/2011	4/22/2011	5/29/2011	6/3/2011	6/24/2011
2010	3/9/2010	3/31/2010	4/6/2010	5/26/2010	5/29/2010	6/5/2010
2009	3/15/2009	3/30/2009	4/2/2009	5/10/2009	5/13/2009	6/15/2009
2008	3/11/2008	4/3/2008	4/7/2008	5/10/2008	5/14/2008	6/5/2008
2007	3/2/2007	4/1/2007	4/4/2007	4/21/2007	4/24/2007	5/30/2007
2006	2/9/2006	3/23/2006	4/4/2006	5/29/2006	6/5/2006	6/19/2006
2005	2/25/2005	3/25/2005	3/27/2005	5/12/2005	5/22/2005	6/11/2005
2004	1/18/2004	3/9/2004	3/14/2004	4/27/2004	5/4/2004	5/26/2004
2003	1/7/2003	3/21/2003	3/25/2003	4/26/2003	4/30/2003	5/29/2003
2002	1/1/2002	3/28/2002	3/30/2002	4/21/2002	4/30/2002	6/3/2002
2001	3/13/2001	3/25/2001	3/30/2001	4/28/2001	5/2/2001	5/14/2001
2000	2/13/2000	3/29/2000	4/2/2000	4/24/2000	4/28/2000	9/26/2000
1999	2/2/1999	3/28/1999	4/4/1999	5/7/1999	5/13/1999	6/4/1999
1998	2/22/1998	3/25/1998	3/26/1998	5/18/1998	5/22/1998	6/25/1998
1997	2/8/1997	3/24/1997	3/25/1997	4/17/1997	4/24/1997	6/5/1997
Median	February	March	March	May	May	June

Source: University of Washington, School of Aquatic and Fishery Science 2022.
CVP = Central Valley Project; SWP = State Water Project.

C.3.5 Spawner Adult Abundance



Source: SacPAS (www.cbr.washington.edu/sacramento/).

Figure C-31. California Central Valley Chinook population adult spring-run escapement and rolling 3-year geometric mean (red diamonds), Sacramento and San Joaquin river systems, spawn years 1960 – 2021

Table C-36. Spring-run Chinook salmon (in-river plus hatchery return) 1960-2021 (December to August). Asterisks denote preliminary data

Year	Annual	3 Year Rolling Geometric Mean
2021 *	24258	8718
2020 *	1688	4247
2019 *	16186	3636
2018 *	2805	2679
2017 *	1059	2226
2016 *	6474	4204
2015 *	1609	6073
2014 *	7133	13753

Year	Annual	3 Year Rolling Geometric Mean
2013 *	19516	12842
2012 *	18688	6851
2011 *	5807	3903
2010 *	2964	4962
2009 *	3457	7246
2008	11927	10568
2007	9228	12825
2006	10725	14355
2005	21319	18249
2004	12938	18115
2003	22035	21794
2002	20854	13794
2001	22528	9289
2000	5587	9605
1999	6369	6250
1998	24903	4696
1997	1540	3444
1996	2702	4073
1995	9824	3274
1994	2546	1768
1993	1404	1521
1992	1547	2440
1991	1623	4053
1990	5790	7917
1989	7085	10280
1988	12100	15496
1987	12675	16107
1986	24263	13838
1985	13589	8807
1984	8037	10931
1983	6256	15206
1982	25980	18996
1981	21636	9110
1980	12195	6518

Year	Annual	3 Year Rolling Geometric Mean
1979	2866	6580
1978	7924	13570
1977	12545	19326
1976	25141	17334
1975	22887	13249
1974	9053	9556
1973	11225	9466
1972	8588	8252
1971	8800	11123
1970	7437	4143
1969	21030	1467
1968	455	400
1967	330	631
1966	427	1829
1965	1788	5373
1964	8021	6811
1963	10817	5544
1962	3642	5587
1961	4327	-
1960	11068	-

Source: Azat 2022.

Table C-37. Upper Sacramento River Chinook salmon population estimates by run for upper Sacramento River basin (upstream of Princeton) for 1952 – 2021

Year	Winter-Run Chinook salmon	Spring-Run Chinook salmon
1952	n/a	n/a
1953	n/a	n/a
1954	n/a	n/a
1955	n/a	n/a
1956	n/a	n/a
1957	n/a	n/a
1958	n/a	n/a
1959	n/a	n/a

Year	Winter-Run Chinook salmon	Spring-Run Chinook salmon
1960	n/a	2368
1961	n/a	1245
1962	n/a	1892
1963	n/a	4117
1964	n/a	4513
1965	n/a	50
1966	n/a	50
1967	n/a	150
1968	n/a	175
1969	n/a	20200
1970	40409	7152
1971	53089	8330
1972	35929	7938
1973	22651	10925
1974	21389	8903
1975	22579	22237
1976	33029	25095
1977	16470	12445
1978	24735	7794
1979	2339	2856
1980	1142	11369
1981	22551	20655
1982	1272	25356
1983	1827	6206
1984	2662	8014
1985	5131	13335
1986	2566	22892
1987	2165	12661
1988	2857	10810
1989	691	5785
1990	426	5540
1991	210	1623
1992	1237	817
1993	378	754

Year	Winter-Run Chinook salmon	Spring-Run Chinook salmon
1994	186	2072
1995	1297	2324
1996	1337	1289
1997	880	905
1998	2992	4644
1999	3288	2690
2000	1352	1469
2001	8224	3750
2002	7441	4445
2003	8218	4631
2004	7869	2380
2005	15839	3727
2006	17296	4188
2007	2541	2357
2008	2830	881
2009	4537	753
2010	1596	971
2011	827	934
2012	2671	2371
2013	6084	2734
2014	3015	2042
2015	3440	626
2016	1547	722
2017	977	544
2018	2639	443
2019	8128	1326
2020	7619	417
2021	10509	3592
Average	8,710	5,701

Source: Killam 2022.

C.3.6 Fecundity

No observations available for spring-run Chinook salmon fecundity because data are limited.

C.3.7 Redds

C.3.7.1 Clear Creek

Table C-38. Clear Creek spring-run Chinook salmon redd and carcass counts from spawning ground surveys

	Redds Observed	Carcasses Collected
2013	142	78
2014	66	84
2015	29	37
2016	22	19
2017	9	12
2018	4	10

Source: Bottaro and Chamberlain 2019.

C.3.7.2 Battle Creek

Table C-39. Battle Creek, total Chinook salmon redds 1995 – 2019, August – November. Observations made during spring-run Chinook salmon snorkel surveys, but may include spring-run Chinook and fall-run Chinook salmon redds.

Year	Total Chinook salmon redds (n)
1995	13
1996	21
1997	66
1998	247
1999	-
2000	-
2001	33
2002	78
2003	173
2004	35
2005	47
2006	122
2007	132
2008	40
2009	88

Year	Total Chinook salmon redds (n)
2010	93
2011	66
2012	320
2013	119
2014	99
2015	28
2016	51
2017	5
2018	29
2019	30

Source: Stanley, C.E., R.J. Bottaro, and L.A. Earley. 2020. Monitoring adult Chinook Salmon, Rainbow Trout, and Steelhead in Battle Creek, California, from March through November 2019. USFWS Report. U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office, Red Bluff, California.

C.3.7.3 American River

There are no observed spring-run Chinook salmon redd survey data from the American River, data are limited.

C.3.7.4 Stanislaus River

There have been intermittent observations of holding adult spring-run Chinook salmon on the Stanislaus River. CDFW redd and carcass surveys in 2021 started the week of October 4, 2021, and four redds were observed that week. CDFW also collected a skeleton and tagged 2 ad-clipped carcasses that were confirmed to be San Joaquin spring-run Chinook salmon. In 2022, CDFW surveyed Goodwin and Two Mile Bar on September 28 and observed four redds. Redd and carcass surveys the week of October 3, 2022, observed an additional three redds (Kok pers. comm.).

C.3.7.5 Sacramento River

Table C-40. Summary of redd count data from 2021 aerial flights on the upper Sacramento River basin: 13 winter-run, 1 spring-run, 2 late fall-run, 0 fall-run surveys

Winter-Run Chinook salmon	Spring-Run Chinook salmon	River Section
331	0	Keswick to A.C.I.D. Dam
246	41	A.C.I.D. Dam to Highway 44 Bridge
1	48	Highway 44 Br. To Airport Rd. Br
0	6	Airport Rd. Br. To Balls Ferry Br.
0	0	Balls Ferry Br. To Battle Creek

Winter-Run Chinook salmon	Spring-Run Chinook salmon	River Section
0	0	Battle Creek to Jelly’s Ferry Br
0	0	Jelly’s Ferry Br. To Bend Bridge
0	0	Bend Bridge to RBDD
0	0	RBDD to Tehama Br
0	0	Tehama Br. To Woodson Bridge
0	0	Woodson Bridge to Hamilton City Br.
0	0	Hamilton City Bridge to Ord Ferry Br.
0	0	Ord Ferry Br. To Princeton Ferry
578	95	Total

Source: Killam 2022.
RBDD = Red Bluff Diversion Dam

Table C-41. Summary of redd count data from 2020 aerial flights on the upper Sacramento River basin: 11 winter-run, 0 spring-run, 2 late fall-run, 2 fall-run surveys

Winter-Run Chinook salmon	Spring-Run Chinook salmon	River Section
229	n/a	Keswick to A.C.I.D. Dam
226	n/a	A.C.I.D. Dam to Highway 44 Bridge
36	n/a	Highway 44 Br. To Airport Rd. Br
0	n/a	Airport Rd. Br. To Balls Ferry Br.
0	n/a	Balls Ferry Br. To Battle Creek
0	n/a	Battle Creek to Jelly’s Ferry Br
0	n/a	Jelly’s Ferry Br. To Bend Bridge
0	n/a	Bend Bridge to RBDD
0	n/a	RBDD to Tehama Br
0	n/a	Tehama Br. To Woodson Bridge
0	n/a	Woodson Bridge to Hamilton City Br.
0	n/a	Hamilton City Bridge to Ord Ferry Br.
0	n/a	Ord Ferry Br. To Princeton Ferry
491	14	Total

Source: Killam 2021.
RBDD = Red Bluff Diversion Dam

Table C-42. Summary of redd count data from 2019 aerial flights on the upper Sacramento River basin: 13 winter-run, 1 spring-run, 0 late fall-run, 2 fall-run surveys

Winter-Run Chinook salmon	Spring-Run Chinook salmon	River Section
9	0	Keswick to A.C.I.D. Dam
256	7	A.C.I.D. Dam to Highway 44 Bridge
213	7	Highway 44 Br. To Airport Rd. Br
36	0	Airport Rd. Br. To Balls Ferry Br.
0	0	Balls Ferry Br. To Battle Creek
0	0	Battle Creek to Jelly's Ferry Br
1	0	Jelly's Ferry Br. To Bend Bridge
0	0	Bend Bridge to RBDD
0	n/a	RBDD to Tehama Br
0	n/a	Tehama Br. To Woodson Bridge
0	n/a	Woodson Bridge to Hamilton City Br.
0	n/a	Hamilton City Bridge to Ord Ferry Br.
0	n/a	Ord Ferry Br. To Princeton Ferry
515	14	Total

Source: Killam 2020.
RBDD = Red Bluff Diversion Dam

Table C-43. Summary of redd count data from 2018 aerial flights on the upper Sacramento River basin: 12 winter-run, 0 spring-run, 5 late fall-run, 3 fall-run surveys

Winter-Run Chinook salmon	Spring-Run Chinook salmon	River Section
54	n/a	Keswick to A.C.I.D. Dam
130	n/a	A.C.I.D. Dam to Highway 44 Bridge
14	n/a	Highway 44 Br. To Airport Rd. Br
0	n/a	Airport Rd. Br. To Balls Ferry Br.
0	n/a	Balls Ferry Br. To Battle Creek
0	n/a	Battle Creek to Jelly's Ferry Br
0	n/a	Jelly's Ferry Br. To Bend Bridge
0	n/a	Bend Bridge to RBDD
0	n/a	RBDD to Tehama Br
0	n/a	Tehama Br. To Woodson Bridge
0	n/a	Woodson Bridge to Hamilton City Br.

Winter-Run Chinook salmon	Spring-Run Chinook salmon	River Section
0	n/a	Hamilton City Bridge to Ord Ferry Br.
0	n/a	Ord Ferry Br. To Princeton Ferry
198	0	Total

Source: Killam 2019.
RBDD = Red Bluff Diversion Dam

Table C-44. Summary of redd count data from 2017 aerial flights on the upper Sacramento River basin: 8 winter-run, 1 spring-run, 1 late fall-run, 3 fall-run surveys

Winter-Run Chinook salmon	Spring-Run Chinook salmon	River Section
0	0	Keswick to A.C.I.D. Dam
23	1	A.C.I.D. Dam to Highway 44 Bridge
3	1	Highway 44 Br. To Airport Rd. Br
0	0	Airport Rd. Br. To Balls Ferry Br.
0	0	Balls Ferry Br. To Battle Creek
0	0	Battle Creek to Jelly's Ferry Br
0	0	Jelly's Ferry Br. To Bend Bridge
0	0	Bend Bridge to RBDD
0	0	RBDD to Tehama Br
0	0	Tehama Br. To Woodson Bridge
0	0	Woodson Bridge to Hamilton City Br.
0	0	Hamilton City Bridge to Ord Ferry Br.
0	0	Ord Ferry Br. To Princeton Ferry
26	2	Total

Source: Killam 2018.
RBDD = Red Bluff Diversion Dam

Table C-45. Summary of redd count data from 2016 aerial flights on the upper Sacramento River basin: 16 winter-run, 1 spring-run, 3 late fall-run, 3 fall-run surveys

Winter-Run Chinook salmon	Spring-Run Chinook salmon	River Section
0	0	Keswick to A.C.I.D. Dam
12	0	A.C.I.D. Dam to Highway 44 Bridge
6	1	Highway 44 Br. To Airport Rd. Br
0	0	Airport Rd. Br. To Balls Ferry Br.

0	0	Balls Ferry Br. To Battle Creek
0	0	Battle Creek to Jelly's Ferry Br
0	0	Jelly's Ferry Br. To Bend Bridge
0	0	Bend Bridge to RBDD
0	0	RBDD to Tehama Br
0	0	Tehama Br. To Woodson Bridge
0	0	Woodson Bridge to Hamilton City Br.
0	0	Hamilton City Bridge to Ord Ferry Br.
0	0	Ord Ferry Br. To Princeton Ferry
18	1	Total

Source: Killam et al. 2017.
RBDD = Red Bluff Diversion Dam

Table C-46. Summary of aerial redd count percentages for Sacramento River for 1969 – 2021. n/a represents no flight conducted. (Keswick Dam to Red Bluff Diversion Dam = % Up; Red Bluff Diversion Dam to Princeton Ferry = % Down)

	Winter-Run Chinook salmon		**Spring-Run Chinook salmon**	
	% Up	**% Down**	**% Up**	**% Down**
1969	n/a	n/a	n/a	n/a
1970	n/a	n/a	n/a	n/a
1971	n/a	n/a	n/a	n/a
1972	n/a	n/a	n/a	n/a
1973	n/a	n/a	n/a	n/a
1974	n/a	n/a	n/a	n/a
1975	n/a	n/a	n/a	n/a
1976	n/a	n/a	n/a	n/a
1977	n/a	n/a	n/a	n/a
1978	n/a	n/a	n/a	n/a
1979	n/a	n/a	n/a	n/a
1980	n/a	n/a	n/a	n/a
1981	88%	12%	n/a	n/a
1982	97%	3%	n/a	n/a
1983	n/a	n/a	81%	19%
1984	n/a	n/a	93%	7%
1985	72%	28%	79%	21%

	Winter-Run Chinook salmon		Spring-Run Chinook salmon	
	% Up	% Down	% Up	% Down
1986	n/a	n/a	100%	0%
1987	96%	4%	n/a	n/a
1988	75%	25%	97%	3%
1989	98%	2%	100%	0%
1990	93%	7%	100%	0%
1991	100%	0%	100%	0%
1992	96%	4%	100%	0%
1993	98%	2%	100%	0%
1994	100%	0%	85%	15%
1995	99%	1%	91%	9%
1996	100%	0%	100%	0%
1997	100%	0%	99%	1%
1998	98%	2%	100%	0%
1999	100%	0%	100%	0%
2000	100%	0%	100%	0%
2001	100%	0%	97%	3%
2002	100%	0%	100%	0%
2003	100%	0%	100%	0%
2004	100%	0%	100%	0%
2005	100%	0%	85%	15%
2006	100%	0%	100%	0%
2007	100%	0%	100%	0%
2008	100%	0%	83%	17%
2009	100%	0%	n/a	n/a
2010	100%	0%	100%	0%
2011	100%	0%	n/a	n/a
2012	100%	0%	n/a	n/a
2013	100%	0%	100%	0%
2014	100%	0%	n/a	n/a
2015	100%	0%	n/a	n/a
2016	100%	0%	100%	0%
2017	100%	0%	100%	0%
2018	100%	0%	n/a	n/a

	Winter-Run Chinook salmon		Spring-Run Chinook salmon	
	% Up	% Down	% Up	% Down
2019	100%	0%	100%	0%
2020	100%	0%	n/a	n/a
2021	100%	0%	100%	0%
AVERAGE	98%	2%	96%	4%

Source: Killam 2022.

C.3.8 Survival of Eggs

There are no available estimates of egg survival for spring-run Chinook salmon.

C.3.9 Fry Exiting Natal Stream Abundance

Table C-47. Red Bluff Diversion Dam RST juvenile anadromous fish abundance estimated passage of spring-run Chinook salmon fry, pre-smolt/smolts, total, and fry-equivalent JPI (90% CI low and high) (brood years 2013 – 2019)

Period	BY	Estimated Fry	Estimated Pre-Smolt / Smolts	Estimated Total	Fry-Equivalent JPI
10/16/2019 - 10/15/2020	2019	33,791 low 13,214 high 54,368	127,653 low 21,601 high 233,704	161,444 low 35,412 high 287,476	250,801 low 52,518 high 449,084
10/16/2018 - 10/15/2019	2018	28,389 low -949 high 57.727	274,765 low -115,272 high 665,801	303,154 low -115,508 high 721,815	495,489 low -191.811 high 1,182,788
10/16/2017 – 10/15/2018	2017	8,180 low 3,070 high 13,290	303,793 low 155,332 high 452,253	311,973 low 158,687 high 465,258	524,627 low 270,106 high 779,149
10/16/2016 – 10/15/2016	2016	49,754 low 28,754 high 70,754	941,937 low -302,850 high 2,186,725	991,691 low -273,472 high 2,256,854	1,651,047 low -480,487 high 3,782,582
10/16/2015 – 10/15/2016	2015	75,738 low 42,025 high 109,451	1,606,339 low -287,792 high 3,500,470	1,682,077 low -244,730 high 3,60,883	2,806,514 low -442,595 high 6,055,623
10/16/2014 – 10/15/2015	2014	32,978	90,617	123,595	187,027
-	2013	-	-	-	-

Sources: For BY 2013, Poytress and Gruber 2015. For BY 2014, Poytress 2016. For BY 2015, Voss and Poytress 2017. For BY 2016, Voss and Poytress 2018. For BY 2017, Voss and Poytress 2019. For BY 2018, Voss and Poytress 2020.For BY 2019, Voss and Poytress 2022.

C.3.10 Survival of Fry

There are no available estimates of fry survival for spring-run Chinook salmon.

C.3.11 Survival of Smolts

Survival estimates of spring-run Chinook salmon smolts are obtained from Juvenile Salmon Acoustic Telemetry System (JSATS) technology from the Central Valley Enhanced Acoustic Tagging Project (EAT) and CalFish Track. Detection histories of tagged individuals are used to calculate reach-specific survival estimates with a CJS model in RMark. This approach assumes that a fish has died if it is not detected at subsequent downstream receivers. Reach-specific survival estimates can be combined multiplicatively to obtain the probability of survival from release to the I80-50 bridge (RKM 170.74) or Tower Bridge (RKM 172; Table XX).

Table C-48. Estimated survival of juvenile spring-run Chinook salmon smolt and total RKM from the start (release site of hatchery fish; capture site of wild fish) to I80-50 bridge (I80-50_Br; RKM 170.74) or Tower Bridge (Tower Br; RKM 172)

Group	Data Source	Year	Start	End	Total RKM	Survival Estimate
Feather River Hatchery	EAT	2013	Gridley	Tower_Br	115.38	0.193
Feather River Hatchery	EAT	2013	Boyds	Tower_Br	68.75	0.350
Feather River Hatchery	EAT	2014	Gridley	Tower_Br	115.38	0.100
Feather River Hatchery	EAT	2014	Boyds	Tower_Br	68.75	0.580
Feather River Hatchery	EAT	2015	Gridley	I80-50_Br	116.64	0.005
Feather River Hatchery	EAT	2015	Boyds	I80-50_Br	70.01	0.089
Feather River Hatchery	EAT	2019	Gridley	I80-50_Br	116.64	0.169
Feather River Hatchery	EAT	2019	Boyds	I80-50_Br	70.01	0.340
Feather River Hatchery	EAT	2020	Gridley	I80-50_Br	116.64	0.100
Feather River Hatchery	EAT	2020	Boyds	I80-50_Br	70.01	0.271
Butte Creek Wild	EAT	2015	Butte Creek	I80-50_Br	78.8	0.049
Butte Creek Wild	EAT	2016	Butte Creek	I80-50_Br	78.8	0.226
Butte Creek Wild	EAT	2017	Butte Creek	I80-50_Br	78.8	0.133
Butte Creek Wild	EAT	2018	Butte Creek	I80-50_Br	78.8	0.040
Butte Creek Wild	EAT	2019	Butte Creek	I80-50_Br	78.8	0.000
Mill/Deer Creek Wild	CalFish	2018	DeerCkRST	Tower_Br	269.73	0.038
Deer Creek Wild	CalFish	2019	DeerCkRST	Tower_Br	269.73	0.125
Butte Creek Wild	CalFish	2019	Butte Creek	Tower_Br	77.54	0.163
Feather River Hatchery	CalFish	2019	Gridley	Tower_Br	115.38	0.374
Feather River Hatchery	CalFish	2019	Boyds	Tower_Br	68.75	0.615
Feather River Hatchery	CalFish	2020	Gridley	Tower_Br	115.38	0.325

Group	Data Source	Year	Start	End	Total RKM	Survival Estimate
Feather River Hatchery	CalFish	2020	Boyds	Tower_Br	68.75	0.211
Feather River Hatchery	CalFish	2021	Boyds	Tower_Br	68.75	0.286

Sources: Data sources include the Central Valley Enhanced Acoustic Tagging Project and CalFish Track.
CalFish = CalFish Track; EAT = Central Valley Enhanced Acoustic Tagging Project.

C.3.12 Juveniles Entering Delta Abundance

No observed information.

C.3.13 Survival of Juvenile in Delta

No observed information.

C.3.14 Juveniles Exiting the Delta Abundance

Table C-49. Chipps Island tag summary, survival index, and expanded fish facility recoveries for CWT fish released in 2021. Only late-fall run releases are shown.

Tag code	Release site/stock	First release	Last date released	CWT count released	Non-CWT count	Average size (mm)	First day recovered	Last day recovered	Number recovered	Minutes fished	Percent sampled	Survival index
056347	Battle Creek (CNFH)	1/4/2021	1/4/2021	67962	0	145	--	--	0	--	--	--
056348	Battle Creek (CNFH)	1/4/2021	1/4/2021	67016	0	145	2/2/2021	2/2/2021	1	200	0.1389	0.01
056349	Battle Creek (CNFH)	1/4/2021	1/4/2021	57104	0	145	2/8/2021	2/9/2021	3	400	0.1389	0.05
056350	Battle Creek (CNFH)	1/4/2021	1/4/2021	62958	0	145	1/20/2021	2/2/2021	5	2100	0.1042	0.10
056351	Battle Creek (CNFH)	1/4/2021	1/4/2021	74516	0	145	--	--	0	--	--	--

Tag code	Release site/stock	First release	Last date released	CWT count released	Non-CWT count	Average size (mm)	First day recovered	Last day recovered	Number recovered	Minutes fished	Percent sampled	Survival index
056352	Battle Creek (CNFH)	1/4/2021	1/4/2021	67174	0	145	1/24/2021	2/4/2021	4	1700	0.0984	0.08
056353	Battle Creek (CNFH)	1/4/2021	1/4/2021	67477	0	145	2/4/2021	2/4/2021	1	200	0.1389	0.01
056354	Battle Creek (CNFH)	1/4/2021	1/4/2021	58824	0	145	1/21/2021	2/9/2021	3	2500	0.0868	0.08
056355	Battle Creek (CNFH)	1/4/2021	1/4/2021	57548	0	145	1/28/2021	2/21/2021	3	2938	0.0816	0.08
056356	Battle Creek (CNFH)	1/4/2021	1/4/2021	52660	0	145	--	--	0	--	--	--
056357	Battle Creek (CNFH)	1/4/2021	1/4/2021	52555	0	145	1/17/2021	1/17/2021	1	200	0.1389	0.02

Source:

C.3.15 Survival of Juveniles in Ocean

No cohort reconstructions or analyses have been formally conducted for spring-run Chinook salmon (Satterthwaite et al. 2018). As such, direct estimates of juvenile survival in the ocean are lacking. However, an annual juvenile survival of 50% based on reconstructions for winter-run Chinook salmon and other Pacific salmon (O'Farrell et al. 2012) may be assumed. It is also feasible to make inferences from established influences on relative juvenile survival from studies of fall-run Chinook salmon (e.g., Satterthwaite et al. 2014).

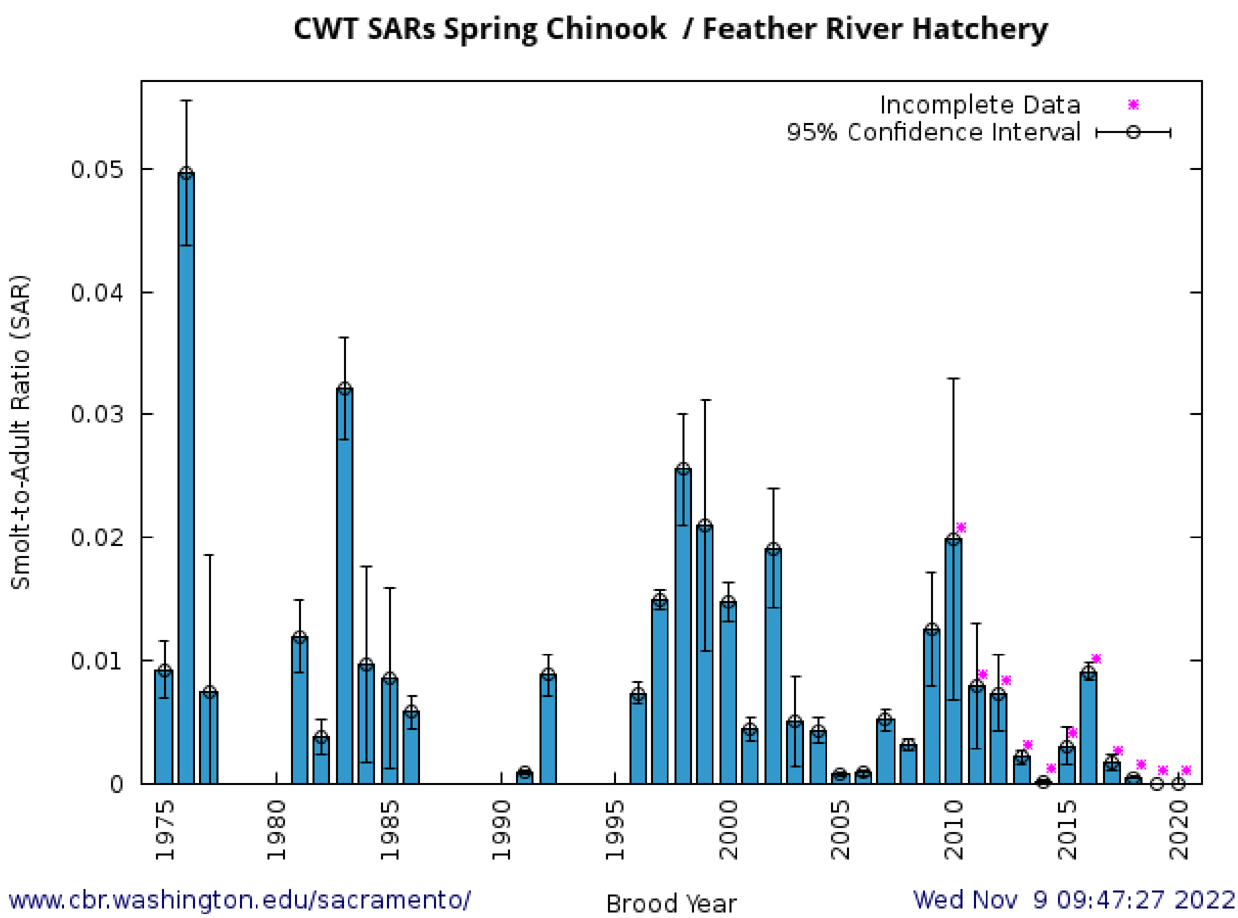
C.3.16 Ocean Abundance

No estimates of ocean abundance are available due to a lack of cohort reconstruction efforts. If cohort reconstructions were to be performed to generate estimates of ocean abundance, they likely would be restricted to Feather River Hatchery fish due to the limited amount of tagging performed on natural-origin fish (Satterthwaite et al. 2018).

C.3.17 Subadult Ocean Survival

Calibrated estimates of overall survival of spring-run Chinook salmon smolts in the ocean, from ocean entry to return for spawning, are reported in the decision analysis research by Peterson and Duarte (2021). Additionally, we can assume annual natural mortality rates of 20% based on past cohort analyses (O'Farrell et al. 2012). Estimates of ocean fishing mortality rates are not currently available for spring-run Chinook salmon (Satterthwaite et al. 2018).

Estimates of SARs for CWT tagged spring-run Chinook salmon from the Feather River Hatchery are available for 1975-2020 from SacPAS (www.cbr.washington.edu/sacramento/). These are calculated only based on the number of released smolts with CWTs and the estimated number of adult returns.



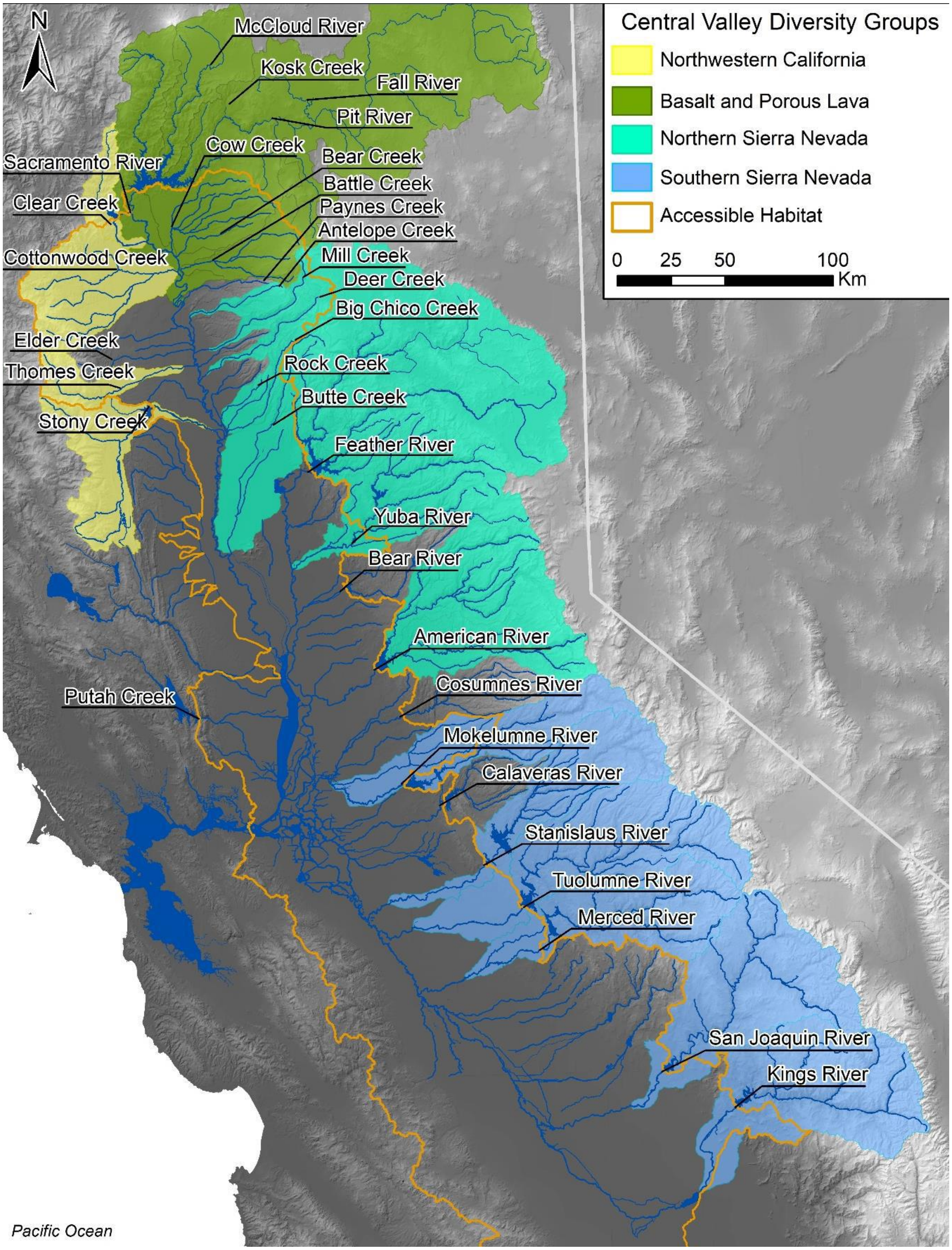
Source: SacPAS (www.cbr.washington.edu/sacramento/).

Figure C-32. Smolt-to-adult ratio (SAR) for coded wire tagged (CWT) winter-run Chinook salmon, 1975 - 2020

As reported for winter-run Chinook salmon, analyses of late-fall-run Chinook observed total marine survival rates varying between 4.2% and 22.8% (Michel 2019). These survival rates encompass both juvenile and subadult ocean survival periods. Similar estimates of marine survival for spring-run Chinook salmon are not available, but this analysis provides a reference point.

C.4 Steelhead – Central Valley Distinct Population Segment

Presently, California Central Valley (CV) steelhead (*Oncorhynchus mykiss*) are found in the Sacramento River downstream of Keswick Dam, in major tributary rivers and creeks to the Sacramento River (American River, Feather River, Butte Creek), in major tributaries to the San Joaquin River (Stanislaus, Tuolumne, Merced Rivers), and the Delta (Mokelumne and Calaveras Rivers). A multiagency effort is underway for an improved monitoring plan for CV steelhead, which involves dividing the Sacramento and San Joaquin basins into four geographically distinct diversity groups (Beakes et al. 2021, Figure C-33).



Source: Beakes et al. 2021.

Figure C-33. Map Illustrating the Location of Target Watersheds within Central Valley Diversity Groups

The populations in the northern Sierra Nevada (Feather and American Rivers) are supported by the Feather and Nimbus hatcheries, and the populations in the southern Sierra Nevada (lower Mokelumne River) are supported by the Mokelumne River Fish Hatchery. Other major steelhead populations in the Sacramento River watershed are found in Basalt and Porous Lava diversity group of Battle, Mill, Deer, Clear, and Butte creeks. Steelhead may be present in all rivers and tributaries used in CVP.

Adult steelhead migrate into freshwater systems in the fall and winter and spawn in their natal streams in winter and spring. Juveniles rear in freshwater habitats for 1 to 4 years before emigrating to the ocean. Both spawning areas and migratory corridors are used by juvenile steelhead for rearing prior to outmigration (National Marine Fisheries Service 2009). Adult steelhead are iteroparous, although repeated spawning rates of anadromous individuals are considered low in populations in the Central Valley (Null et al. 2013).

Summaries of the temporal life-history domains for CV steelhead can be found on Figure C-34.

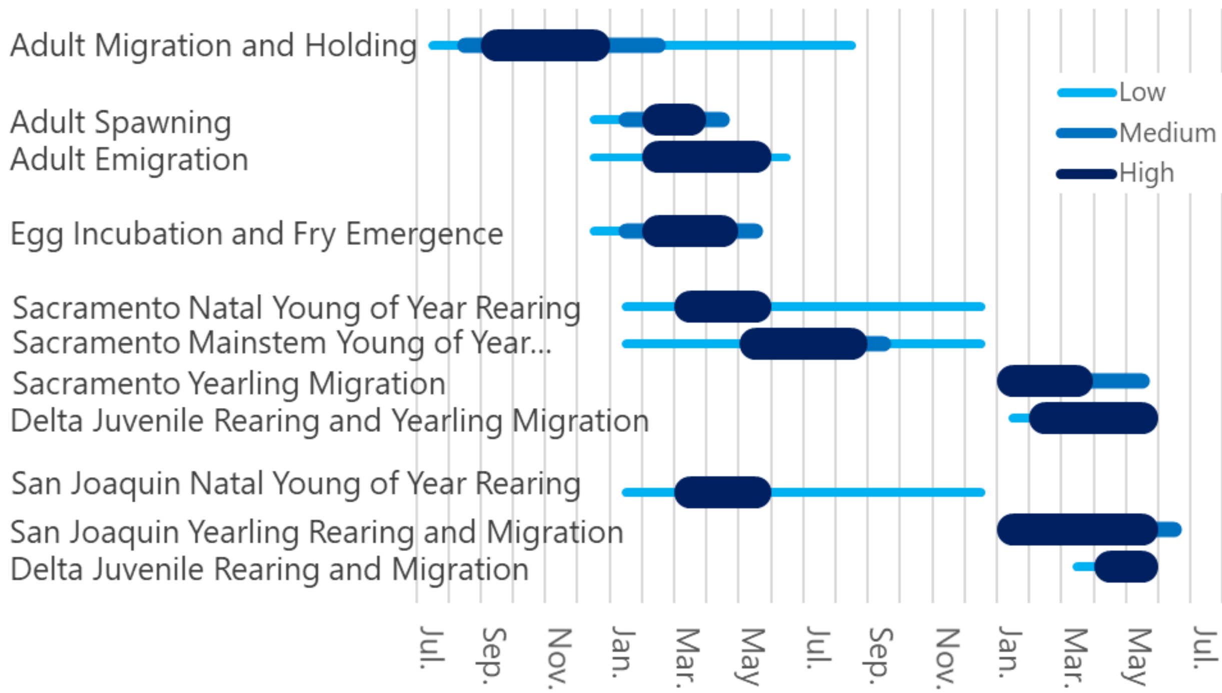


Figure C-34. Temporal Life Stage Domains for California Central Valley Steelhead

C.4.1 Adult Migration and Holding

CV steelhead exhibit life histories in which they spawn within a few months of entering freshwater or stage in pools for more extended periods until the first high flows (Moyle 2002; Williams 2006). Due to their varying life-history strategies and iteroparity, migrating adult steelhead are difficult to monitor using the same strategies employed for Chinook salmon in the California Central Valley. Historical data at the Fremont Weir have shown that adult CV steelhead migrate upstream in the Sacramento River during most months of the year, beginning in July, peaking in September, and continuing through February or March (Hallock 1989; McEwan 2001; Hallock et al. 1957). The latest records of adult steelhead migration into the Sacramento River include passage estimates based on observations at Red Bluff Diversion Dam ladders between 1994–2007.[1] These data suggested that the first passage at Red Bluff Diversion Dam occurs in August, and the last passage by September, prior to the dam being decommissioned in 2013.

Adult migration data are limited for other rivers and tributaries of the Bay-Delta. In the American River, adult steelhead migration occurs June through early April, with peak abundance in January and February (Sacramento Water Forum 2015). In Clear Creek, *O. mykiss* >16 inches have been seen migrating upstream through video monitoring as early as August and throughout February (Killam 2022). In the Stanislaus River, *O. mykiss* > 16 inches have been seen migrating upstream through video monitoring as early as September and throughout March (Hellmair 2022).

Estimates of migrating adults in the San Joaquin River are made from CDFW angling report cards and suggest that migration starts in July, peaks in December and January, and ends in March (California Department of Fish and Game 2007). Migration timing in the Delta ranges from July until May, with peaks at both the beginning of the spawning season, as migrants move to their natal streams, and at the end of the season, in May, potentially as post-spawn kelts emigrate back to the ocean (Moyle 2002; Hallock 1961).

C.4.2 Adult Spawning

Redd surveys are conducted for CV steelhead in Clear Creek and the American, Calaveras, Tuolumne, Yuba, lower Mokelumne, and Feather rivers. Redd survey data for rivers and streams within the CVP were available for Clear Creek and the American River. Construction of redds provide observations of spawning, although redd data are not typically linked to life-history type. Spawning for CV steelhead starts as early as November, peaks December through April, and can last until June (McEwan 2001). Alternative methods for assessing spawning periodicity include video monitoring and adult counts at spawning facilities. The latter two methods are utilized at the Coleman National Fish Hatchery (CNFH) for annual spawner estimates on Battle Creek.

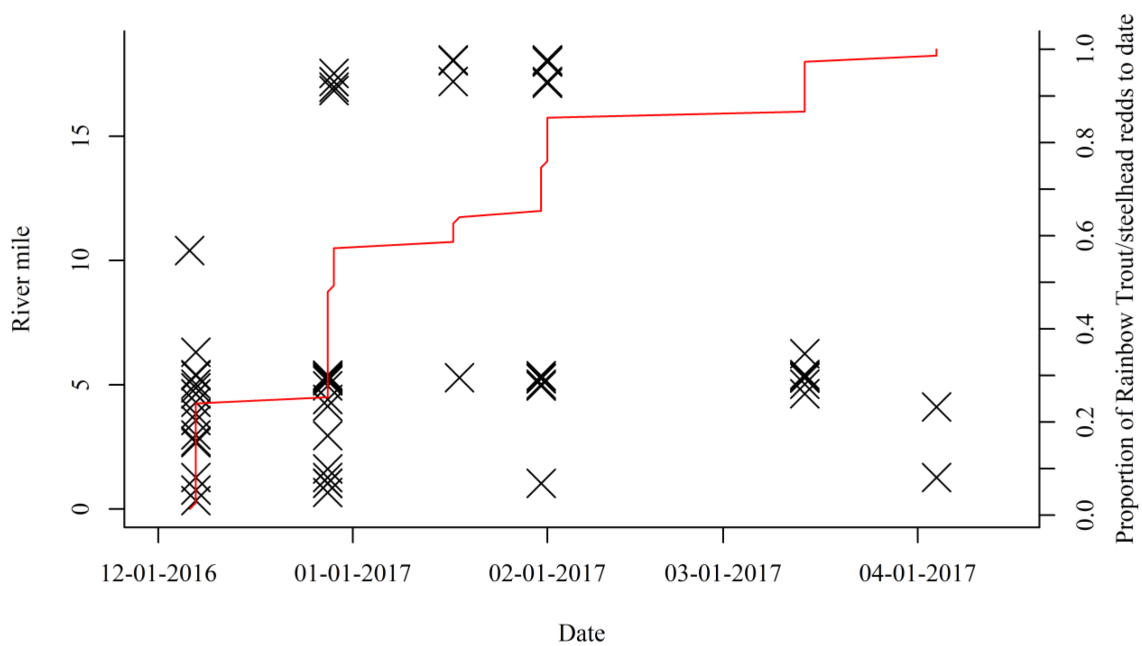
Redd estimates on Clear Creek are observed through annual kayak surveys that start in December and span April and are documented in USFWS reports (Provins and Chamberlain 2019a, 2019b). Based on the number of redds observed, most spawning appears to occur near to the confluence with the Sacramento River, between river miles 6.5 and 0 (Figure C-35 and Figure C-36). The temporal distribution of the redd count data shows peak spawning occurring from December–January, with 90% of redds constructed by February. Redd construction tapers

[1] Raw data were only available on hard copies (i.e., datasheets or notebooks) that were moved to electronic ledgers by CDFW staff. Digitizing these data required review and interpretation of procedures for data collection and analysis by CDFW (Killam pers. comm.). When information on these procedures was limited, the raw data were recorded based on what CDFW predecessors had originally reported. CDFW summaries in their Upper Sacramento River annual report supplementation materials include periodicity.

off in the month of March, and all redds have been constructed by the end of April (Table C-50 and Figure C-37). The lack of redds observed in December 2014 may be due to two storm events, given that increases in discharge lead to increased turbidity, redd scour, and reduction in visibility (Provins and Chamberlain 2019a).

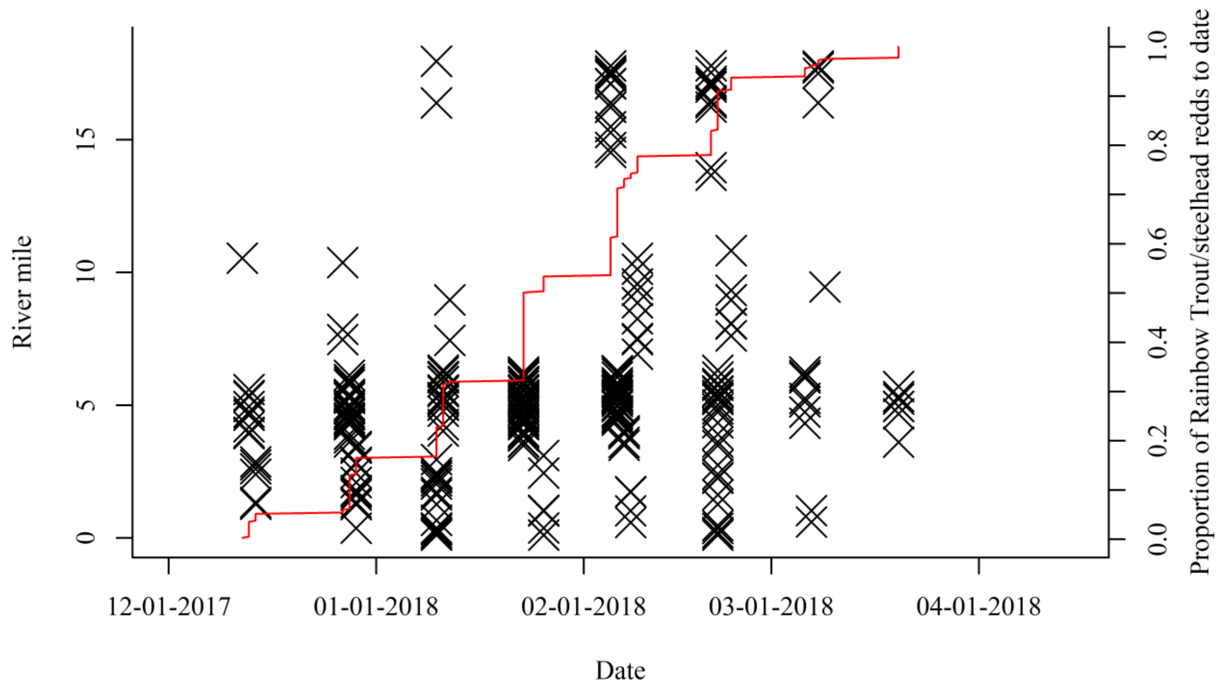
Estimates of spawners on Battle Creek are made through video monitoring and adult counts at the spawning building in CNFH. In 2001, CNFH initiated a comprehensive (100%) marking program of hatchery-produced CV steelhead, with adipose fin-clipped fish marked as hatchery produced and unclipped fish labeled as natural origin. Peak spawning at the hatchery occurs in March (Figure C-38 and Figure C-39); however, unclipped steelhead that arrive at the facility are not spawned and are released above the barrier prior to the opening of the barrier weir fish ladder on March 1. Unclipped releases prior to opening of the barrier on March 1 are not included in the migration timing figures (Figure C-38 and Figure C-39).

Redd estimates on the lower American River are observed through redd surveys that start during the first week of August and extend through the end of May. Based on the number of redds observed from 2002–2021, CV steelhead start spawning in January, continue building redds throughout the month of February, and 90% of the redds have been constructed by March. By mid-April, the last redd has been constructed (Figure C-37 and Table C-51).



Source: Provins and Chamberlain 2019b.
Note: The X axis indicates the initial survey date at which the redd was first observed. The red line displays the cumulative proportion of redds to date scaled to the right Y axis.

Figure C-35. Plot Illustrating the Distribution of *O. mykiss* Observations by Date and River Mile on Clear Creek for the 2016–2017 Survey Season



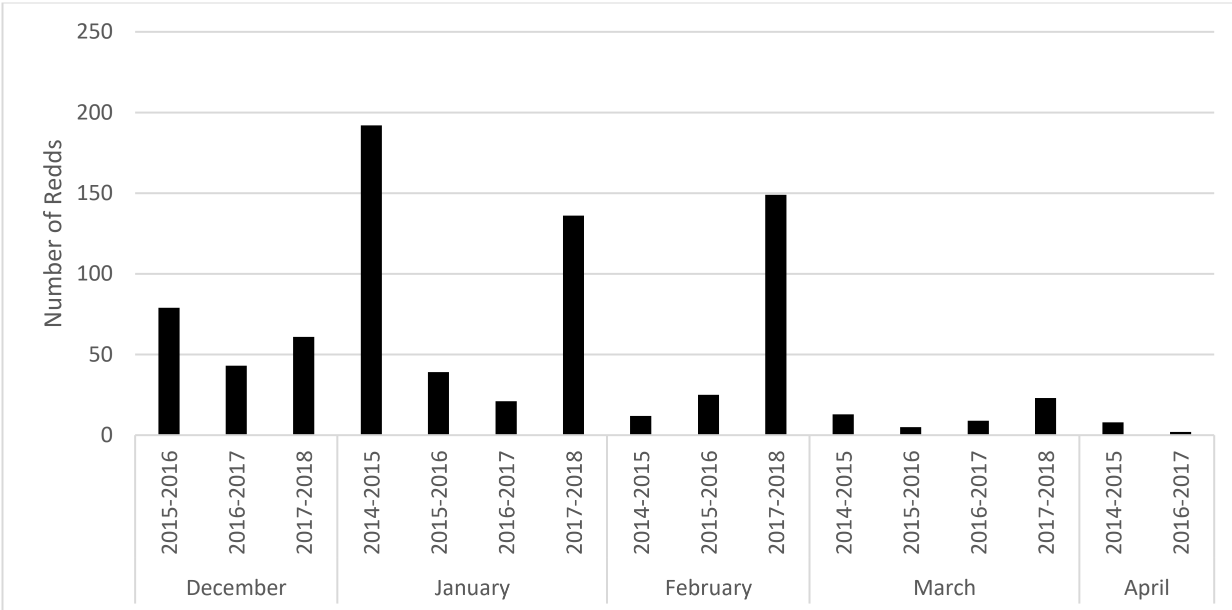
Source: Provins and Chamberlain 2020.
Note: The X axis indicates the initial survey date at which the redd was first observed. The red line displays the cumulative proportion of redds to date scaled to the right Y axis.

Figure C-36. Plot Illustrating the Distribution of *O. mykiss* Observations by Date and River Mile on Clear Creek for the 2017–2018 Survey Season

Table C-50. Redd Construction Timing on Clear Creek, 2014–2018

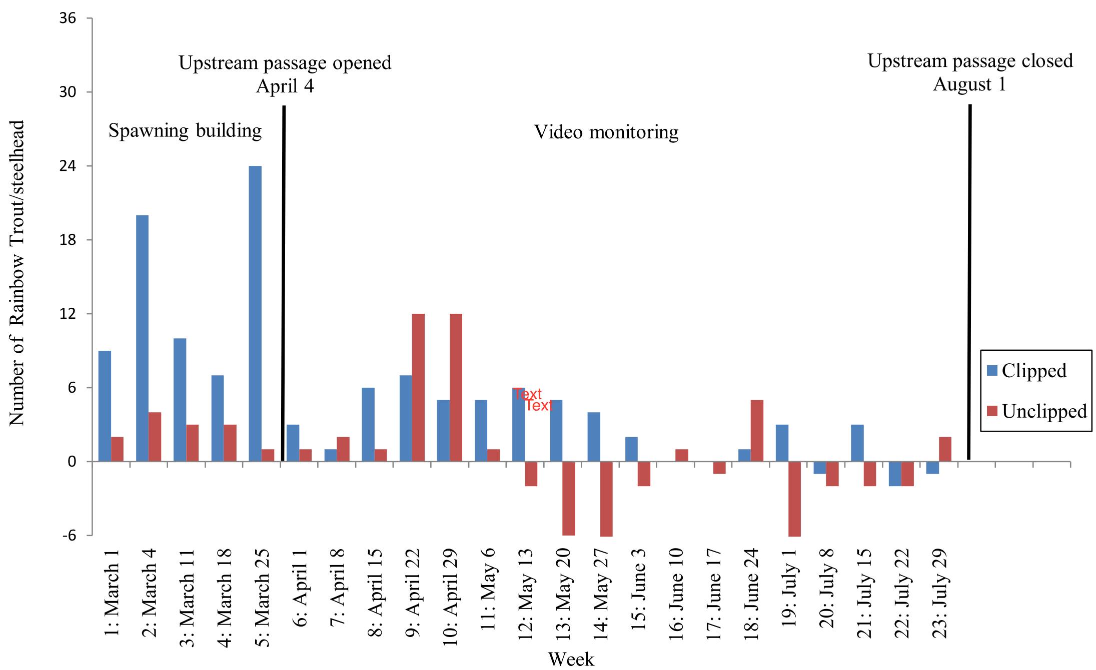
Observation Year	**First**	**5% Passing**	**10% Passing**	**90% Passing**	**95% Passing**	**Last**
2017–2018	Dec 17	Dec 17	Dec 17	Feb 18	Mar 18	Mar 18
2016–2017	Dec 16	Dec 16	Dec 16	Mar 17	Mar 17	Apr 17
2015–2016	Dec 15	Dec 15	Dec 15	Feb 16	Feb 16	Mar 16
2014–2015	Jan 15	Jan 15	Jan 15	Feb 15	Mar 15	Apr 15
Median Month	December	December	December	February	March	March/April

Sources: Schaefer et al. 2019; Provins and Chamberlain 2019a, 2019b, 2020



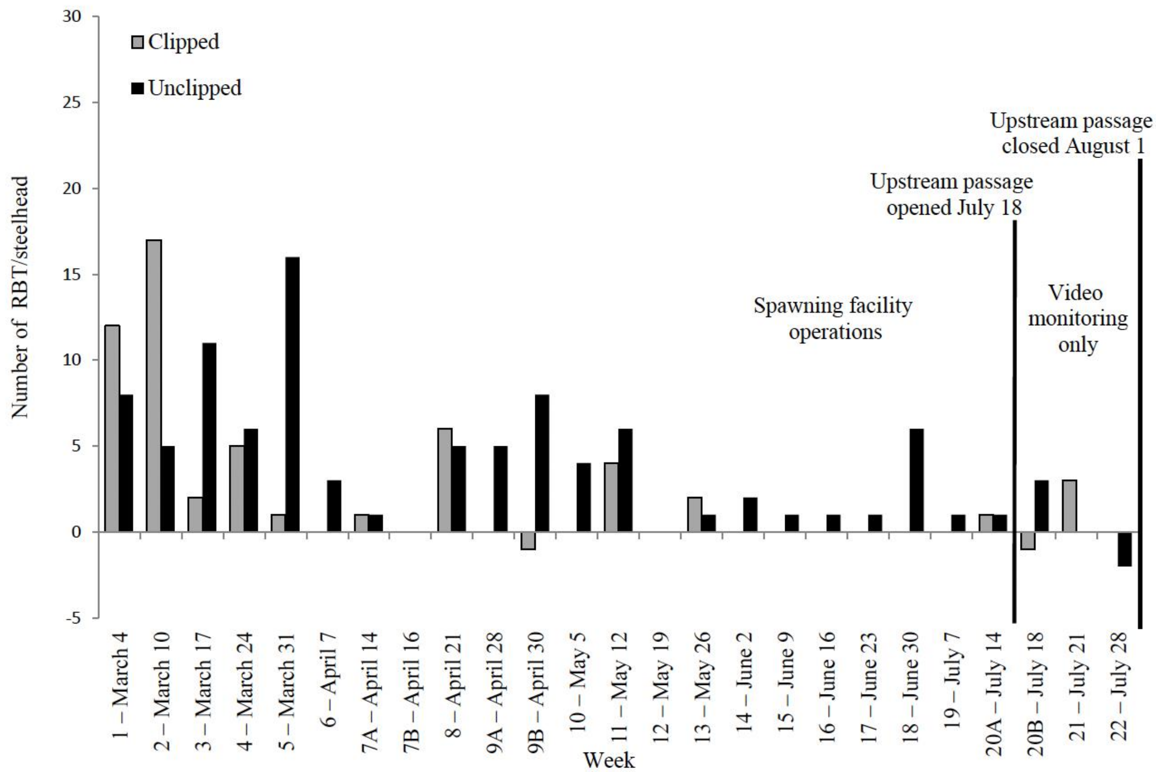
Sources: Schaefer et al. 2019; Provins and Chamberlain 2019a, 2019b, 2020.

Figure C-37. Plot of Central California Valley Steelhead/Rainbow Trout Redds Observed on Clear Creek During Annual Kayak Surveys for 2014–2018



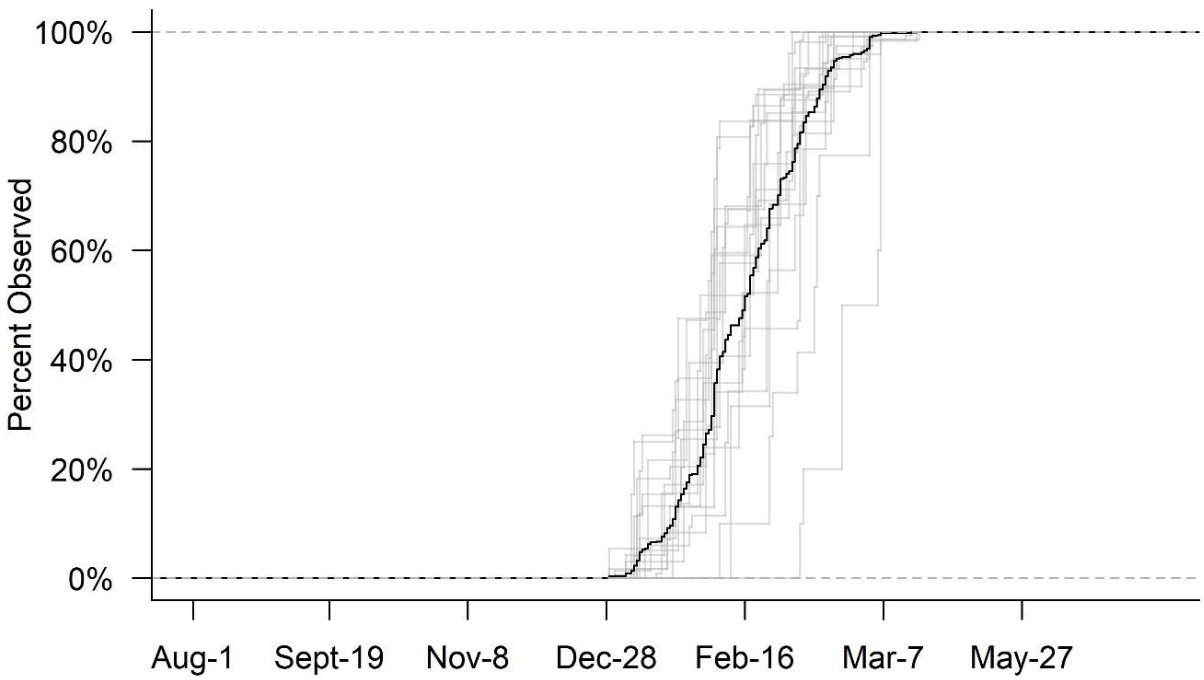
Source: Bottaro and Earley 2020a.
Note: Dates begin the Sunday of each week.

Figure C-38. Plot Illustrating the Distribution of *O. mykiss* Observations at Coleman National Fish Hatchery Fish Ladder (in the Spawning Building and by Video) in 2018, by Week



Source: Bottaro and Earley 2020b.
Note: Dates begin the Sunday of each week.

Figure C-39. Plot Illustrating the Distribution of *O. mykiss* Observations at Coleman National Fish Hatchery Fish Ladder (in the Spawning Building and by Video) in 2019, by Week



Source: Cramer Fish Sciences 2021.
Note: Multiple redds at a single observation location are not distinguished due to variability in how the observation was recorded across years.

Figure C-40. Lower American River *O. mykiss* Redd Construction Timing, 2002–2021

Table C-51. Lower American River *O. mykiss* Redd Construction Timing, 2002–2021

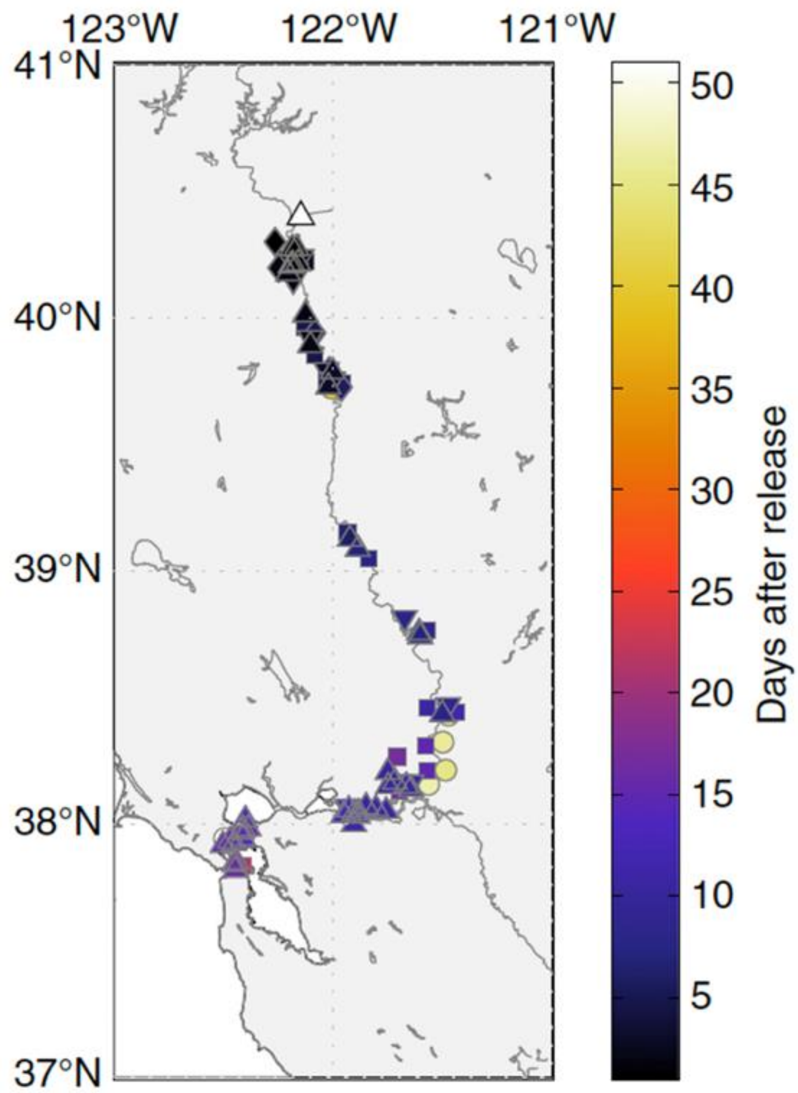
Observation Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2021	Jan 6	Jan 6	Jan 6	Mar 15	Mar 17	Mar 18
2020	Jan 8	Jan 8	Jan 8	Mar 2	Mar 3	Mar 16
2019	Jan 8	Jan 8	Jan 8	Mar 20	Mar 20	Apr 19
2018	Jan 11	Jan 22	Jan 23	Mar 19	Mar 20	Mar 20
2017	Mar 8	Mar 8	Mar 9	Apr 6	Apr 6	Apr 6
2016	Jan 7	Jan 7	Jan 7	Mar 4	Mar 4	Mar 4
2015	Jan 21	Jan 21	Jan 22	Mar 6	Mar 19	Mar 20
2014	Jan 15	Jan 17	Jan 17	Mar 13	Mar 21	Apr 3
2013	Jan 9	Jan 9	Jan 9	Mar 5	Mar 11	Mar 11
2012	Jan 4	Jan 18	Jan 18	Mar 10	Mar 29	Mar 30
2011	Jan 4	Jan 25	Jan 25	Mar 1	Mar 8	Mar 9
2010	Jan 12	Jan 12	Jan 12	Mar 9	Mar 22	Apr 20

Observation Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2009	Feb 11	Feb 11	Feb 11	Mar 26	Mar 27	Dec 29
2007	Jan 4	Jan 19	Feb 2	Mar 2	Mar 16	Mar 16
2005	Jan 19	Jan 20	Jan 20	Mar 15	Mar 15	Apr 4
2004	Jan 13	Jan 27	Feb 7	Mar 17	Mar 31	Dec 29
2003	Jan 7	Jan 9	Jan 22	Mar 17	Mar 18	Dec 31
2002	Feb 7	Feb 7	Feb 23	Apr 2	Apr 2	Apr 2
Median Month	January	January	January	March	March	March

Source: Cramer Fish Sciences 2021.

C.4.3 Adult Kelt Emigration

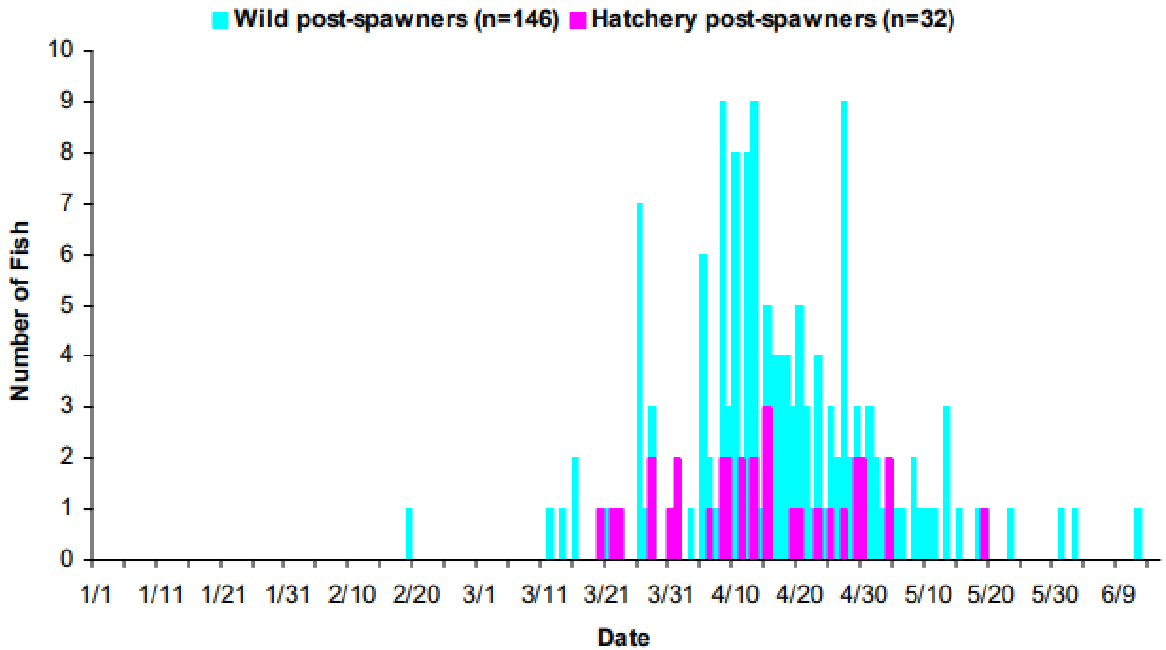
CV steelhead exhibit some of the most complex life-history strategies of all salmonids, ranging from fully anadromous to completely resident. Some adults will change their life-history strategy post-spawn, as demonstrated in Battle Creek, where kelts chose to stay in freshwater rather than emigrate to the ocean (Null et al. 2013). A study by Teo et al. (2011) has shown the spatial distribution for CV steelhead kelts and the complexity of their migration patterns, as some migrate to San Francisco Bay and back into freshwater several weeks later. In this study, CV steelhead kelts were implanted with acoustic tags, released in May, and tracked over a 50-day period throughout the Sacramento basin and Bay-Delta region (Figure C-41). The spatial distribution of kelt emigration is both highly variable, as demonstrated by Teo et al. (2011), and difficult to track on a temporal scale because iteroparity in California steelhead populations is considered relatively rare (Moyle 2002; Null et al. 2013). Much of the available information on repeat spawning for steelhead comes from the Pacific Northwest. In these steelhead populations, timing of kelt emigration starts in February, peaks March through May, and ends by June (Mayer et al. 2008; Table C-42).



Release location of steelhead kelts (white Δ) and approximate locations of acoustic tag detections. Five steelhead were detected after release and symbols indicate individual steelhead: A (◊), B (Δ), D (□), E (∇), and I (○). Locations of acoustic tag detections are jittered for clarity

Source: Teo et al. 2011.

Figure C-41. Distribution of *O. mykiss* Kelts in Acoustic Telemetry Study



Source: Mayer et al. 2008.

Figure C-42. Daily Catch of Post-Spawning Steelhead by Origin at the Asotin Creek, Washington, Weir in 2007

C.4.4 Egg Incubation

CV steelhead eggs start incubating when redd construction occurs. Spawning success is associated with water flow and water temperature. Studies on incubation temperature by the Washington State Department of Ecology have found that water temperatures between 40 degrees Fahrenheit (°F) and 55°F (4.4 degrees Celsius [°C] and 12.8°C) are suitable for successful spawning, egg incubation, and fry development for steelhead (Washington State Department of Ecology 2002). Steelhead egg incubation to post-hatch varies with temperature and requires approximately 490 accumulated temperature units. For example, in 50°F (10°C) water, incubation would end approximately 50 days after incubation starts. On the American River, egg incubation starts in December and ends in May, with peak incubation between March and May (Hannon pers. comm., Table C-26).

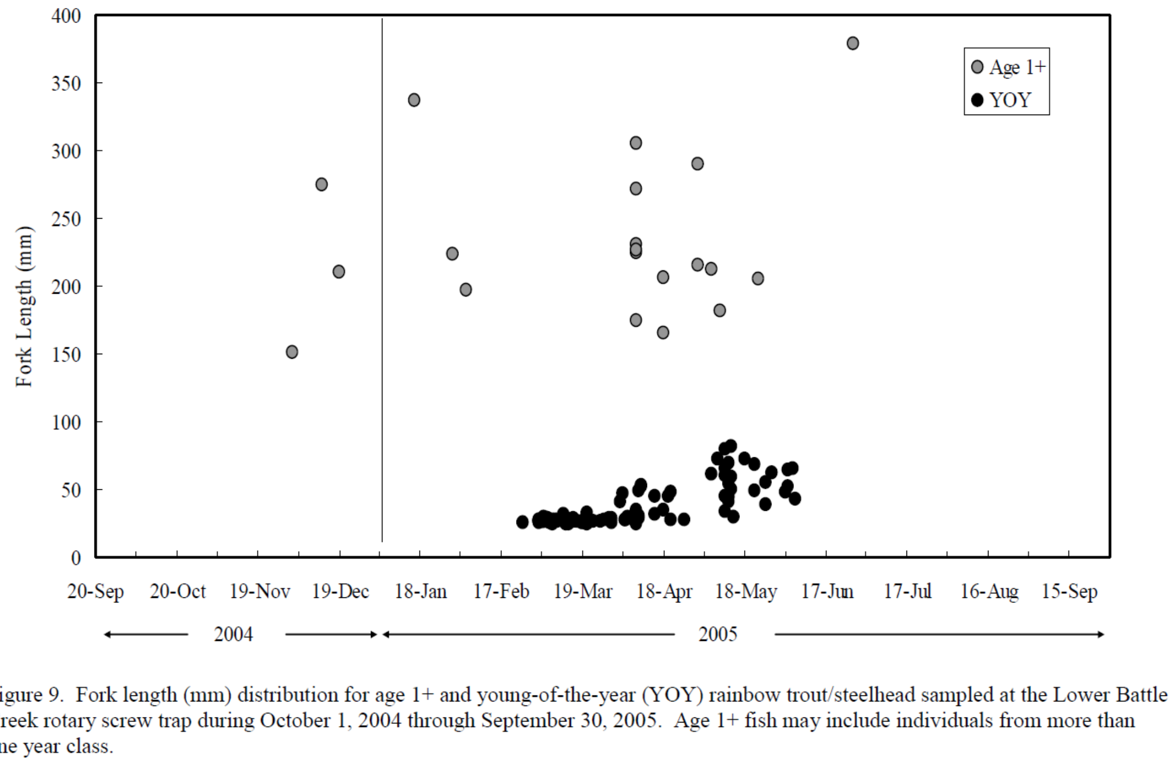
Table C-52. Steelhead Egg Incubation

Life stage	First	5% Fertilized	10% Fertilized	90% Fertilized	95% Fertilized	Last
Steelhead Egg Incubation	December	January	January	May	May	May

Source: Hannon pers. comm.

C.4.5 Young-of-the-Year Fry Migration

Once CV steelhead embryos emerge out of their redds to become young-of-the-year fry, they rear in freshwater for one to four years before emigrating to the ocean. Specific data on the young-of-the-year life stage is available from the lower Battle Creek rotary screw trap, which suggests migration occurs from February through June on Battle Creek (Figure C-43; Schraml and Earley 2019).



Source: Schraml and Earley 2019.

Figure C-43. Representative Year of Rotary Screw Trap *O. mykiss* Catch in Battle Creek Showing Two Cohorts of *O. mykiss* Rearing and Migrating

C.4.6 Juvenile and Yearling Natal River Rearing and Migration

The timing of yearling and juvenile migration depends on the watershed and water year. Upper reaches of the Sacramento River basin appear to have the longest migration period detected for yearlings and juveniles, including detection of juveniles year-round at the mainstem at Red Bluff Diversion Dam (Table C-54 and Table C-59). In Battle Creek and Clear Creek, occurrence of yearlings and juveniles at the monitoring traps starts in November, and the last yearlings and juveniles are detected in June (Table C-53, Table C-56, and Table C-57).

USFWS also estimates juvenile passage for the mainstem Sacramento River at the Knights Landing rotary screw trap, where juveniles are first detected later in the season, in January; 90% median passage occurs in May, and the last detection occurs by June (Table C-30 and Table C-31). A lower tributary in the Sacramento River, the American River exhibits a similar timing as the mainstem near Knights Landing, with the first occurrence in January, 90% median passage occurring in May, and the last occurrence in June (Table C-53 and Table C-58). Ferguson (2108) reported natural steelhead smolts has a wider emigration window than Nimbus hatchery-released smolts, peaking in mid-February and reaching the ocean in May.

CDFW estimates the presence of steelhead juveniles from the San Joaquin River Basin annually, based on the Mossdale Trawl and by PSMFC at the Stanislaus River Caswell screw trap. The Mossdale Trawl captures steelhead juveniles, although usually in small numbers (i.e., under 25 juveniles each year according to SacPAS from 2007–2020). These limited datasets give misleading median month timing, but still start in January, with 90% median passage occurring in May, and end in June (Table C-55 and Table C-62). The Stanislaus River screw trap detects juvenile median monthly passage from January to June, with 90% passing by May, and may see year-round presence in select years (see Brood Years 2000, 2002, and 2011 in Table C-55 and Table C-61).

Table C-53. Summary of Sacramento River Basin Natal River Yearling and Juvenile Rearing for *O. mykiss* (from Table C-56, Table C-57, and Table C-58)

Tributary	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
Clear Creek	November	February	March	May	June	June
Battle Creek	November	April	April	June	June	June
American River	January	March	March	May	May	May

Source: University of Washington, School of Aquatic and Fishery Science 2022.

Table C-54. Summary of Sacramento River Mainstem Yearling and Juvenile Migration for *O. mykiss* (Table C-59 and Table C-60)

Station	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
RBDD	January	May	May	August	September	December
KNL	January	January	January	April	May	May

Source: University of Washington, School of Aquatic and Fishery Science 2022.
RBDD = Red Bluff Diversion Dam

Table C-55. Summary of San Joaquin River Basin Natal River Yearling and Juvenile Emigration for *O. mykiss* (from Table C-61 and Table C-62)

Station	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
Stanislaus	January	January	January	May	June	June
Mossdale Trawl	March	April	April	May	May	May
San Joaquin River Juvenile	January	January	January	May	May	May

Source: University of Washington, School of Aquatic and Fishery Science 2022.

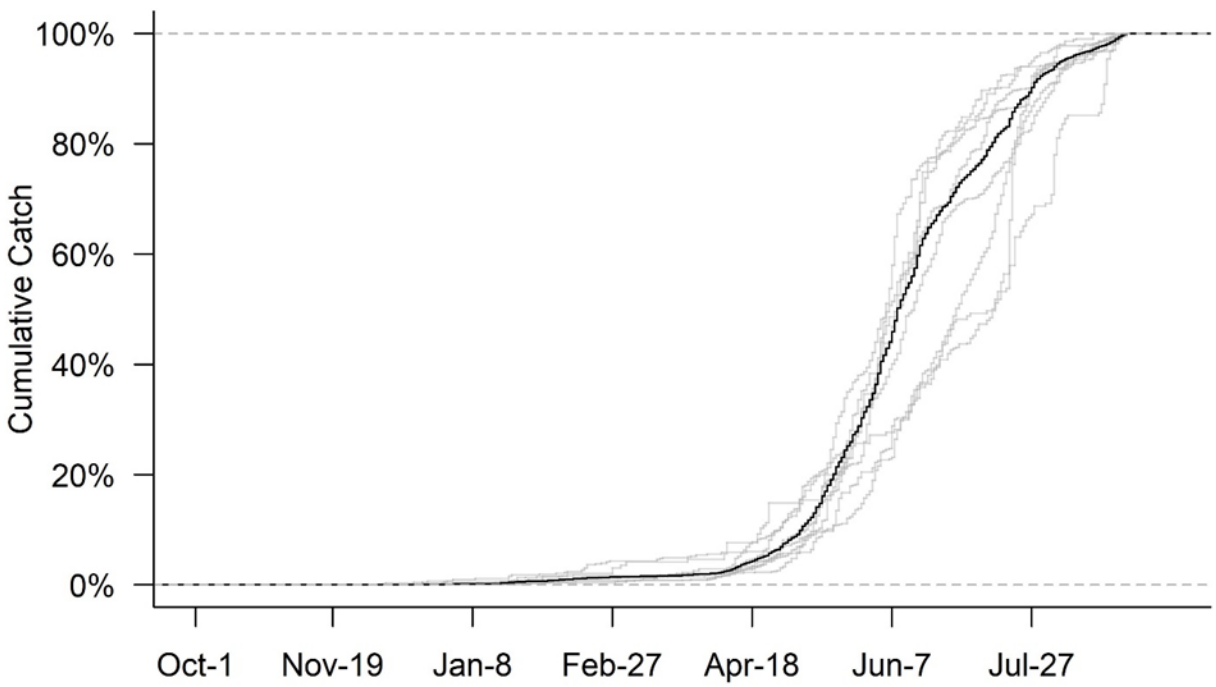
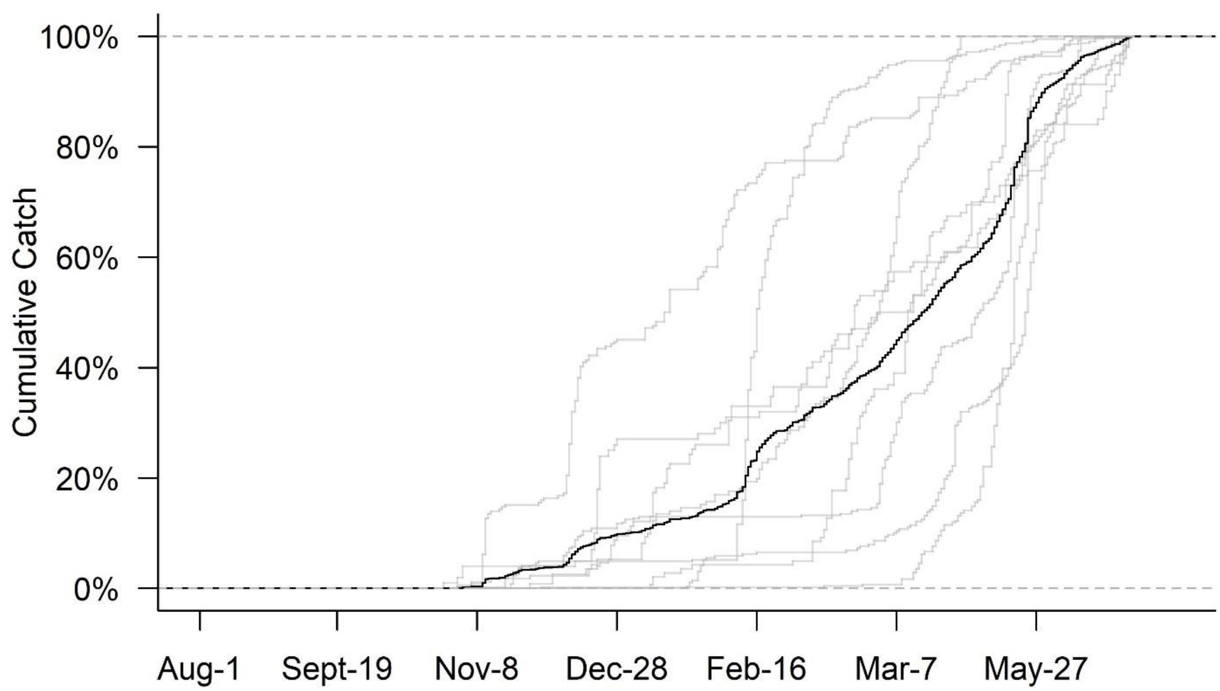


Figure C-44. Lower Clear Creek Rotary Screw Trap, *O. mykiss* Catch, all Yearling and Juvenile Age Classes, 2011–2018

Table C-56. Lower Clear Creek Rotary Screw Trap, *O. mykiss* Catch, all Yearling and Juvenile Age Classes, 2011–2018

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2018	Nov 27	Feb 6	Feb 19	Jun 22	Jun 23	Jun 30
2017	Oct 6	Feb 18	Feb 26	May 14	Jun 4	Jun 25
2016	Oct 19	Jan 25	Mar 15	Jun 4	Jun 15	Jun 30

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2015	Nov 7	Feb 11	Feb 26	May 26	Jun 7	Jun 29
2014	Nov 18	Feb 25	Mar 17	May 27	Jun 11	Jun 30
2013	Nov 5	Feb 24	Mar 8	May 12	May 27	Jun 30
2012	Nov 15	Feb 26	Mar 10	May 25	Jun 7	Jun 30
2011	Nov 1	Mar 3	Mar 11	May 31	Jun 10	Jun 29
Median Month	November	February	March	May	June	June



Source: Bottaro and Earley 2020a.

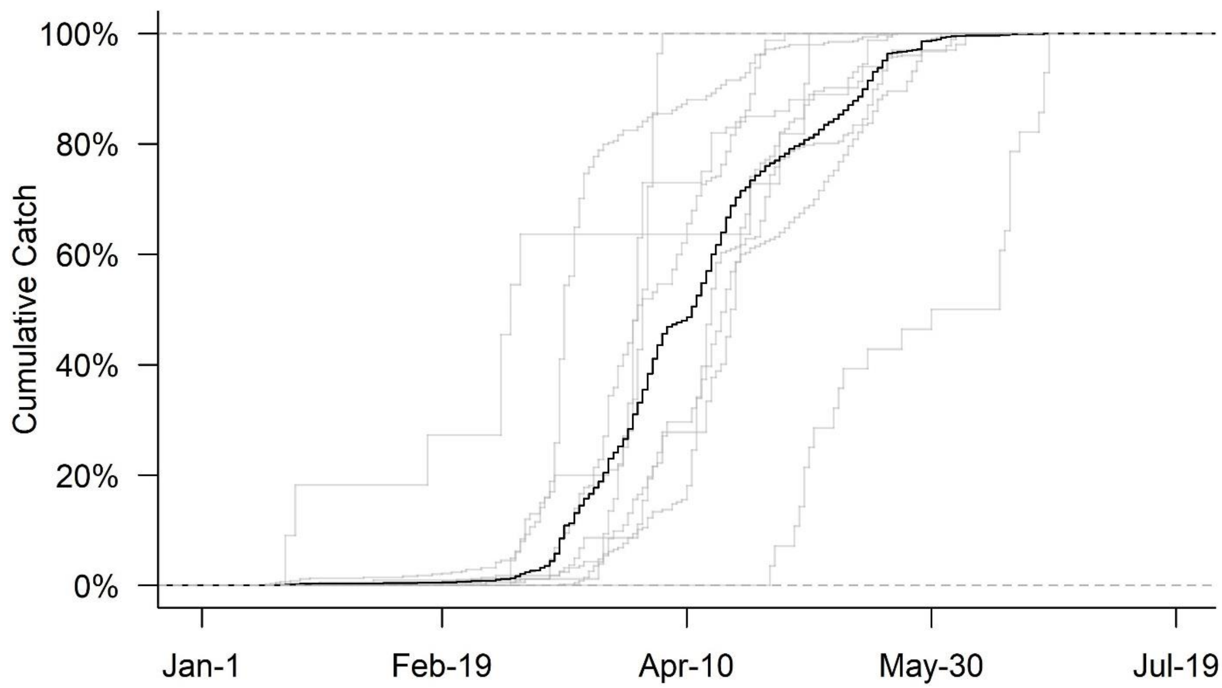
Figure C-45. Upper Battle Creek, Coleman Hatchery Barrier Weir Trap, *O. mykiss* Catch, all Yearling and Juvenile Age Classes, 2010–2018

Table C-57. Upper Battle Creek, Coleman Hatchery Barrier Weir Trap, *O. mykiss* Catch, all Yearling and Juvenile Age Classes, 2010–2018

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2018	Nov 27	Dec 24	Jan 1	Jun 6	Jun 23	Jun 29
2017	Jan 9	Mar 8	Mar 12	May 17	May 18	Jun 12
2016	Oct 27	Dec 19	Dec 21	Jun 21	Jun 26	Jun 29

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2015	Nov 5	Nov 10	Nov 11	Apr 28	May 12	Jun 19
2014	Dec 1	Apr 16	Apr 23	May 26	Jun 9	Jun 30
2013	Nov 20	Jan 29	Feb 9	Mar 18	Apr 6	Jun 6
2012	Nov 9	Dec 9	Dec 16	Jun 9	Jun 23	Jun 29
2011	Jan 22	Jan 28	Apr 6	Jun 11	Jun 16	Jun 29
2010	Jan 1	Mar 2	Mar 11	Jun 23	Jun 26	Jun 30
Median Month	November	April	April	June	June	June

Source: Bottaro and Earley 2020a.



Source: Bottaro and Chamberlain 2019.
Note: Data include brood years 2013–2021. Function is plotted for individual years (gray lines) and the across all years (black line).

Figure C-46. Plotted Empirical Cumulative Distribution of Juvenile Steelhead Rotary Screw Trap Catch as a Function of Julian Day

Table C-58. Summary of Juvenile *O. mykiss* Catch, Passage in the Lower American River Screw Trap, 2013–2021

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2021	Feb 7	Mar 23	Mar 31	May 25	May 31	Jun 3
2020	Feb 5	Mar 5	Mar 7	May 12	May 19	Jun 5
2019	Jan 20	Mar 13	Mar 16	Apr 23	Apr 24	Apr 29
2018	Mar 4	Mar 18	Mar 30	May 7	May 16	May 21
2017	Apr 26	Apr 28	May 2	Jun 21	Jun 22	Jun 22
2016	Jan 19	Mar 23	Mar 24	Apr 3	Apr 3	Apr 4
2015	Jan 18	Jan 19	Jan 20	May 3	May 3	May 4
2014	Jan 14	Mar 5	Mar 8	Apr 15	Apr 23	May 22
2013	Mar 14	Mar 24	Mar 28	May 27	May 29	May 31
Median Month	January	March	March	May	May	May

Source: CalFish 2022a.

Table C-59. Summary of Juvenile *O. mykiss* Catch, Passage at Red Bluff Diversion Dam, 2006–2020

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	Jan 01	Jul 03	Jul 08	Sep 11	Sep 28	Dec 30
2019	Jan 12	May 09	May 15	Dec 17	Dec 21	Dec 28
2018	Jan 03	Apr 11	Apr 27	Sep 09	Sep 27	Dec 29
2017	Mar 09	Mar 19	Apr 28	Oct 03	Oct 31	Dec 31
2016	Jan 10	Jan 11	Apr 13	Sep 26	Oct 18	Dec 19
2015	Jan 23	Apr 16	Apr 19	Sep 20	Oct 19	Dec 29
2014	Jan 03	Feb 28	Feb 28	Aug 19	Sep 05	Dec 10
2013	Jan 11	Apr 22	May 04	Aug 23	Sep 04	Dec 31
2012	Jan 12	May 27	Jun 14	Sep 14	Oct 02	Dec 19
2011	Jan 01	Apr 28	May 09	Sep 21	Oct 07	Dec 30
2010	Jan 13	May 07	May 17	Sep 28	Oct 10	Dec 13
2009	Jan 12	May 22	Jun 25	Aug 28	Sep 13	Dec 25
2008	Jan 08	May 30	Jun 05	Sep 06	Sep 25	Dec 29
2007	Jan 08	Jul 14	Aug 02	Aug 19	Sep 04	Dec 31
2006	Jan 22	Apr 23	Apr 27	Sep 12	Oct 06	Dec 31
Median Month	January	May	May	August	September	December

Source: University of Washington, School of Aquatic and Fishery Science 2022.

Table C-60. Summary of Juvenile Unclipped *O. mykiss* Catch in the Knights Landing Screw Trap, 2006–2020

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	Jan 27	Jan 27	Jan 27	Apr 30	Apr 30	Apr 30
2019	Jan 14	Jan 14	Jan 14	May 30	May 30	May 30
2018	Jan 12	Jan 12	Jan 12	Apr 27	Apr 27	Apr 27
2017	Feb 10	Feb 10	Feb 10	May 10	May 19	May 19
2016	Jan 17	Jan 17	Jan 17	Mar 29	Mar 29	Mar 29
2015	Feb 10	Feb 10	Feb 10	May 25	May 25	May 25
2014	Feb 13	Mar 2	Mar 2	Apr 1	Apr 5	Jun 2
2013	–	–	–	–	–	–
2012	Jan 27	Jan 27	Mar 18	Apr 5	Apr 5	Apr 5
2011	Feb 18	Feb 18	Feb 18	Feb 18	Feb 18	Feb 18
2010	Jan 19	Jan 19	Jan 27	Apr 28	May 3	May 3
2009	Jan 28	Jan 28	Feb 22	May 11	May 20	May 20
2008	Jan 19	Jan 19	Jan 19	May 22	May 22	May 22
2007	Feb 13	Feb 13	Feb 13	Jun 1	Jun 1	Jun 1
2006	Jan 21	Jan 21	Jan 23	Apr 15	Apr 20	Apr 20
Median Month	January	January	January	April	May	May

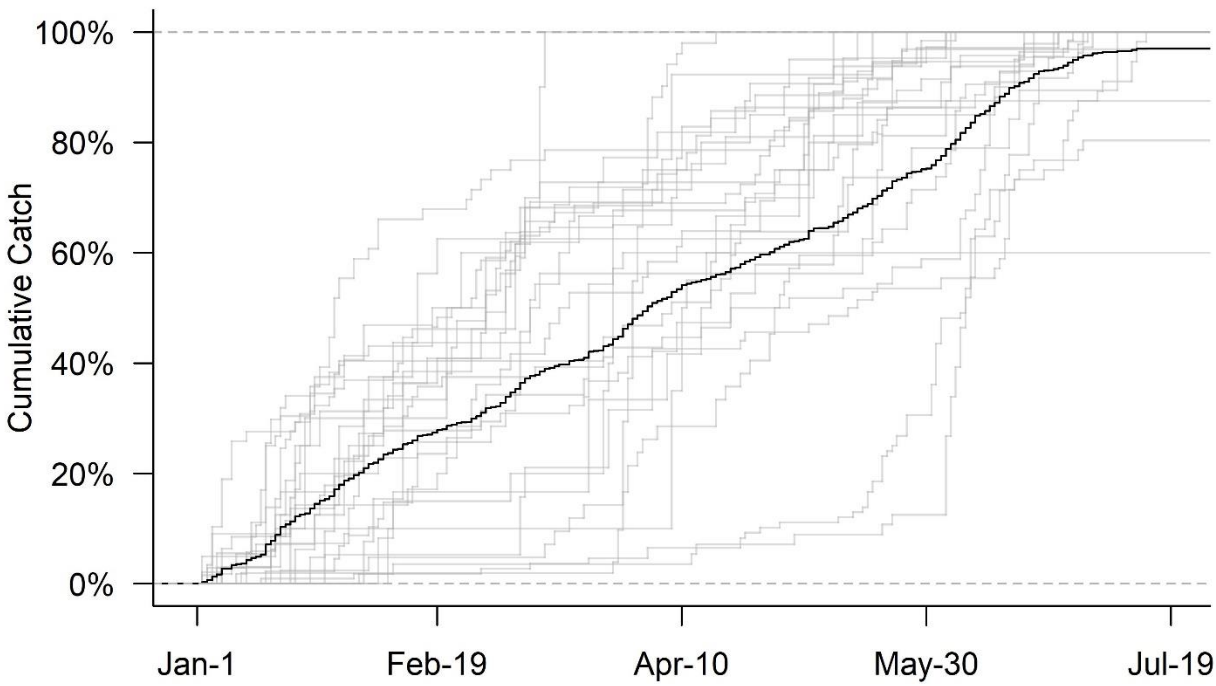
Source: University of Washington, School of Aquatic and Fishery Science 2022.

Table C-61. Summary of Juvenile Unclipped *O. mykiss* Catch in the Stanislaus River Caswell Screw Trap, 1996–2021.

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2021	Jan 24	Jan 27	Jan 29	May 6	May 12	Jun 2
2020	Jan 2	Jan 29	Apr 7	Jun 2	Jun 15	Jun 18
2019	Jan 16	Jan 17	Jan 18	May 25	Jun 7	Jun 20
2018	Feb 7	Feb 9	Feb 14	May 5	May 7	May 10
2017	Jan 20	Jan 21	Jan 23	Mar 11	Mar 12	Mar 12
2016	Jan 10	Mar 27	Mar 28	Apr 3	Apr 6	Apr 16
2015	Feb 9	Feb 9	Feb 10	Apr 30	May 2	May 15
2014	Jan 6	Jan 16	Jan 20	May 5	May 20	Jun 25

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2013	Jan 2	Jan 7	Jan 14	May 25	Jun 4	Jun 25
2012	Jan 14	Apr 7	May 13	Jun 21	Jun 28	Jul 2
2011	Jan 3	Jan 16	Jan 21	Dec 3	Dec 8	Dec 13
2010	Jan 21	Jan 24	Jan 28	Aug 9	Oct 16	Oct 18
2009	Jan 15	Jan 30	Feb 1	Jun 10	Jun 17	Jun 30
2008	Jan 9	Jan 15	Jan 15	May 10	May 18	Jul 1
2007	Jan 5	Jan 15	Feb 7	Jun 13	Jun 23	Jun 28
2006	Feb 3	Apr 12	Apr 12	Jul 1	Jul 10	Jul 13
2005	Jan 4	Jan 6	Jan 22	May 24	Jun 3	Jun 3
2004	Jan 3	Jan 4	Jan 6	May 20	May 22	May 25
2003	Jan 5	Jan 10	Jan 14	May 9	May 24	Jun 2
2002	Jan 11	Jan 18	Jan 18	Apr 23	May 18	Dec 19
2001	Jan 2	Jan 16	Jan 17	May 22	May 23	Jun 4
2000	Jan 6	Jan 12	Jan 25	Dec 14	Dec 19	Dec 28
1999	Jan 18	Mar 12	Mar 17	Jun 6	Jun 22	Jun 24
1998	Jan 27	Mar 5	Mar 7	Jun 19	Jul 7	Jul 7
1996	Feb 4	Feb 6	Feb 11	Apr 7	Apr 11	May 18
Median Month	January	January	January	May	June	June

Source: CalFish 2022b; Pacific States Marine Fisheries Commission Caswell screw trap.



Source: CalFish 2022.
Note: Data include brood years 1996–2021 (less 1997). Function is plotted for individual years (gray lines) and the across all years (black line). Data available on CalFish Stanislaus River – RST Monitoring.

Figure C-47. Plotted Empirical Cumulative Distribution of Stanislaus River Caswell Juvenile Steelhead Rotary Screw Trap Catch as a Function of Julian Day

Table C-62. Summary of Juvenile Unclipped *O. mykiss* Catch, Passage from the Mossdale Trawls by USWFS, 2006–2020

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	–	–	–	–	–	–
2019	–	–	–	–	–	–
2018	May 06	May 06	May 06	May 06	May 06	May 06
2017	Apr 10	Apr 10	Apr 10	May 08	May 08	May 08
2016	–	–	–	–	–	–
2015	Apr 07	Apr 07	Apr 07	Apr 30	Apr 30	Apr 30
2014	Mar 31	Apr 09	Apr 13	May 21	May 28	May 28
2013	Mar 05	Mar 05	Apr 04	May 31	Jun 02	Jun 02
2012	Jan 07	Apr 02	Apr 04	May 17	May 18	May 18
2011	Apr 05	Apr 05	Apr 06	May 22	May 24	May 24

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2010	Mar 30	Mar 30	Mar 30	May 24	May 24	May 24
2009	Apr 22	Apr 22	Apr 22	May 14	May 14	May 14
2008	Apr 08	Apr 08	Apr 08	Apr 08	Apr 08	Apr 08
2007	May 08	May 08	May 08	May 29	May 29	May 29
2006	Feb 28	Apr 02	Apr 06	May 14	May 19	May 29
Median Month	March	April	April	May	May	May

Source: University of Washington, School of Aquatic and Fishery Science 2022.

C.4.7 Delta Juvenile and Yearling Migration

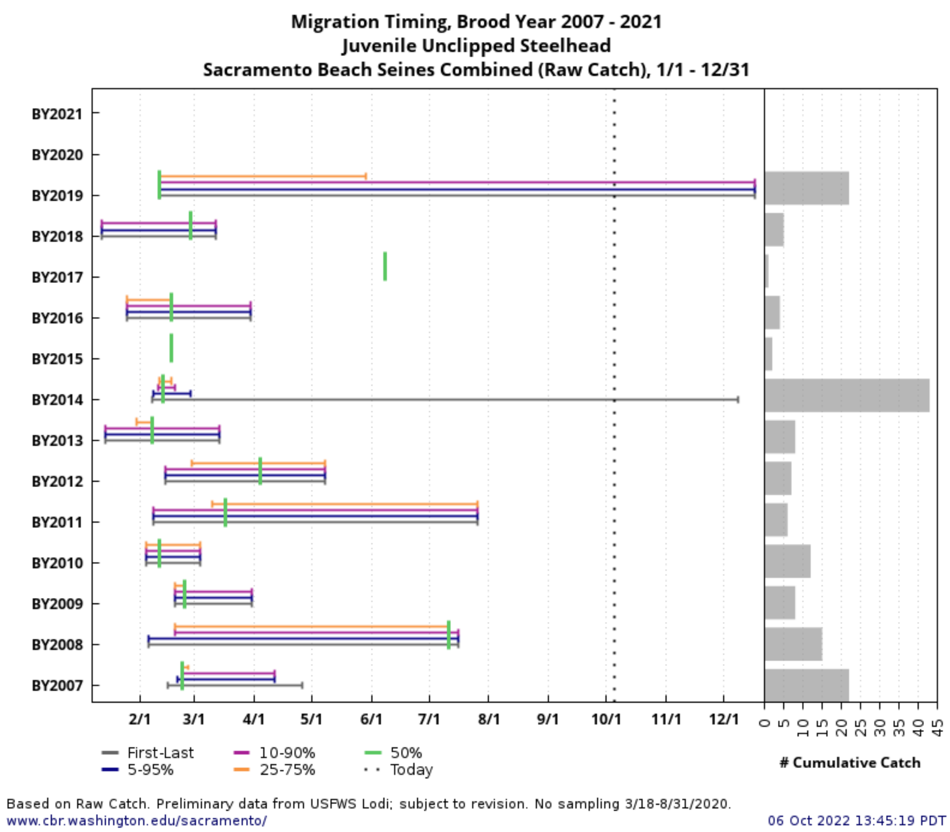
Juvenile steelhead can be found in all waterways of the Delta, but particularly in the main channels leading from their natal river systems (National Marine Fisheries Service 2009). Delta entry is monitored at the Sacramento beach seines and trawl locations. Median passage of juvenile steelhead recovered in the Sacramento trawls occurs February through May and in combined catch data from Sacramento Beach Seines January through March, but with potential for year-round presence of juveniles. Delta exit is monitored at the Chipps Island trawl location and median passage occurs February through May. Chipps Island catch data indicate a difference in the emigration timing between natural origin (i.e., unclipped) and hatchery-reared (i.e., clipped) steelhead smolts from the Sacramento River 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; Bureau of Reclamation 2008:3–11). The timing of unclipped steelhead emigration is more protracted and, based on salvage records at the CVP and SWP fish-collection facilities, emigration occurs over approximately 6 months, with the highest levels of recovery in February through June (Figure C-50; Aasen 2011, 2012). Median timing of juveniles captured in the Sacramento beach seines is January through March, but with potential for year-round presence of juveniles (see Brood Year 2018–2019: Figure C-48, Table C-63, and Table C-64). Trawl data at Sherwood Harbor, south of Sacramento, shows juvenile migration is first detected in January, with 90% median passage occurring by May, and the last passage occurring in June (Table C-65).

Emigrating steelhead smolts enter the Delta primarily from the Sacramento and San Joaquin rivers. Mokelumne River steelhead smolts can follow either 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 CDFW has routinely documented steelhead in trawls at Mossdale since 1988 (San Joaquin River Group Authority 2011), it is unknown whether successful emigration occurs outside the historical-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.

Table C-63. Summary of Juvenile *O. mykiss* Passage in the Delta by Median Month from USFWS Raw Catch Data on SacPAS

Station	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
Sacramento Seines	January	February	February	March	March	March
Sacramento Trawl	February	February	February	May	May	May
Chipps Island	February	February	February	May	May	May
Delta Juvenile	January	February	February	May	May	May

Source: University of Washington, School of Aquatic and Fishery Science 2022.
Note: Delta juvenile timing is based on the earliest or latest observation of that percentile.



Source: University of Washington, School of Aquatic and Fishery Science 2022.

Figure C-48. Unclipped *O. mykiss* Juvenile Migration Timing, Sacramento Beach Seines 2007–2020

Table C-64. Unclipped *O. mykiss* Juvenile Migrating Timing, Sacramento Beach Seines, 2006–2019

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2019	Feb 11	Feb 11	Feb 11	Dec 17	Dec 17	Dec 17
2018	Jan 12	Jan 12	Jan 12	Mar 12	Mar 12	Mar 12
2017	Jun 08	Jun 08	Jun 08	Jun 08	Jun 08	Jun 08
2016	Jan 25	Jan 25	Jan 25	Mar 29	Mar 29	Mar 29
2015	Feb 17	Feb 17	Feb 17	Feb 17	Feb 17	Feb 17
2014	Feb 07	Feb 08	Feb 10	Feb 19	Feb 27	Dec 08
2013	Jan 14	Jan 14	Jan 14	Mar 14	Mar 14	Mar 14
2012	Jan 15	Feb 14	Feb 14	May 07	May 07	May 07
2011	Jan 16	Feb 08	Feb 08	Jul 26	Jul 26	Jul 26
2010	Jan 17	Feb 04	Feb 04	Mar 04	Mar 04	Mar 04
2009	Jan 18	Feb 19	Feb 19	Mar 31	Mar 31	Mar 31
2008	Jan 19	Feb 05	Feb 19	Jul 15	Jul 15	Jul 15
2007	Jan 20	Feb 20	Feb 23	Apr 12	Apr 12	Apr 26
2006	Jan 21	Feb 23	Feb 23	Feb 28	May 23	May 23
Monthly Median	January	February	February	March	March	March

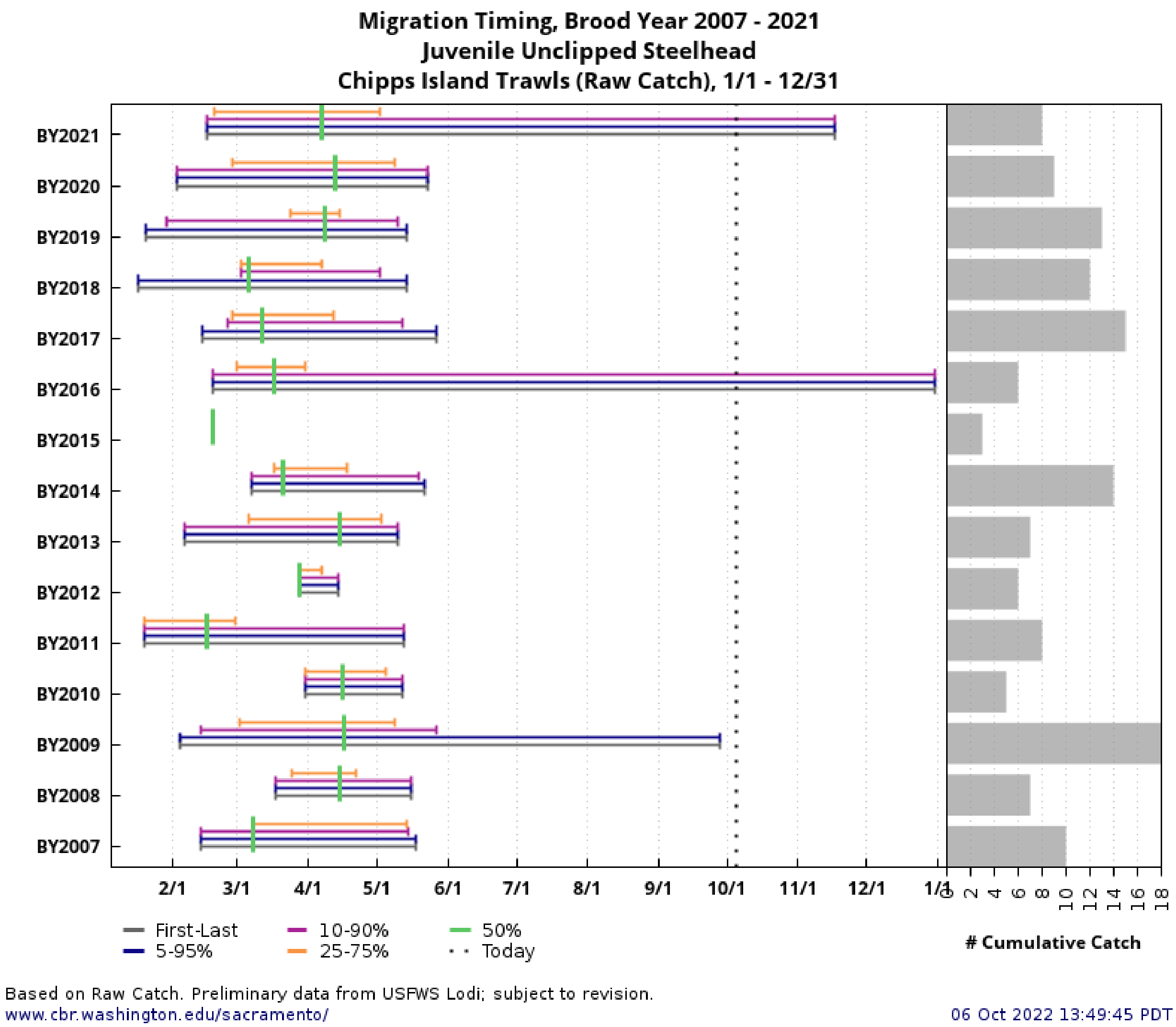
Source: University of Washington, School of Aquatic and Fishery Science 2022.

Table C-65. Unclipped *O. mykiss* Juvenile Migrating Timing, Sacramento Trawl at Sherwood Harbor, 2006–2020

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2020	Jan 13	Jan 13	Jan 13	May 22	May 22	May 22
2019	Jan 25	Jan 25	Feb 10	Apr 21	May 28	May 28
2018	Feb 27	Feb 27	Feb 27	May 14	May 14	May 14
2017	Feb 23	Feb 23	Feb 23	May 25	Jun 02	Jun 02
2016	–	–	–	–	–	–
2015	Apr 20	Apr 20	Apr 20	Apr 20	Apr 20	Apr 20
2014	Feb 11	Feb 11	Feb 11	Apr 07	Apr 07	Apr 07
2013	Apr 12	Apr 12	Apr 12	May 31	May 31	May 31
2012	Jan 27	Jan 27	Jan 27	May 01	May 01	May 01
2011	May 10	May 10	May 10	Jun 21	Jun 21	Jun 21
2010	Feb 08	Feb 08	Feb 08	Jun 10	Jun 10	Jun 10

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2009	May 02	May 02	May 02	May 07	May 07	May 07
2008	Jan 11	Jan 11	Jan 11	Jan 11	Jan 11	Jan 11
2007	Feb 12	Feb 12	Feb 12	Jun 12	Jun 12	Jun 12
2006	Feb 15	Feb 15	Feb 15	Jun 14	Jun 14	Jun 14
Median Month	February	February	February	May	May	May

Source: University of Washington, School of Aquatic and Fishery Science 2022.



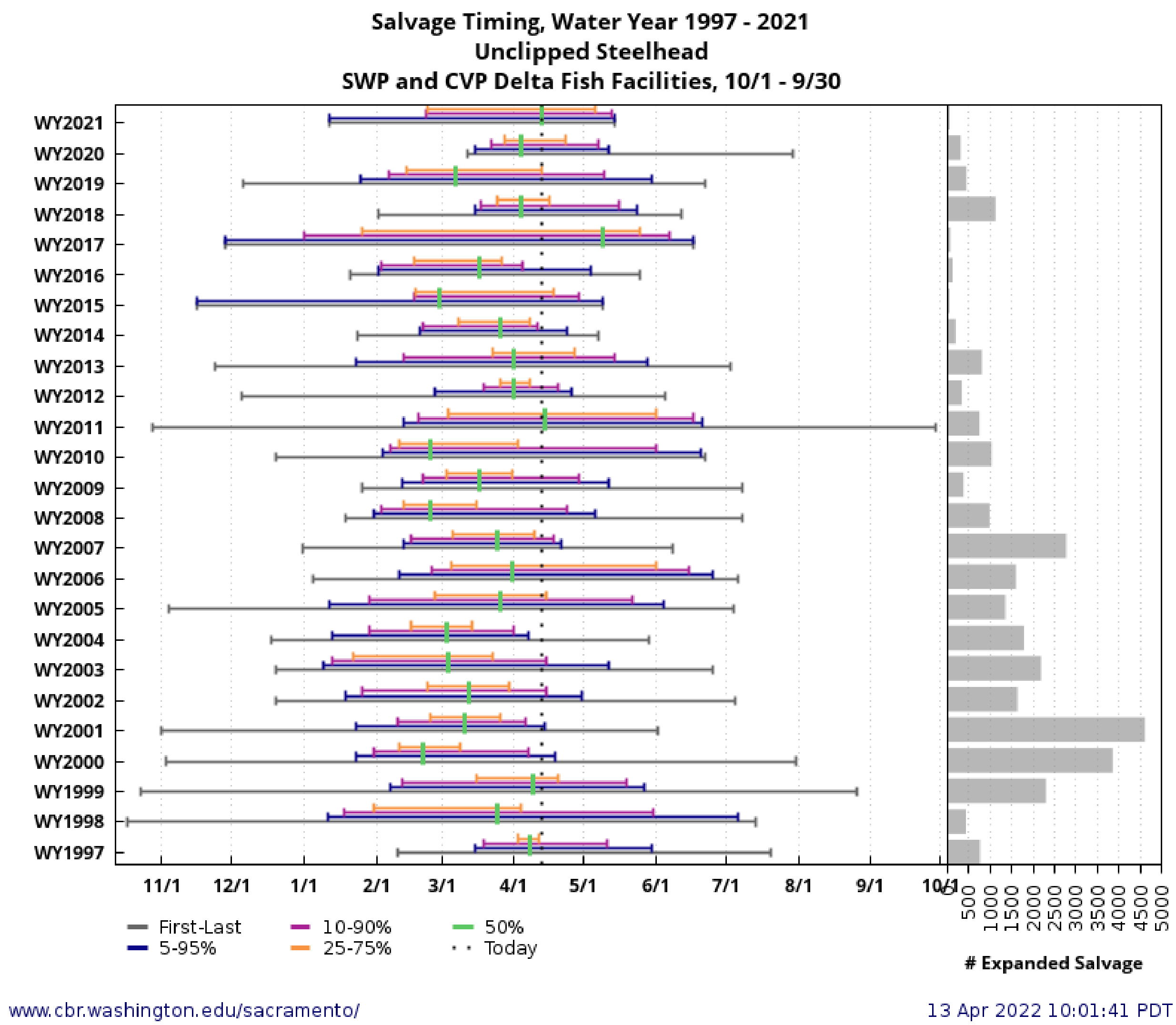
Source: University of Washington, School of Aquatic and Fishery Science 2022.

Figure C-49. Unclipped *O. mykiss* Juvenile Migration Timing, Chipps Island Migration Timing, 2006–2021

Table C-66. Unclipped *O. mykiss* Juvenile Migration Timing, Chipps Island Migration Timing, 2006–2021

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Final
2021	Feb 16	Feb 16	Feb 16	Nov 17	Nov 17	Nov 17
2020	Feb 03	Feb 03	Feb 03	May 11	May 22	May 22
2019	Jan 29	Jan 29	Jan 29	May 10	May 14	May 14
2018	Jan 17	Jan 17	Mar 03	May 02	May 14	May 14
2017	Feb 14	Feb 14	Feb 25	May 12	May 27	May 27
2016	Feb 18	Feb 18	Feb 18	Dec 30	Dec 30	Dec 30
2015	Feb 18	Feb 18	Feb 18	Feb 18	Feb 18	Feb 18
2014	Mar 07	Mar 07	Mar 07	May 19	May 22	May 22
2013	Feb 06	Feb 06	Feb 06	May 10	May 10	May 10
2012	Mar 27	Mar 27	Mar 27	Apr 13	Apr 13	Apr 13
2011	Jan 19	Jan 19	Jan 19	May 13	May 13	May 13
2010	Mar 31	Mar 31	Mar 31	May 12	May 12	May 12
2009	Feb 04	Feb 04	Feb 13	May 27	Sep 28	Sep 28
2008	Mar 17	Mar 17	Mar 17	May 15	May 15	May 15
2007	Feb 13	Feb 13	Feb 13	May 15	May 18	May 18
2006	Feb 09	Feb 13	Mar 03	Jun 09	Jun 14	Jun 26
Median Month	February	February	February	May	May	May

Source: University of Washington, School of Aquatic and Fishery Science 2022.



Source: University of Washington, School of Aquatic and Fishery Science 2022.

Figure C-50. Unclipped *O. mykiss* Juvenile Migration Timing, Salvage at CVP and SWP Fish Facilities, 2006–2021

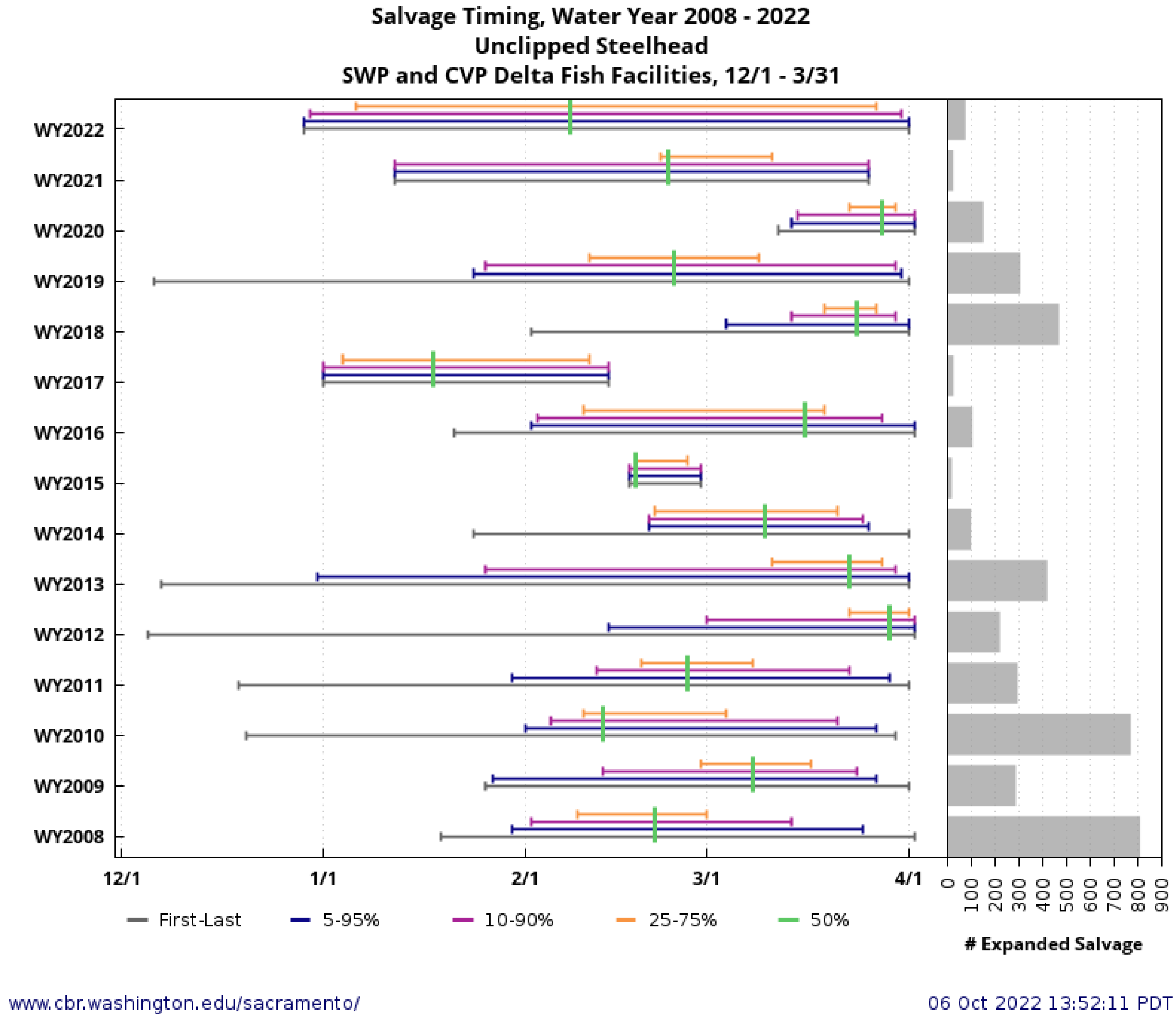
Table C-67. Unclipped *O. mykiss* Juvenile Migration Timing, Salvage at CVP and SWP Fish Facilities, 2006–2021

Water Year	First	5%	10%	90%	95%	Last
2021	1/11/2021	1/11/2021	2/21/2021	5/12/2021	5/13/2021	5/13/2021
2020	3/10/2020	3/13/2020	3/20/2020	5/5/2020	5/10/2020	7/28/2020
2019	12/6/2018	1/24/2019	2/5/2019	5/9/2019	5/29/2019	6/21/2019
2018	2/1/2018	3/14/2018	3/17/2018	5/15/2018	5/23/2018	6/11/2018
2017	11/27/2016	11/27/2016	12/31/2016	6/6/2017	6/16/2017	6/16/2017

Water Year	First	5%	10%	90%	95%	Last
2016	1/20/2016	2/1/2016	2/2/2016	4/3/2016	5/2/2016	5/23/2016
2015	11/16/2014	11/16/2014	2/16/2015	4/28/2015	5/8/2015	5/8/2015
2014	1/23/2014	2/19/2014	2/20/2014	4/10/2014	4/23/2014	5/6/2014
2013	11/23/2012	1/22/2013	2/12/2013	5/13/2013	5/27/2013	7/2/2013
2012	12/5/2011	2/25/2012	3/17/2012	4/18/2012	4/24/2012	6/3/2012
2011	10/28/2010	2/12/2011	2/18/2011	6/16/2011	6/20/2011	9/28/2011
2010	12/20/2009	2/3/2010	2/6/2010	5/31/2010	6/19/2010	6/21/2010
2009	1/25/2009	2/11/2009	2/20/2009	4/28/2009	5/11/2009	7/7/2009
2008	1/18/2008	1/30/2008	2/2/2008	4/22/2008	5/4/2008	7/6/2008
2007	12/31/2006	2/12/2007	2/15/2007	4/17/2007	4/20/2007	6/7/2007
2006	1/4/2006	2/10/2006	2/24/2006	6/14/2006	6/24/2006	7/5/2006
2005	11/3/2004	1/11/2005	1/28/2005	5/21/2005	6/3/2005	7/3/2005
2004	12/18/2003	1/12/2004	1/28/2004	3/30/2004	4/5/2004	5/27/2004
2003	12/20/2002	1/8/2003	1/12/2003	4/14/2003	5/11/2003	6/24/2003
2002	12/20/2001	1/18/2002	1/25/2002	4/14/2002	4/29/2002	7/4/2002
2001	10/31/2000	1/22/2001	2/9/2001	4/5/2001	4/13/2001	6/1/2001
2000	11/3/1999	1/22/2000	1/30/2000	4/5/2000	4/17/2000	7/29/2000
1999	10/23/1998	2/6/1999	2/11/1999	5/18/1999	5/26/1999	8/25/1999
1998	10/17/1997	1/10/1998	1/17/1998	5/30/1998	7/5/1998	7/13/1998
1997	2/9/1997	3/14/1997	3/18/1997	5/10/1997	5/29/1997	7/19/1997
Median Month	December	January	February	May	May	June

Source: University of Washington, School of Aquatic and Fishery Science 2022.

This figure shows data also presented in data tables in this file.



Source: University of Washington, School of Aquatic and Fishery Science 2022.

Figure C-51. Clipped *O. mykiss* Juvenile Migration Timing, Salvage at SWP and CVP Fish Facilities, 1997–2021

Table C-68. Clipped *O. mykiss* Juvenile Migration Timing, Salvage at SWP and CVP Fish Facilities, 1997–2021

Water Year	First	5%	10%	90%	95%	Last
2021	1/20/2021	2/6/2021	2/12/2021	4/28/2021	5/5/2021	5/11/2021
2020	10/17/2019	3/5/2020	3/9/2020	4/19/2020	4/23/2020	5/6/2020
2019	12/6/2018	1/24/2019	2/3/2019	3/23/2019	4/5/2019	6/7/2019
2018	1/21/2018	3/2/2018	3/3/2018	4/9/2018	4/14/2018	5/27/2018
2017	1/31/2017	2/6/2017	2/6/2017	5/10/2017	6/3/2017	6/3/2017
2016	1/19/2016	1/25/2016	2/1/2016	3/22/2016	3/28/2016	6/3/2016
2015	1/23/2015	1/30/2015	2/16/2015	3/11/2015	3/18/2015	4/23/2015
2014	2/18/2014	2/18/2014	2/18/2014	4/15/2014	4/24/2014	6/17/2014
2013	1/26/2013	1/30/2013	2/7/2013	4/22/2013	5/4/2013	7/4/2013
2012	1/25/2012	2/5/2012	2/16/2012	4/17/2012	4/23/2012	7/7/2012
2011	1/19/2011	1/24/2011	1/29/2011	6/12/2011	6/20/2011	6/29/2011
2010	1/19/2010	1/27/2010	2/3/2010	3/8/2010	3/21/2010	6/24/2010
2009	1/18/2009	2/16/2009	2/18/2009	3/30/2009	4/8/2009	5/23/2009
2008	1/20/2008	1/28/2008	1/31/2008	3/4/2008	3/23/2008	7/8/2008
2007	1/25/2007	2/14/2007	2/22/2007	4/10/2007	4/16/2007	5/31/2007
2006	2/2/2006	2/22/2006	2/27/2006	3/19/2006	3/21/2006	6/4/2006
2005	1/22/2005	1/28/2005	1/29/2005	4/4/2005	4/24/2005	5/31/2005
2004	1/19/2004	2/8/2004	2/14/2004	3/7/2004	3/12/2004	4/12/2004
2003	12/21/2002	1/10/2003	1/13/2003	2/26/2003	3/23/2003	6/9/2003
2002	1/14/2002	1/21/2002	1/25/2002	3/23/2002	3/30/2002	5/8/2002
2001	12/14/2000	2/1/2001	2/8/2001	3/17/2001	3/22/2001	5/5/2001
2000	1/1/2000	1/20/2000	1/28/2000	2/29/2000	3/10/2000	5/28/2000
1999	1/16/1999	1/16/1999	1/21/1999	4/23/1999	4/30/1999	6/9/1999
1998	12/16/1997	12/18/1997	1/5/1998	2/4/1998	2/10/1998	2/21/1998
1997	3/24/1997	3/24/1997	3/24/1997	3/24/1997	3/24/1997	3/24/1997
Median	January	January	February	March	April	May

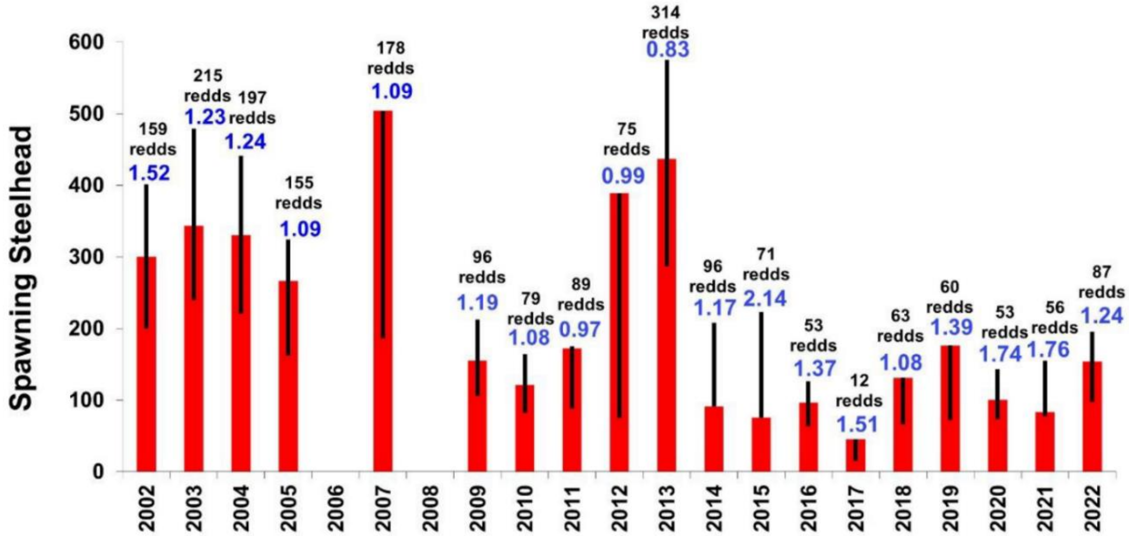
Source: University of Washington, School of Aquatic and Fishery Science 2022.

C.4.8 Spawner Adult Abundance

C.4.8.1 Sacramento River

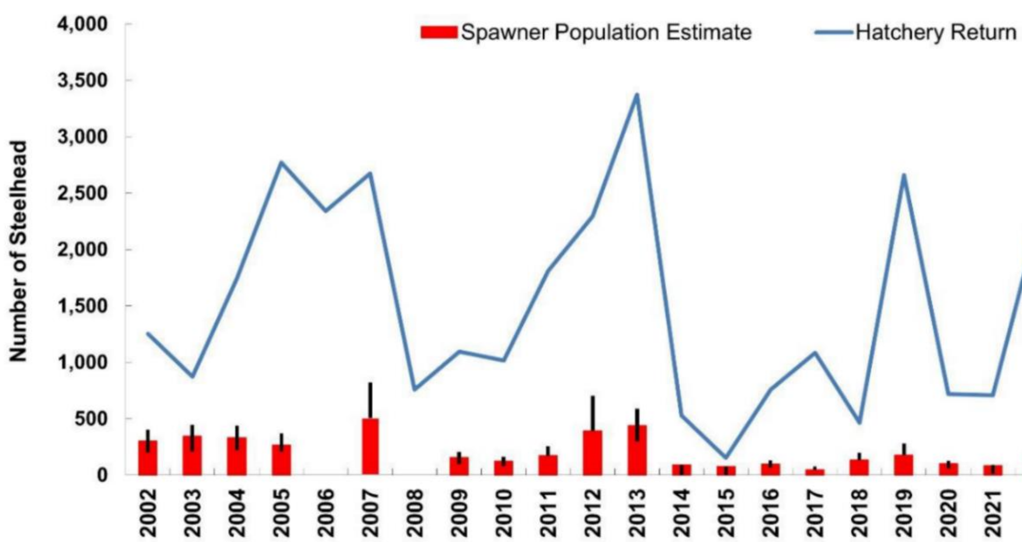
No available information.

C.4.8.2 American River



Source: Sweeney Et al. 2022.

Figure C-52. In-river steelhead spawner population estimates based on redd counts and spawning steelhead observations: 2002: 2022. Error estimates are the range of population estimates using the assumption of either 1 or 2 redds per female. Male to female ratio in blue text. Actual redds observed in black text.



Source: Sweeney et al. 2022.

Figure C-53. Steelhead spawner population estimate compared to Nimbus Hatchery steelhead return: 2002 – 2022. Bars are spawner population estimates, error estimates are range of redd-based population estimates using the assumption of either 1 or 2 redds per female.

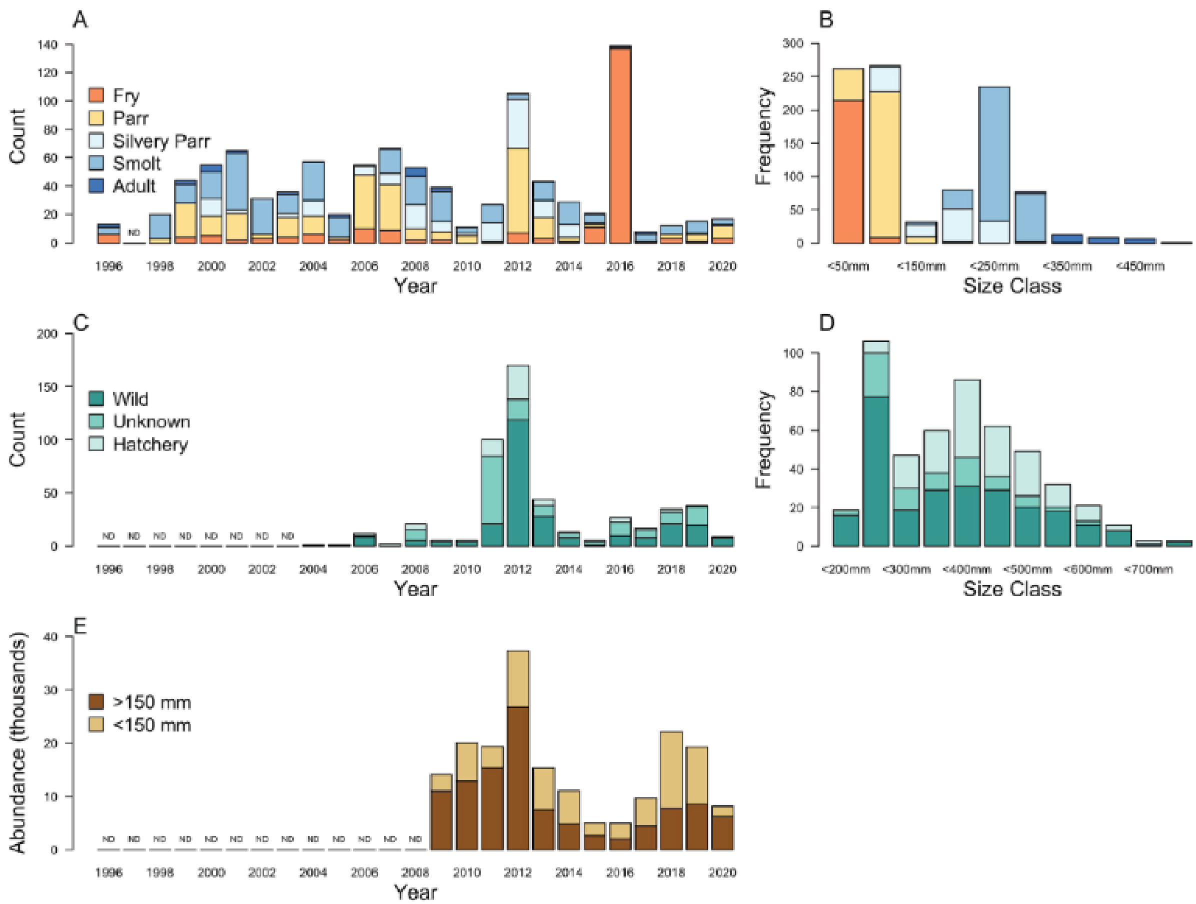
C.4.8.3 Clear Creek

Table C-69. Clear Creek steelhead redd and carcass counts from surveys

	Redds	Carcass
2017/2018	369	0
2016/2017	75	0
2015/2016	149	5
2014/2015	225	2

Sources: For 2014/2015, Provins and Chamberlain 2019a. For 2015/2016, Schaefer et al. 2019. For 2016/2017, Provins and Chamberlain 2019b. For 2017/2018, Provins and Chamberlain 2020.

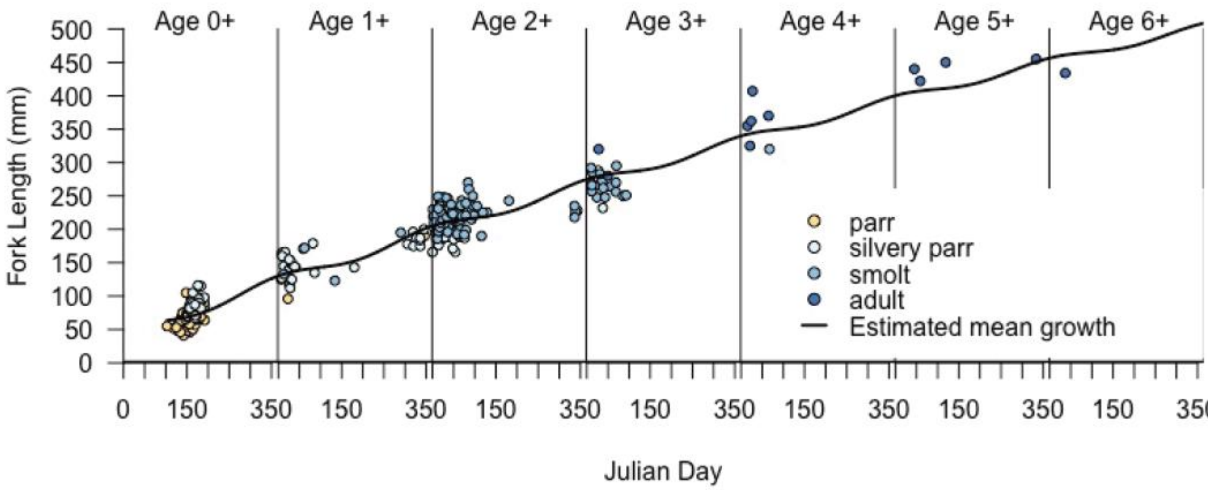
C.4.8.4 Stanislaus River



Source: Eschenroeder et al. 2022.

Figure C-54. Summary of *O. mykiss* monitoring on the Stanislaus River.

Panel A–Annual detections of outmigrating *O. mykiss* at the rotary screw trap (RST) near Oakdale, CA, which has been operated every year since 1996 except for 1997 color coded by assigned life stage (Interagency Ecological Program 2008). The typical operation period is from January into June. Panel B–The frequency of individuals in each size class captured by the RST (total n = 1,034), also color coded by assigned life stage. Panel C–Annual upstream passages of *O. mykiss* at the fish counting weir located near Riverbank, CA, from 2004 through 2019. Color coding indicates fish origin based on whether the presence of an adipose fin clip could be clearly discerned. The typical weir operation period is from September through December. Panel D–The frequency of individuals per 50 millimeters (mm) total length bin detected by the weir, with color coding indicating origin. Note the first size bin is 150 to 199 mm and that fish smaller than approximately 200 mm total length have low detection at the weir. Based on length, 180 individuals were classified as Steelhead (i.e., > 406 mm [> 16 inches]), of which 89 had an intact adipose fin, 75 had a clipped adipose fin, and 16 were inconclusive. Panel E–*O. mykiss* abundance estimates from summer snorkel surveys that have been conducted in reaches above Oakdale since 2009.



Source: Eschenroeder et al 2022.

Figure C-55. Growth and age composition of *O. mykiss* (n = 350) captured in the Stanislaus River rotary screw trap near Oakdale, CA

Individuals are color coded by assigned life stage (Interagency Ecological Program 2008). *Solid black line* is the estimated seasonally fluctuating von Bertalanffy growth through time. Typical operation of the trap is from January into June, but the trap was occasionally operated in December. RST has provided age information on *O. mykiss* and indicates a diverse age composition. The majority of aged fish captured in the RST were determined to be age-0 (n = 167), followed by age–2 (n = 116), age–1 (n = 35), age–3 (n = 21), age–4 (n = 6), age–5 (n = 4), and age–6 (n = 1).

Table C-70. Adult *O. mykiss* passage at Stanislaus River weir: 2003 – 2019

Year	Observed Passages	Female	Male	Unknown	Percent with Adipose Fin Clip
2003	1	1	0	0	0
2004	1	1	0	0	0
2005	12	5	0	7	8
2006	2	0	0	2	0
2007	21	0	1	20	48
2008	6	1	1	4	0
2009	6	0	0	6	0
2010	100	7	10	83	64
2011	170	15	5	150	11
2012	44	0	1	43	23
2013	13	8	1	4	38
2014	6	0	0	6	50
2015	27	9	6	12	48
2016	13	4	1	8	38
2017	35	2	8	25	31
2018	38	2	0	36	45
2019	4	0	0	4	50

Source: Eschenroeder et al. 2022:Attachment A.

Table C-71. Monthly summary of adult *O. mykiss* passage at Stanislaus River weir: 2003 – 2019

	Upstream Passage		Downstream Passage	
	TL < 406 mm	TL > 406 mm	TL < 406 mm	TL > 406 mm
Jan	62	32	5	4
Feb	51	21	5	2
Mar	60	7	0	0
Apr	13	0	0	0
May	5	0	0	0
Jun	14	0	0	0
Jul	8	4	2	1
Aug	36	54	6	7

	Upstream Passage		Downstream Passage	
	TL < 406 mm	TL > 406 mm	TL < 406 mm	TL > 406 mm
Sep	41	34	1	4
Oct	29	28	5	5
Nov	62	32	5	4
Dec	51	21	5	2

Source: Eschenroeder et al. 2022: Attachment A.

Table C-72. *O. mykiss* passage by life stage at Stanislaus River Oakdale RST: 1996 – 2019. The number of individuals measured (number by life stage: fry, parr, silvery parr, smolt, adult, unknown) was not always equal to the annual total catch.

Year	Total Catch	Fry	Parr	Silvery Parr	Smolt	Adult	Unknown
1996	13	6	0	0	5	2	0
1998	20	0	3	0	16	0	0
1999	44	4	22	0	13	3	0
2000	56	5	14	12	19	5	1
2001	65	2	19	2	40	2	0
2002	32	3	3	0	25	0	1
2003	36	4	14	3	13	2	0
2004	58	6	13	11	27	0	1
2005	22	2	2	0	14	2	2
2006	56	10	38	6	1	0	1
2007	69	9	32	8	17	1	2
2008	55	2	8	17	20	6	2
2009	45	2	6	7	21	3	5
2010	16	0	5	2	4	0	5
2011	35	0	1	13	13	0	8
2012	108	8	60	34	4	0	2
2013	47	3	15	12	13	0	4
2014	35	1	3	9	16	0	6
2015	21	10	2	1	6	1	0
2016	143	45	0	1	1	0	4
2017	10	1	0	0	5	2	2
2018	12	3	3	0	6	0	0

Year	Total Catch	Fry	Parr	Silvery Parr	Smolt	Adult	Unknown
2019	16	1	5	1	8	0	1

Source: Eschenroeder et al. 2022:Attachment B.

Table C-73. Monthly summary of *O. mykiss* by life stage at Stanislaus River Oakdale RST: 1996 – 2019

	Fry	Parr	Silvery Parr	Smolt	Adult	Unknown
Jan	2	8	36	109	6	10
Feb	4	0	28	64	12	6
Mar	122	2	10	81	8	13
Apr	61	28	4	29	2	8
May	18	101	5	14	0	4
Jun	13	123	33	2	1	5
Jul	0	7	5	2	0	0
Aug	0	0	1	0	0	2
Sep	0	0	4	0	0	0
Oct	0	1	13	7	0	0
Nov	2	8	36	109	6	10
Dec	4	0	28	64	12	6

Source: Eschenroeder et al 2022:Attachment B.

C.5 Fecundity and Survival of Eggs

C.5.1.1 Sacramento River

No observations of survival in the river.

C.5.1.2 American River

No observations of survival in the river.

The following tables display Nimbus Fish Hatchery (NIM) annual operations summaries for 2021-2022, 2020-2021, 2019-2020, and 2018-2019.

Table C-74. Brood Stock Collection and Spawning: American River Winter-Run Steelhead Trout (2021 – 2022)

Trapped	Spawned	Fecundity	% Survival to Eyed
1,224 male hatchery origin 985 female hatchery origin 62 juvenile hatchery origin 6 male natural origin 4 female natural origin 2 juvenile natural origin 271 CV SH	220 females	Historical averages 6,700 eggs/female	62.78

Source: California Department of Fish and Wildlife Annual Reports for Nimbus Fish Hatchery.

Table C-75. July 1, 2020 – June 30, 2021, Brood Stock Collection and Spawning: American River Winter-Run Steelhead Trout (2020 – 2021)

Trapped	Spawned	Fecundity	% Survival to Eyed
448 male hatchery origin 257 female hatchery origin 13 juvenile hatchery origin 6 male natural origin 1 female natural origin	148 females	Historical averages 6,700 eggs/female	85.33

Source: California Department of Fish and Wildlife Annual Reports for Nimbus Fish Hatchery.

Table C-76. July 1, 2019 – June 30, 2020, Brood Stock Collection and Spawning: American River Winter-Run Steelhead Trout

Trapped	Spawned	Fecundity	% Survival to Eyed
457 males 262 females 74 grilse	-	-	93.33

Source: California Department of Fish and Wildlife Annual Reports for Nimbus Fish Hatchery.

Table C-77. July 1, 2018 – June 30, 2019, Brood Stock Collection and Spawning: American River Winter-Run Steelhead Trout

Trapped	Spawned	Fecundity	% Survival to Eyed
1,547 males 1,112 females 261 grilse	-	-	88.80

Source: California Department of Fish and Wildlife Annual Reports for Nimbus Fish Hatchery.

C.5.1.3 Stanislaus River

No available information.

C.5.1.4 Clear Creek

No available information.

C.5.2 Redds

C.5.2.1 Sacramento River

No available redd and carcass data.

C.5.2.2 Clear Creek

Table C-78. Clear Creek – USFWS redd surveys, steelhead and late fall-run Chinook salmon Winter 2014 – Spring 2018

		Steelhead / Rainbow Trout	Late Fall-Run Chinook Salmon
Clear Creek	Winter 2014 – Spring 2015	225	99
	Winter 2015 – Spring 2016	149	22
	Winter 2016 – Spring 2017	75	20
	Winter 2017 – Spring 2018	369	32

Sources: For 2014/2015, Provins and Chamberlain 2019a. For 2015/2016, Schaefer et al. 2019. For 2016/2017, Provins and Chamberlain 2019b. For 2017/2018, Provins and Chamberlain 2020.

C.5.2.3 Battle Creek

No available data redd and carcass data.

C.5.2.4 American River

Table C-79. Steelhead redd density by mile by reach: 2002 – 2022

	Nimbus Dam to Sacramento River	Nimbus Dam to Paradise Beach	Nimbus Dam to Ancil Hoffman Park	Ancil Hoffman Park to Watt Avenue	Watt Avenue to Paradise Beach
River Miles	1 to 23	5 to 23	17 to 23	11 to 17	5 to 11
2002	6.9	8.8	16.1	4.4	3.7
2003	9.3	11.9	19.6	17.7	0
2004	8.6	10.9	19.8	9.1	0.8

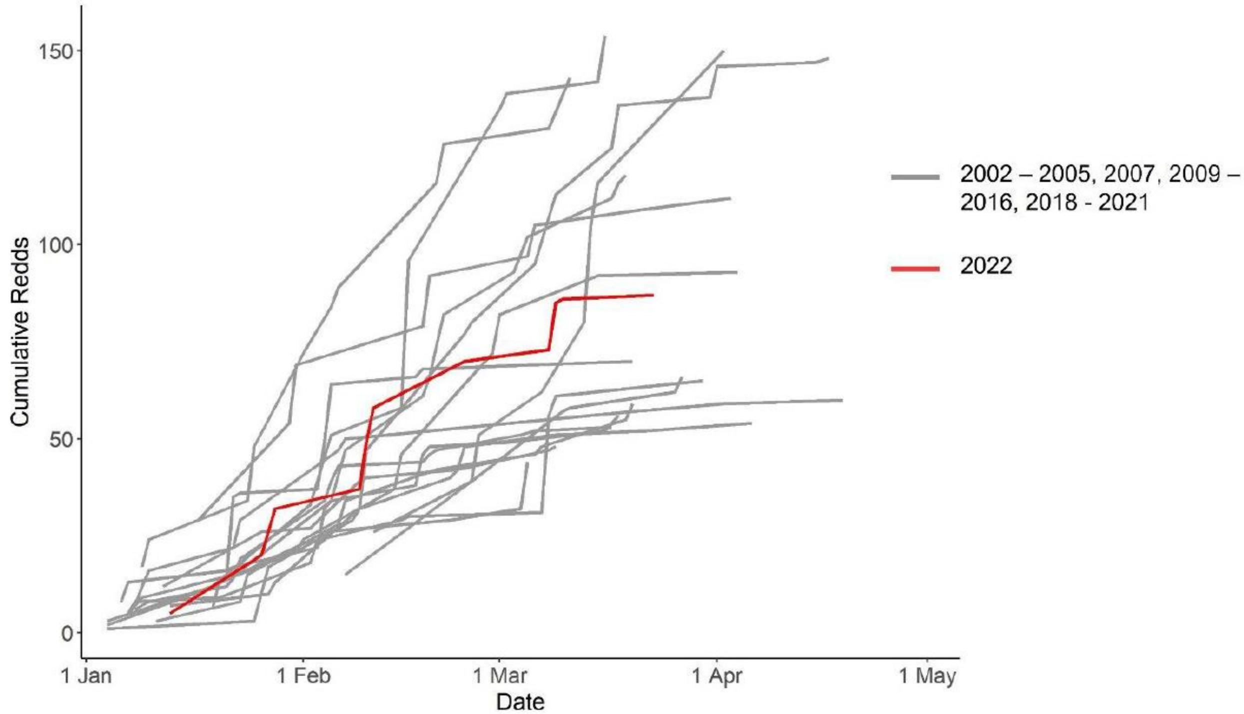
	Nimbus Dam to Sacramento River	Nimbus Dam to Paradise Beach	Nimbus Dam to Ancil Hoffman Park	Ancil Hoffman Park to Watt Avenue	Watt Avenue to Paradise Beach
2005	6.1	7.9	17.6	4.3	2.8
2006	NA	NA	NA	NA	NA
2007	7.7	9.9	19.9	5	0.2
2008	NA	NA	NA	NA	NA
2009	4.4	5.3	15	1	0.5
2010	3.6	4.4	12	1.2	0.2
2011	3.9	4.9	10.8	3.3	0.2
2012	3.3	4.2	12.5	0	0.2
2013	13.8	17.6	46.5	4.4	1.4
2014	3.8	4.8	8.5	5.1	0
2015	3.1	3.9	9.8	1.7	0
2016	2.3	2.9	6.2	2.3	0.2
2017	0.4	0.6	0.5	1	0
2018	2.7	2.7	5.8	3.7	1
2019	2.7	3.3	7.2	1.8	1.7
2020	2.4	2.9	6.8	1.5	0.5
2021	2.5	3.1	4.2	4.8	0.3
2022	4	4.8	7.8	6.2	0.5
2002	6.9	8.8	16.1	4.4	3.7

Source: Sweeney and Merz 2022.

Year	Location (river mile in parenthesis)															
	Nimbus to Upper Sailor Bar (22)	Lower Sailor Bar to Upper Sunrise (21)	Upper Sunrise to Sunrise Bridge (20)	Sunrise Bridge to Lower Sunrise (19)	Sacramento Bar to San Juan Rapids(18)	San Juan Rapids to Rossmoor (17)	Lower Rossmoor to Ancil Hoffman (16)	Smud Cables to Upper Riverbend (15)	Riverbend Side Channel (14)	Lower River Bend to Arden Rapids (13)	Below River Bend to Gristmill (12)	Gristmill (11)	Gristmill to Watt (10)	Watt (9)	Paradise Beach (5)	Total
2003	28	46	11	21	16	11	4	22	15	15	5	7	5	9	0	**215**
2004	31	45	2	21	8	10	2	20	13	6	17	2	0	9	1	**187**
2005	40	27	6	10	3	0	3	11	5	3	2	3	1	3	14	**131**
2006	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**NA**
2007	33	25	9	21	13	18	18	7	3	1	9	1	12	2	0	**172**
2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**NA**
2009	72	13	5	0	0	0	0	0	0	0	3	0	0	3	0	**96**
2010	59	0	0	13	0	0	0	0	0	4	2	0	0	1	0	**79**
2011	32	17	0	2	1	3	9	10	4	0	9	0	0	0	1	**88**
2012	38	17	6	10	1	1	1	0	0	0	0	0	0	0	1	**75**
2013	65	118	19	33	11	4	28	2	2	1	21	0	0	12	0	**316**
2014	21	3	12	4	2	7	1	0	0	21	12	0	1	0	0	**84**
2015	27	1	5	9	0	19	8	2	0	8	3	1	0	0	0	**83**
2016	12	8	7	6	1	0	1	1	10	0	4	0	1	1	0	**52**
2017	0	0	0	1	1	0	1	3	0	4	0	0	0	0	0	**10**
2018	5	14	6	5	5	1	5	1	5	5	7	2	0	6	0	**67**
2019	4	25	6	4	0	4	0	0	2	0	5	0	1	4	5	**60**
2020	14	4	11	5	5	2	3	2	0	1	0	0	0	4	2	**53**
2021	3	0	14	2	4	2	6	2	0	8	13	0	0	1	1	**56**
2022	30	1	13	0	3	0	24	1	6	2	4	0	0	0	3	**87**

Source: Sweeney and Merz 2022.

Figure C-56. Steelhead redd distribution by American River location: 2003-2005, 2007, 2009-2022



Source: Sweeney and Merz 2022.

Figure C-57. Lower American River cumulative number of steelhead redd observations, 2002-2022. Spawning survey data from 2002-2005, 2007, 2009-2016, and 2018-2021 are plotted in gray for comparison. Note that surveys were not performed in 2006 and 2008 due to poor visibility.

C.5.2.5 Stanislaus River

No available redd and carcass data.

C.5.3 Fry Exiting Natal Stream Abundance

C.5.3.1 Sacramento River

Table C-80. Red Bluff Diversion Dam RST juvenile anadromous fish abundance estimated passage of *O. mykiss* (brood years 2013 – 2019)

Period	BY	Estimated Total
1/1/2019 – 12/31/2019	2019	24,472 low 5,950 high 42,995
1/1/2018 – 12/31/2018	2018	28,227 low 10,386 high 46,069

Period	BY	Estimated Total
1/1/2017 – 12/31/2017	2017	10,159 low -468 high 20,785
1/1/2016 – 12/31/2016	2016	28,133 low 9,234 high 47,023
1/1/2015 – 12/31/2015	2015	16,511 low 7,134 high 25,888
-	2014	-
-	2013	-

Source: For BY 2019, Voss and Poytress. 2022. For BY 2018, Voss and Poytress 2020. For BY 2017, Voss and Poytress 2019. For BY 2016, Voss and Poytress 2018. For BY 2015, Voss and Poytress 2017. For BY 2014, Poytress 2016. For BY 2013, Poytress and Gruber 2015.

C.5.3.2 Clear Creek

Table C-81. Summary for steelhead by life stage and brood year at Clear Creek upper rotary screw trap (RST; river mile RM 8.4) and lower rotary screw trap (RST RM 1.7): 2014 – 2018

		Clear Creek RST RM 8.4		Clear Creek RST RM 1.7	
Brood Year	Life Stage	Number	Percent	Number	Percent
2018	Yolk-sac fry	5	0.7	2	0.2
-	Fry	524	73.0	1,067	91.1
-	Parr	185	25.8	101	8.6
-	Silvery Parr	3	0.4	1	0.1
-	Smolt	1	0.1	0	0.0
2017	Yolk-sac fry	0	0.0	0	0.0
-	Fry	0	0.0	0	0.0
-	Parr	27	73.0	4	80.0
-	Silvery Parr	9	24.3	1	20.0
-	Smolt	1	2.7	0	0.0
2016	Yolk-sac fry	4	1.5	4	0.2
-	Fry	137	52.3	1,535	83.3
-	Parr	110	42.0	296	16.1

Brood Year	Life Stage	Clear Creek RST RM 8.4		Clear Creek RST RM 1.7	
		Number	Percent	Number	Percent
-	Silvery Parr	11	4.2	8	0.4
-	Smolt	0	0.0	0	0.0
2015	Yolk-sac fry	0	0.0	0	0.0
-	Fry	56	13.5	281	35.2
-	Parr	334	80.5	513	64.2
-	Silvery Parr	20	4.8	4	0.5
-	Smolt	5	1.2	1	0.1
2014	Yolk-sac fry	3	1.1	18	1.2
-	Fry	156	58.0	1,357	93.8
-	Parr	104	38.7	71	4.9
-	Silvery Parr	6	2.2	1	0.1
-	Smolt	0	0.0	0	0.0

Sources: For BY 2018, Schraml and Chamberlain 2021. For BY 2017, Schraml et al. 2020a. For BY 2016, Schraml and Chamberlain 2020. For BY 2015, Schraml and Chamberlain 2019b. For BY 2014, Schraml and Chamberlain 2019a.

C.5.3.3 American River

Table C-82. Potential fry production estimated from redd count data: 2007 – 2022. Calculated as in previous years and based on 1.5 redds per female, the average fecundity at Nimbus Hatchery (6,700 eggs per female for 2022), and an egg to fry survival rate of 50%, resulting in an estimate of 194,300 fry.

Year	Redds Counted	Females Spawning (1.5 redds/female)	Fecundity	Total Eggs Spawned	Fry Produced at 50% ETF Phi
2002	159	106	6,149	651,794	325,897
2003	215	143	6,238	894,113	447,057
2004	197	131	6,136	805,861	402,931
2005	155	103	4,464	461,280	230,640
2007	178	119	4,590	544,680	272,340
2009	96	64	7,706	493,184	246,592
2010	79	53	6,667	351,129	175,564
2011	89	59	6,112	362,645	181,323
2012	75	50	7,285	364,250	182,125
2013	314	209	7,903	1,651,727	825,864

Year	Redds Counted	Females Spawning (1.5 redds/female)	Fecundity	Total Eggs Spawned	Fry Produced at 50% ETF Phi
2014	96	64	7,265	464,960	232,480
2015	71	47	5,914	279,929	139,965
2016	53	35	7,272	256,944	128,472
2017	12	8	5,350	42,800	21,400
2018	59	39	7,455	293,230	146,615
2019	60	40	6,773	270,920	135,460
2020	53	35	6,593	210,163	105,081
2021	56	37	6,569	245,243	122,621
-	87	58	6,700	388,600	194,300
-	-	-	-	-	-

Source: Sweeney et al. 2022.

C.5.3.4 Stanislaus River

There are no observed estimates of fry abundance.

C.5.4 Survival of Fry

There are no available estimates of survival of natural produced steelhead fry in the river.

C.5.5 Survival of Smolts

There is very limited estimates of survival of natural produced steelhead smolts in Central Valley rivers. In the American River, Ferguson (2018) reported that steelhead that traveled further had reduced survival to the confluence with the Sacramento River compared to smolts acoustically tagged close to the confluence.

Table C-83. Estimated survival of steelhead smolt and total RKM from the start (release site of hatchery fish; capture site of wild fish) to I80-50 bridge (RKM 170.74) or Tower Bridge (RKM 172)

Group	Data Source	Year	Start	End	Total RKM	Survival Estimate
Wild Deer Creek	EAT	2018	Deer Creek RST	Tower Bridge	269.72	0.286
Wild Deer Creek	EAT	2018	Deer Creek	Benicia Bridge	389.49	0.286
Wild Deer Creek	EAT	2019	Deer Creek RST	Tower Bridge	269.72	0.429
Wild Deer Creek	EAT	2019	Tower Bridge	I80-50 Bridge	1.26	1
Wild Deer Creek	EAT	2019	Deer Creek	Benicia Bridge	389.49	0.336
Wild Mill Creek	EAT	2019	Mill Creek RST	Tower Bridge	278.7	0.769

Group	Data Source	Year	Start	End	Total RKM	Survival Estimate
Wild Mill Creek	EAT	2019	Tower Bridge	I80-50 Bridge	1.26	0.916
Wild Mill Creek	EAT	2019	Mill Creek	Benicia Bridge	398.46	0.577
SJR Steelhead (March)	EAT	2021	Durham Ferry (180)	Benicia Bridge	X	0.03
SJR Steelhead (March)	EAT	2021	Stockton (135.5)	Benicia Bridge	X	0.05
SJR Steelhead (March)	EAT	2021	Head of Old River (156.0)	Benicia Bridge	X	0.01
SJR Steelhead (April)	EAT	2021	Durham Ferry (180)	Benicia Bridge	X	0.055
SJR Steelhead (April)	EAT	2021	Stockton (135.5)	Benicia Bridge	X	0.10
SJR Steelhead (April)	EAT	2021	Head of Old River (156.0)	Benicia Bridge	X	0.02
Wild Mill Creek	EAT	2021	Mill Creek RST	Tower Bridge	278.7	0.202
Wild Deer Creek	EAT	2021	Deer Creek RST	Tower Bridge	269.72	0.248
Wild Mill Creek	EAT	2021	Mill Creek	Benicia Bridge	398.46	0.162
Wild Deer Creek	EAT	2021	Deer Creek	Benicia Bridge	389.49	0.200
SJR Steelhead (May)	EAT	2021	Durham Ferry (180)	Benicia Bridge	127.76	0
SJR Steelhead (May)	EAT	2021	Stockton (135.5)	Benicia Bridge	83.26	0.082
SJR Steelhead (May)	EAT	2021	Head of Old River (156.0)	Benicia Bridge	103.76	0.034
SJR Steelhead (March)	EAT	2022	Durham Ferry (180)	Benicia Bridge	127.76	0.052
SJR Steelhead (March)	EAT	2022	Stockton (135.5)	Benicia Bridge	83.26	0.121
SJR Steelhead (March)	EAT	2022	Head of Old River (156.0)	Benicia Bridge	103.76	0.090
SJR Steelhead (April)	EAT	2022	Durham Ferry (180)	Benicia Bridge	127.76	0.084
SJR Steelhead (April)	EAT	2022	Stockton (135.5)	Benicia Bridge	83.26	0.210
SJR Steelhead (April)	EAT	2022	Head of Old River (156.0)	Benicia Bridge	103.76	0.062

Sources: Data sources include the Central Valley Enhanced Acoustic Tagging Project and CalFish Track.
CalFish = CalFish Track; EAT = Central Valley Enhanced Acoustic Tagging Project.

C.5.6 Juveniles Entering Delta Abundance

There is no estimate of steelhead juvenile abundance entering the Delta.

C.5.7 Survival of Juvenile in Delta

Table C-84. Route-specific tagged steelhead survival (SE) by release group

Year	Release Dates	Mossdale to Chipps	San Joaquin River at HOR to Chipps	Near HOR to Chipps	San Joaquin River at HOR to Turner Cut Junction	MacDonald Island to Chipps	Turner Cut Junction to Chipps
2011	22-26 March	0.69(0.03)	0.72(0.04)	0.71(0.04	0.92(0.02	0.82(0.04	0.37(0.13
	3-7 May	0.52(0.03)	0.57(0.04	0.51(0.04	0.88(0.03	0.81(0.05	0.32(0.08
	17-21 May	0.44(0.03)	0.51(0.05	0.49(0.05	0.83(0.03	0.69(0.05	0.35(0.10
	22-26 May	0.60(0.03)	0.69(0.04	0.55(0.05	0.89(0.03	0.81(0.05	0.69(0.08
	15-18 June	0.38(0.05)	0.34(0.06	0.46(0.07	0.72(0.07	0.50(0.13	0.34(0.11
	2011 Total	0.54(0.01)	0.58(0.02	0.55(0.02	0.86(0.01	0.75(0.03	0.42(0.05
2012	4-7 April	0.26(0.02)	0.28(0.02	0.07(0.04	0.79(0.04	0.42(0.04	0.12(0.05
	1-6 May	0.35(0.03)	0.36(0.03	0.10(0.07	0.83(0.02	0.52(0.04	0.17(0.05
	18-23 May	0.33(0.04)	0.37(0.04	0.05(0.03	0.91(0.02	0.50(0.05	0.24(0.06
	2012 Total	0.32(0.02)	0.34(0.02	0.07(0.03	0.84(0.02	0.48(0.03	0.18(0.03
2013	6-9 March	0.15(0.02)	0.00(0.00	0.17(0.02	0.00(0.00	NA	NA
	3-6 April	0.09(0.02)	0.13(0.06	0.08(0.02	0.24(0.07	0.81(0.18	0.25(0.22
	8-11 May	0.20(0.02)	0.21(0.06	0.20(0.02	0.37(0.07	0.84(0.11	0.00(0.00
	2013 Total	0.14(0.01)	0.11(0.03	0.15(0.01	0.20(0.03	0.82(0.10	0.13(0.11
2014	24-27 April	0.43(0.03)	0.45(0.03	0.32(0.09	0.80(0.02	0.74(0.03	0.17(0.04
	21-24 May	0.06(0.02)	0.08(0.03	0.09(0.09	0.21(0.05	0.43(0.13	NA
	2014 Total	0.24(0.02)	0.26(0.02	0.21(0.06	0.50(0.02	0.59(0.07	0.17(0.04
2015	4-7 March	0.15(0.03)	0.19(0.07	0.15(0.03	0.32(0.08	0.81(0.12	NA
	25-28 March	0.35(0.03)	0.48(0.05	0.28(0.04	0.64(0.05	0.78(0.06	0.60(0.22
	22-25 April	0.20(0.04)	0.38(0.07	0.08(0.08	0.49(0.07	0.94(0.06	0.33(0.19
	2015 Total	0.23(0.02)	0.35(0.04	0.17(0.03	0.48(0.04	0.84(0.05	0.47(0.15
2016	24-27 February	0.39(0.03)	0.24(0.09	0.43(0.04	0.60(0.10	0.34(0.16	0.50(0.20
	16-19 March	0.42(0.02)	0.51(0.05	0.40(0.03	0.74(0.05	0.82(0.06	0.33(0.11
	27-30 April	0.59(0.02)	0.61(0.02	0.17(0.06	0.89(0.02	0.81(0.02	0.31(0.05
	2016 Total	0.47(0.02)	0.45(0.03	0.33(0.03	0.74(0.04	0.66(0.06	0.38(0.08

Source: Buchanan et al. 2021

Table C-85. Number and proportion of fish that used each through-Delta route, and success to the Golden Gate Bridge

		Steelhead	
		2009	2010
West Delta	Number of fish	72	60
	Proportion utilizing route	0.231	0.288
	Number to Golden Gate	7	18
	Proportion of success to ocean	0.10	0.30
East Delta	Number of fish	53	59
	Proportion utilizing route	0.17	0.188
	Number to Golden Gate	10	6
	Proportion of success to ocean	0.19	0.10
Mainstem	Number of fish	187	109
	Proportion utilizing route	0.599	0.524
	Number to Golden Gate	46	36
	Proportion of success to ocean	0.25	0.33
Total Fish in Delta	-	312	208

Source: Singer et al. 2013.

Table C-86. Tagged steelhead success, 2009 and 2010, based on raw detections from Elkhorn Landing release site

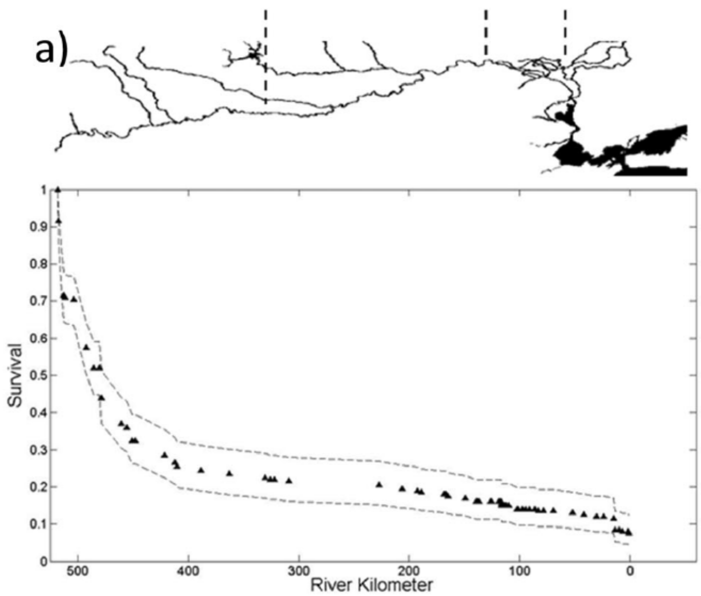
	2009			2010		
	Success to Site	From Release Site	Reach Specific %	Success to Site	From Release Site	Reach Specific %
Steelhead						
Elkhorn Landing	500			500		
I 80/50	378	75.6	75.6	339	67.8	67.8
Freeport	357	71.4	94.4	310	62.0	91.4
Benicia	238	47.6	66.7	111	22.2	35.8
Carquinez	214	42.8	89.9	100	20.0	90.1
Richmond	160	32.0	74.8	92	18.4	92.0
Golden Gate	73	14.6	45.6	69	13.8	75.0

Source: Singer et al. 2013

Table C-87. Survival estimates, steelhead, from best fit model, 2009 and 2010. Note that the estimates for the Pt. Reyes reach are confounded, as there are no downstream monitors.

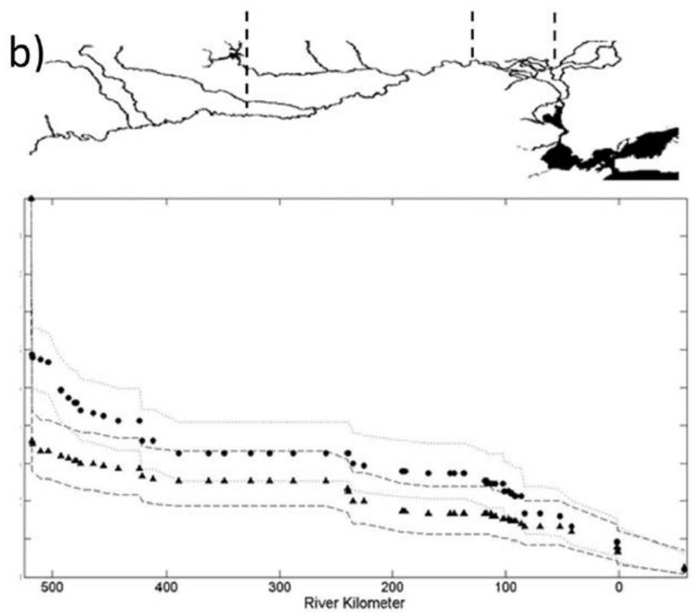
Reach	Year	Estimate	SE	LCI	UCI
Elkhom to 180/50	2009	0.828629	0.037245	0.743048	0.889929
180/50 to Freeport	2009	1	1.00E-07	1	1
Freeport to Benicia (MS)	2009	0.898	0.045987	0.766946	0.959271
Freeport to Benicia (WD)	2009	0.738349	0.093568	0.522014	0.879393
Freeport to Benicia (ED)	2009	0.791391	0.092839	0.557527	0.919497
Benicia to Carquinez	2009	0.882348	0.063369	0.693898	0.961258
Carquinez to RSR Bridge	2009	0.856703	0.101689	0.541064	0.968069
RSR bridge to GG East	2009	0.531836	0.091866	0.355341	0.700709
GG East to GG West	2009	1	5.98E-05	0.999883	1.000117
GG West to Pt. Reyes	2009	0.261186	21.37851	0	1
Elkhorn to 180/50	2010	0.725212	0.054341	0.607304	0.818309
180/50 to Freeport	2010	0.91465	0.090799	0.523001	0.990543
Freeport to Benicia (MS)	2010	0.7403	0.083363	0.549256	0.869596
Freeport to Benicia (WD)	2010	0.66825	0.098578	0.457291	0.828042
Freeport to Benicia (ED)	2010	0.40753	0.102376	0.230545	0.612271
Benicia to Carquinez	2010	0.966342	0.029029	0.833125	0.99398
Carquinez to RSR Bridge	2010	0.932232	0.037539	0.811051	0.97782
RSR Bridge to GG East	2010	0.716216	0.056568	0.593938	0.813251
GG East to GG West	2010	0.843623	0	0.843623	0.843623
GG West to Pt. Reyes	2010	2.13E-05	0	2.13E-05	2.13E-05

Source: Singer et al. 2013.
Note: The estimates for the Pt. Reyes reach are confounded, as there are no downstream monitors.



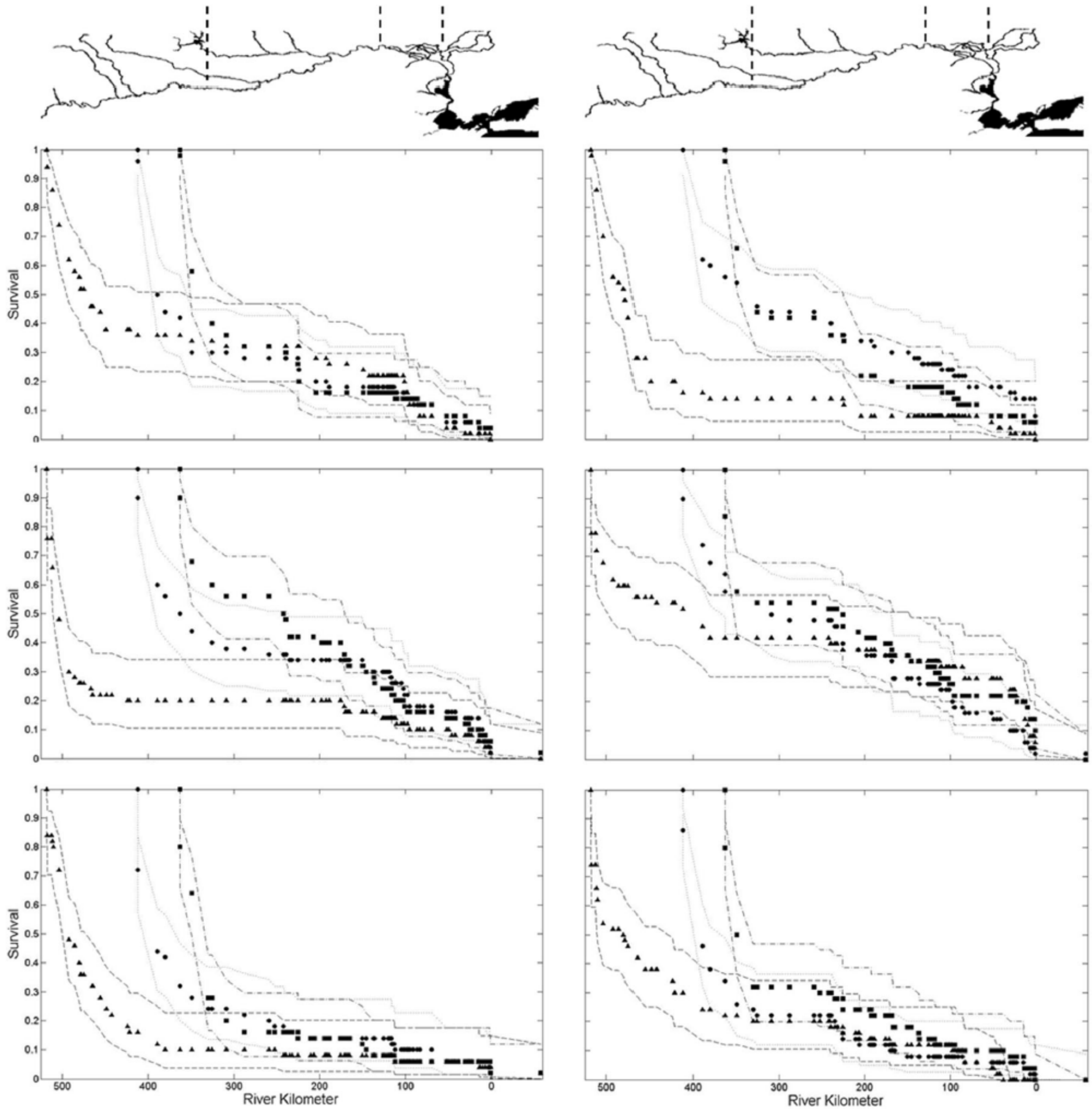
Source: Sandstrom et al. 2020.

Figure C-58. Cumulative survival estimates for tagged juvenile steelhead, Ball's Ferry to the ocean (95% confidence intervals), 2006/2007



Source: Sandstrom et al. 2020.

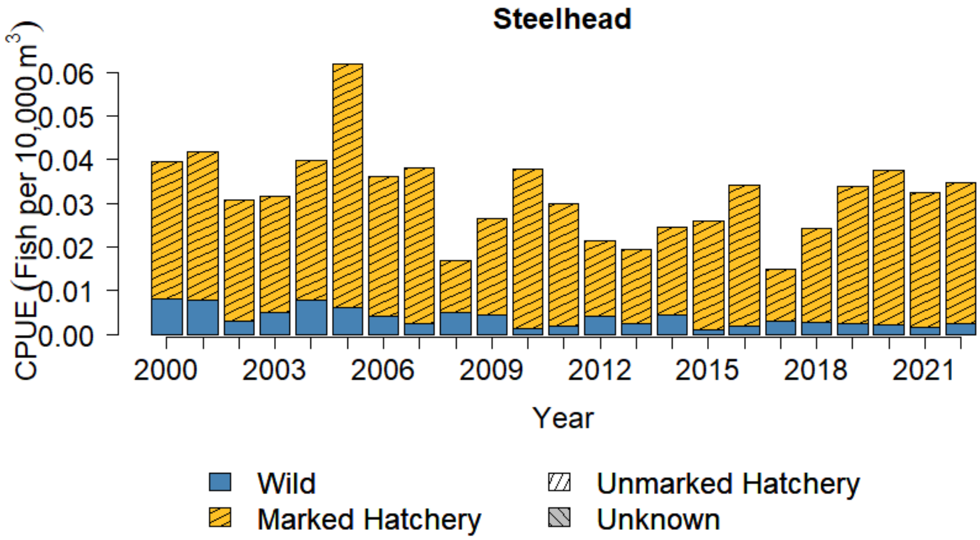
Figure C-59. Cumulative survival estimates for tagged juvenile steelhead, Jelly's Ferry to the ocean (95% confidence intervals), released in December 2010 (triangles) and January 2011 (circles)



Source: Sandstrom et al. 2020.

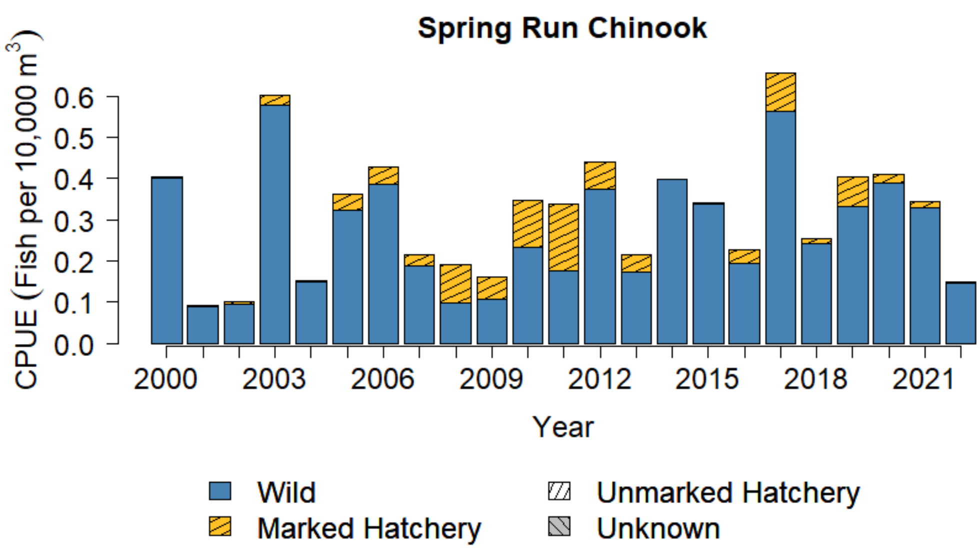
Figure C-60. Cumulative survival estimates for tagged juvenile steelhead, upper river to the Ocean (95% confidence intervals). Top to bottom: 2007/2008, 2008/2009, and 2009/2010. Left to right: December release group and January release group.

C.5.8 Juveniles Exiting the Delta Abundance



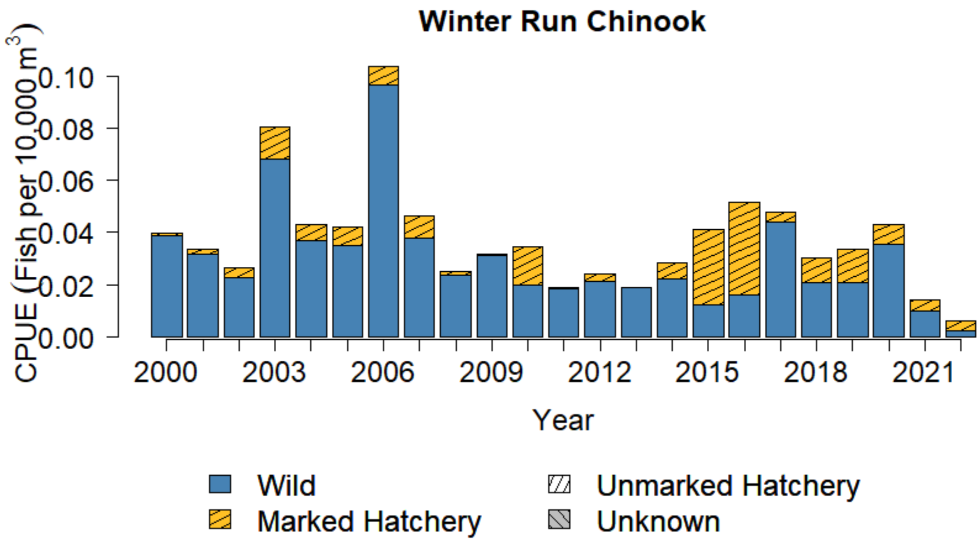
Source: Nanninga and Huber (2022).

Figure C-61. Monthly catch-per-unit-effort (CPUE) for hatchery- and natural-origin juvenile steelhead entering the San Francisco estuary from the Sacramento-San Joaquin Delta from 2000 to 2021



Source: Nanninga and Huber (2022).

Figure C-62. Monthly catch-per-unit-effort (CPUE) for hatchery- and natural-origin juvenile spring-run LAD Chinook Salmon entering the San Francisco estuary from the Sacramento-San Joaquin Delta from 2000 to 2021



Source: Nanninga and Huber (2022).

Figure C-63. Monthly catch-per-unit-effort (CPUE) for hatchery- and natural-origin juvenile winter-run LAD Chinook Salmon entering the San Francisco estuary from the Sacramento-San Joaquin Delta from 2000 to 2021

C.5.9 Survival of Juveniles in Ocean

Although numerous studies estimate survival of steelhead to ocean entry using hatchery smolts from the Central Valley, no studies have reported juvenile survival estimates in the ocean (Eschenroeder et al. 2022).

C.5.10 Ocean Abundance

No cohort reconstructions have been conducted for steelhead, and as such no estimates of ocean abundance are available.

C.5.11 Subadult Ocean Survival

Dedicated estimates of subadult ocean survival are not currently available for CV steelhead. However, acoustic telemetry tracking of hatchery kelts released from the Coleman National Fish Hatchery in 2005 and 2006 indicated that 43% of fish that made it to the Delta survived to make a repeat migration to spawn again in freshwater (Null et al. 2013).

Researchers have used PIT tagged hatchery steelhead from Wind River, WA, to determine effects of environmental conditions on smolt-to-adult marine survival; they observed effects of fish size, river exist date, interaction between year and river exit date, and the biological transition date on marine survival (Wilson et al. 2021). These results are similar to those reported for fall-run Chinook salmon from the Central Valley and suggest commonalities in release and environmental effects on marine survival across species and populations.

C.5.12 Kelts

Acoustic telemetry tracking of hatchery kelts released from the Coleman National Fish Hatchery in 2005 and 2006 (n=46) indicated that 43% of fish that successfully outmigrated to the Delta survived the Delta and ocean environments to make a repeat migration to spawn again in freshwater (Null et al. 2013). Of the 46 total fish released, a total of 31 were presumed to have died in the freshwater, Delta, and ocean combined (67% mortality, or 33% survival to repeat spawning). Hatchery kelts released in early April and that exhibited anadromy were observed to outmigrate past the Golden Gate Bridge between April and mid-July.

Tagging of large hatchery steelhead kelts from the Coleman National Fish Hatchery, using both geolocating archival tags and acoustic tags, allowed observation of detailed post-spawning migratory behavior (Teo et al. 2013). Migration time from release to arrival in the San Francisco Bay varied between 2 and 7 weeks. Geolocating archival tag from two recovered kelts showed residence time in the estuary is variable among fish; one anadromous fish spent little time in the estuary before migrating to the ocean, while the other fish that exhibited a freshwater residence life history spent two weeks in the estuary before returning to freshwater. Small sample sizes of tag recoveries precluded analysis of survival. Summarize Null et al and Teo et al with any survival data

Most of 14 reconditioned steelhead kelts tagged with acoustic and geolocating tags released at CNFH (Battle Creek) moved rapidly downstream after release but with individual variability (2 fish reached San Francisco Bay within 2-3 weeks, 1 fish took 6-7 weeks) (Teo et al. 2013). Two of the tagged fish were recovered at CNFH post-release (Table C-88, Table C-89, Table C-90).

Both J and M remained relatively close to the surface throughout their migration but exhibited diurnal differences in the vertical movements. For example, J tended to dive deeper during the day in freshwater but deeper during the night in the ocean. Authors note the study's small sample size and recommend future research on larger numbers of steelhead from various natal origins. Both steelhead kelts appeared to be less oceanic than a previous study in Scott Creek, a small coastal stream approximately 100 kilometers (km) south of the mouth of San Francisco Bay, suggesting a difference in behavior based on natal origin (large river and estuary system vs. small coastal stream) (Hayes et al. 2011).

Table C-88. Release and recovery information, behavior, and environmental conditions of two steelhead kelts tagged and released in 2008 at Coleman National Fish Hatchery.

Parameter	**Fish J**	**Fish M**
Post-release recovery (d)	219 days	295 days
Post-spawning migration "phases"	5 phases (see table below)	6 phases (see table below)
Growth (release to recapture)	8.9 cm	2.2 cm
Entered Ocean?	Yes	No
Maximum recorded depth (m)	51 m	12.5 m
Temperature range (°C)	8.2 to 24.4 °C	9.4 to 19.4 °C

Source: Teo et al. 2013.

Table C-89. Steelhead J (5 phases): light level, depth and diving behavior, water temperature changes by post-spawning migration phase

Post-Spawning Migration Phase	Fish J
Phase I Initial Freshwater	Daily temperature flux (day = warmer; night = cooler) Mean ± SD °C between daily peak temperature 2.01 ± 0.51 °C Mean ± SD °C afternoon temperatures 13.60 ± 0.32 °C Mean ± SD °C dawn temperatures 11.58 ± 0.60 °C Swam deeper during the day 3.08 ± 1.50 m (day) vs 1.65 ± 1.15 m (night)
Phase II 1st Hot Spike	Temperature spike and associated rise in water opacity
Phase III Ocean and Estuarine	Change in diving behavior from within top 2m to numerous dives > 20m Crepuscular diving behavior: diving deeper depths at sunset, back to surface at sunrise Deeper night-time depths (influenced by moon phase) 1.32 ± 1.61 m (day) vs 5.63 ± 6.11 m (night) West of mouth of SFB, temperatures not freshwater diurnal cycle
Phase IV 2nd Hot Spike	Rapid increase in water temperature Temperature spike and associated rise in water opacity
Phase V Return Freshwater	Gradual decrease in water temperature with cyclic variations Relatively high nighttime light level

Source: Teo et al. 2013.

Table C-90. Steelhead M (6 phases): light level, depth and diving behavior, water temperature changes by post-spawning migration phase.

Post-Spawning Migration Phase	Fish M
Phase I Initial Freshwater	Diurnal temperature cycles Mean ± SD °C between daily peak temperature 2.74 ± 0.18 °C Shallow diving behavior
Phase II 1st Hot Spike	Spike in temperatures up to 19.4 °C Did not mirror Steelhead J in entering the ocean No associated increase in opacity
Phase III Estuarine	Spent ~2 weeks in the estuary post-temperature spike Recorded temperatures were not fluctuating cyclically Swam to deeper depths East of mouth of SFB, likely remained in river-estuarine system

Post-Spawning Migration Phase	Fish M
Phase IV Freshwater Residency	Freshwater residency about 3.5 months Water temperature diurnal fluctuations Shallower nighttime dives
Phase V 2nd Hot Spike	Rapid increase in water temperature Smaller spike than Steelhead J No associated increase in opacity
Phase VI Return Freshwater	Gradual decrease in water temperature with cyclic variations

Source: Teo et al. 2013.

Kelts released on Battle Creek in April of 2005 (n = 25) and 2006 (n = 21) exhibited anadromous and non-anadromous list histories (some changed or alternated between years exhibiting both anadromous and potamodromous behavior in separate years) (Null et al. 2013). 90% exhibited anadromy while 10% were residualized exhibiting 2 movement patterns: residency near the release site and potamodromy. The emigration pattern was similar for all tagged fish that exhibited anadromous life history: a short-term residence near the release site, a sustained downstream emigration, and arrival at the Golden Gate Bridge between April to mid-July. The spawning migration pattern was also similar for all tagged fish that exhibited anadromous life history: migrations began late-September through October of the release year, there was high fidelity to Battle Creek late-September through November, and most fish entered Coleman NFH December and January.

Overall, survival for tagged fish was high. Most migrated to the Delta (90%) and 74% were detected at the Golden Gate Bridge receivers. Average repeat spawning migration rates over the two-year study were 41% (36% in 2005, 48% in 2006). Rate of return to Coleman NFH was 26% and fish exhibited high fidelity to Battle Creek (14/15 or 93% returned to natal spawning area). Growth: the body lengths of returning fish was significantly greater for anadromous vs residualized kelts (mean increase of FL returning 7.1 centimeter (cm) (range = 4.0-11.0 cm) for fish that emigrated vs. 1.6 cm (range = 0.0-2.8 cm) for fish that residualized.

Table C-91. River kilometer, median travel time, median travel rate, and number of detections at each receiver for emigrating *O. mykiss* kelts

Location	River Kilometer	Median Travel Time (d)	Range of Travel Time (d)	Median Travel Rate (k/d)	Total Number Detected
2005					
Battle Creek					
Battle Creek Wildlife Area	5	7	< 1-33	0.6	19
Sacramento River					
Battle Creek confluence	436	18	1-38	0.5	21
Bend Bridge	415	26	1-65	1.2	14
Red Bluff Diversion Dam	391	28	1-69	2.0	16

Location	River Kilometer	Median Travel Time (d)	Range of Travel Time (d)	Median Travel Rate (k/d)	Total Number Detected
Thomes Creek	365	28	2-70	2.9	16
Scotty's Landing	317	30	3-69	4.3	11
Butte Creek	221	40	29-70	5.6	12
Knight's Landing	145	39	5-94	7.7	18
Rio Vista	19	43	31-96	10.0	14
San Joaquin River					
Brannon Island	5	40	8-44	N/A	3
San Francisco Estuary					
Golden Gate Bridge	--	46	35-98	9.7	13
2006					
Battle Creek					
Battle Creek Wildlife Area	5	Lost	--	--	--
Sacramento River					
Battle Creek confluence	436	23	< 1-80	0.2	20
Bend Bridge	415-420	37	4-67	0.7	16
Red Bluff Diversion Dam	391	38	16-91	1.3	16
Thomes Creek	365	40	16-94	1.9	16
Scotty's Landing	317	Stolen	--	--	--
Butte Creek	221	Stolen	--	--	--
Knight's Landing	145	44	4-100	6.7	17
Rio Vista	19	73	7-102	5.8	7
San Joaquin River					
Brannon Island	5	Removed	--	--	--
San Francisco Estuary					
Golden Gate Bridge	--	47	10-84	9.4	15

Source: Null et al. 2013:Table 1.

Table C-92. River kilometer, median travel time, median travel rate, and number of detections at each receiver for returning *O. mykiss* kelts

Location	River Kilometer	Median Travel Time (d)	Range of Travel Time (d)	Median Travel Rate (k/d)	Total Number Detected
2005					
Battle Creek					
Coleman NFH	9	260	207-261	4.2	7
Battle Creek Wildlife Area	5	189	185-192	12.8	2
Sacramento River					

Location	River Kilometer	Median Travel Time (d)	Range of Travel Time (d)	Median Travel Rate (k/d)	Total Number Detected
Battle Creek confluence	436	Stolen	--	--	--
Bend Bridge	415	197	186-205	9.8	6
Red Bluff Diversion Dam	391	198	193-202	9.1	2
Thomes Creek	365	191	176-203	10.0	7
Scotty's Landing	317	Stolen	--	--	--
Butte Creek	221	Stolen	--	--	--
Knight's Landing	145	171	141-187	9.1	6
Rio Vista	19	170	137-182	1.2	5
San Joaquin River					
Brannon Island	5	40	8-44	N/A	3
San Francisco Estuary					
Golden Gate Bridge	--	155	153-156	--	2
2006					
Battle Creek					
Coleman NFH	9	265	246-305	4.3	5
Battle Creek Wildlife Area	5	Lost	--	--	--
Sacramento River					
Battle Creek confluence	436	195	175-216	13.2	5
Bend Bridge	415	197	172-221	12.0	6
Red Bluff Diversion Dam	391	194	170-219	12.4	6
Thomes Creek	365	191	167-217	12.8	6
Scotty's Landing	317	183	160-214	15.1	7
Butte Creek	221	Lost	--	--	--
Knight's Landing	145	175	100-198	11.1	7
Rio Vista	19	158	102-189	N/A	5
San Joaquin River					
Brannon Island	5	Removed			
San Francisco Estuary					
Golden Gate Bridge	--	162	137-166	--	7

Source: Null et al. 2013:Table 2.

C.6 Delta Smelt

Delta smelt are a small, euryhaline, pelagic fish species endemic to the San Francisco Estuary San Francisco Estuary in Northern California. Delta smelt are listed as threatened at the federal level and endangered at the state level. Primarily an annual species, their life cycle follows the seasons, hatching in spring in freshwater, mostly migrating to the low-salinity zone (i.e., less than 6 parts per thousand salinity) to rear in summer and fall and returning to freshwater in the winter to spawn (Bennett 2005; Interagency Ecological Program 2015). Most individuals within the population follow this semi-anadromous life history, but smaller portions of the population may remain resident completely in freshwater or completely in brackish water for the full life cycle (Hobbs et al. 2019). Delta smelt have a reproductive strategy that is more closely aligned with perennial species, characterized by low fecundity, low spawning frequency, and an extended spawning period. Each life stage of Delta smelt has specific environmental requirements (Bennett 2005). Delta smelt are generally found in the tidal freshwater and brackish portions of the San Francisco Estuary, from Suisun Marsh and Grizzly Bay to the Cache Slough Complex on the Sacramento River, although the location within the San Francisco Estuary varies with life stage (Bennett 2005; Merz et al. 2011). Their overall geographic distribution spans from the northern San Francisco Bay in the west to the confluence of the Sacramento and Feather Rivers in the northeast (individuals have been collected as far upstream as Knights Landing on the Sacramento River; Vincik and Julienne 2012) and the divergence of Old and San Joaquin Rivers in the south Delta (Merz et al. 2011).

Survey sampling captures life stage to characterize the timing of that life stage in the upper San Francisco Estuary. Overall, adult and subadult/juvenile delta smelt may be present year-round in the upper San Francisco Estuary, whereas larval delta smelt are generally present in the system between March and July.

Patterns of occurrence discussed further below are based on historical data because delta smelt today are close to extinction, with fewer than 50 total fish caught during monitoring during the calendar year of 2021. For the summary herein, three size classes were identified for delta smelt, defined by fork length (FL, in millimeters): larvae (<20-mm FL), juvenile (20-mm to 58-mm FL), and adult (>58-mm FL) life stages. Data was acquired from the 'deltafish' R package that compiled datasets from various fish surveys in the San Francisco Bay-Delta (https://github.com/Delta-Stewardship-Council/deltafish). Note that unmeasured fish that were collected alongside measured fish were converted to have fish length per 'deltafish' data documentation. For the online version of the tables, please see: https://bmahardja.github.io/spatiotemporal-domain/DeltaSmelt.html.

The following surveys were used to evaluate the occurrence of Delta smelt in the Bay-Delta:

1. San Francisco Bay Study (1994–2020)
2. Suisun Marsh Study (1994–2021)
3. Fall Midwater Trawl (1994–2020)
4. Spring Kodiak Trawl (2002–2021)
5. Delta Juvenile Fish Monitoring Program (1994–2020)
6. Enhanced Delta Smelt Monitoring (2016–2021)
7. 20-mm Survey (1995–2021)
8. Smelt Larval Survey (2009–2021)
9. Summer Townet Survey (1994–2021)

The San Francisco Bay-Delta can be split into three regions to better describe the spatial and temporal patterns of Delta smelt presence within the estuary (Figure C-64).

The following regional cutoffs were used to evaluate the occurrence of Delta smelt within areas of the Bay-Delta:

1. San Joaquin River at Twitchell Island
2. San Joaquin River at Prisoners Point
3. Franks Tract
4. Holland Cut
5. Middle River
6. Upper San Joaquin River
7. Victoria Canal
8. Grant Line Canal and Old River
9. San Joaquin River near Stockton
10. Old River
11. Disappointment Slough
12. Rock Slough and Discovery Bay
13. Mildred Island

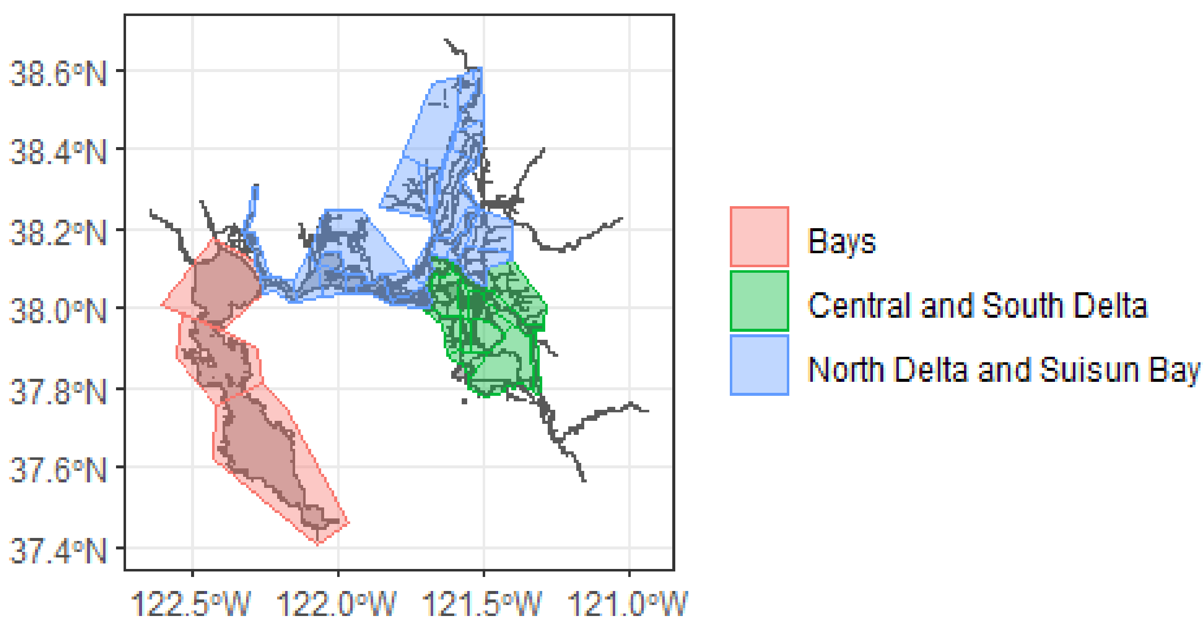


Figure C-64. Regions Used to Summarize Delta Smelt Occurrence in the San Francisco Estuary

C.6.1 Brood Year Cutoff for the Life Stages

- Larvae: brood year = calendar year
- Juvenile: brood year starts on March 1st of current year to February 28th or February 29th of the following year
- Adult: brood year starts on June 1st of current year to May 31st of the following year

C.6.2 Adult Delta Smelt

Adult spawning migration generally occurs during the first flush of turbid freshwater following precipitation events in winter (Grimaldo et al. 2009; Sommer et al. 2011). Adults generally migrate from brackish waters in the low-salinity zone to freshwater spawning habitat in Suisun Marsh, the lower Sacramento River, the Cache Slough Complex, and the Napa River (Moyle et al. 1992; Merz et al. 2011). Delta smelt exhibit pre-spawning holding behavior similar to other migratory species. They hold for long periods of time, estimated to be at least a month, before spawning (Sommer et al. 2011). Hobbs et al. (2019) found that there was life-history diversity within the species surrounding all life stages, including spawning. The majority of fish studied were semianadromous; however, a small percentage resided either in freshwater or brackish water year-round. The study also found evidence of spawning occurring in fresh and brackish waters, further confirming residency. This confirms that Delta smelt have resident and migratory contingents within a year-class, also known as *partial migration* (Hobbs et al. 2019).

The 2022 Phase 1 of the USFWS Enhanced Delta Smelt Monitoring (EDSM) program focused on adult Delta smelt throughout eight regions of the San Francisco Estuary following the release of 55,733 captively produced fish between December 2021 and February 2022. Results show that all the fish captured were marked with either an adipose fin clip or a visible tag, signifying a recapture of a captively released fish. The fish were released in the Sacramento River at Rio Vista, in the Sacramento Deepwater Shipping Channel, and in Suisun Marsh. A total of 56 fish were recaptured, primarily in the three regions where they were released, with the exception of two adult fish recaptured in the lower San Joaquin region and one in the Cache Slough Complex. Fish were caught between mid-December and late March (USFWS EDSM Phase 1 2022).

Most adult delta smelt die after spawning, but a small proportion of adult delta smelt can reside for over a year in the upper San Francisco Estuary and spawn at age 2. Table C-93, Table C-94, and Table C-95 summarize the occurrence of adult (i.e., >58 mm) Delta smelt as the cumulative percentage of fish from June 1 of the first year to May 31 of the following year for the three different regions: Bays, Central and South Delta, and North Delta and Suisun Bay. In general, a small percentage of >58-mm fish occur during June/July, reflecting fish entering their second year, with most occurring between November/ December and May, largely reflecting the prevailing one-year life-history pattern. The phenomenon of 1+-year-old adult delta smelt was more common in the 1990s, when the species was more abundant. The considerably higher fecundity of these older and larger fish (Damon et al. 2016) may be evidence of a survival tactic to ensure population persistence (Bennett 2005). Examples of overlapping cohorts of adult Delta smelt are shown on Figure C-65 and Figure C-66.

As shown on Figure C-65 and Figure C-66, adult Delta smelt are present in the San Francisco Estuary year-round. They are detected from the Napa River through to the east and south Delta and up through Cache Slough and the Sacramento Deepwater Shipping Channel from January to April, with the greatest densities detected in the Suisun Marsh and Bay and the confluence of the Sacramento and San Joaquin Rivers (Confluence). Adults also appear to be abundant in the Cache Slough Complex and San Joaquin River during February. In May, the detection of adults begins to decrease, with no adults detected in the Napa River. From June to August, the frequency of detection significantly decreases. In general, a small percentage of >58-mm fish occurs during June to August, reflecting fish entering their second year, with most occurring between November/December and May, largely reflecting the prevailing one-year life-history pattern. From September to December, the frequency of detection significantly increases in the regions of the Suisun Bay and Marsh, the Confluence, lower Sacramento River, Cache Slough, and the Sacramento Deepwater Shipping Channel. In November and December, Delta smelt are frequently detected in the lower San Joaquin River, in addition to the aforementioned regions.

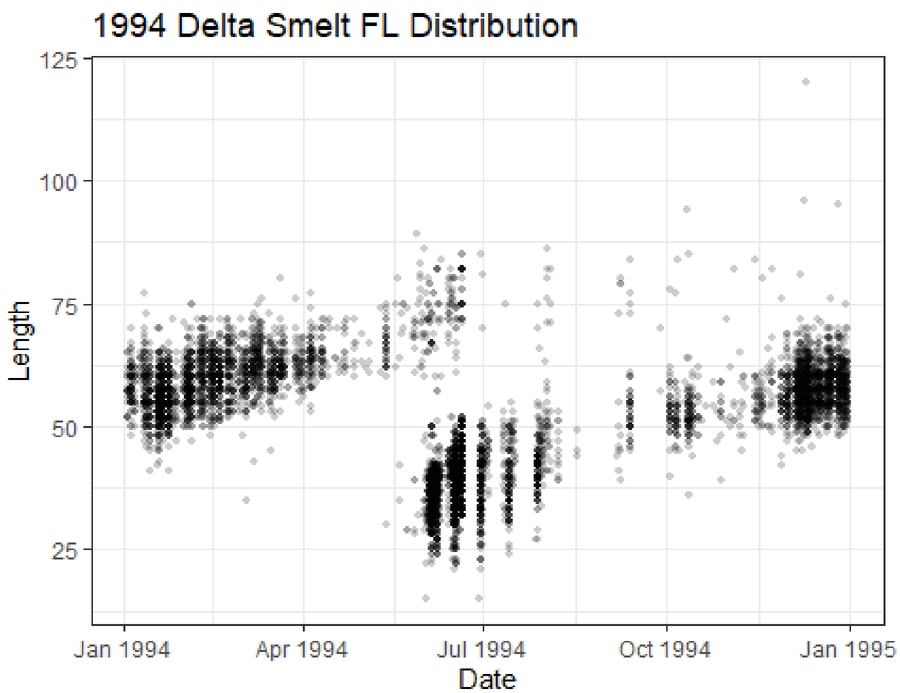


Figure C-65. Distribution of Delta Smelt in 1994 Showing Overlapping 1- and 2-Year-Old Adult Delta Smelt

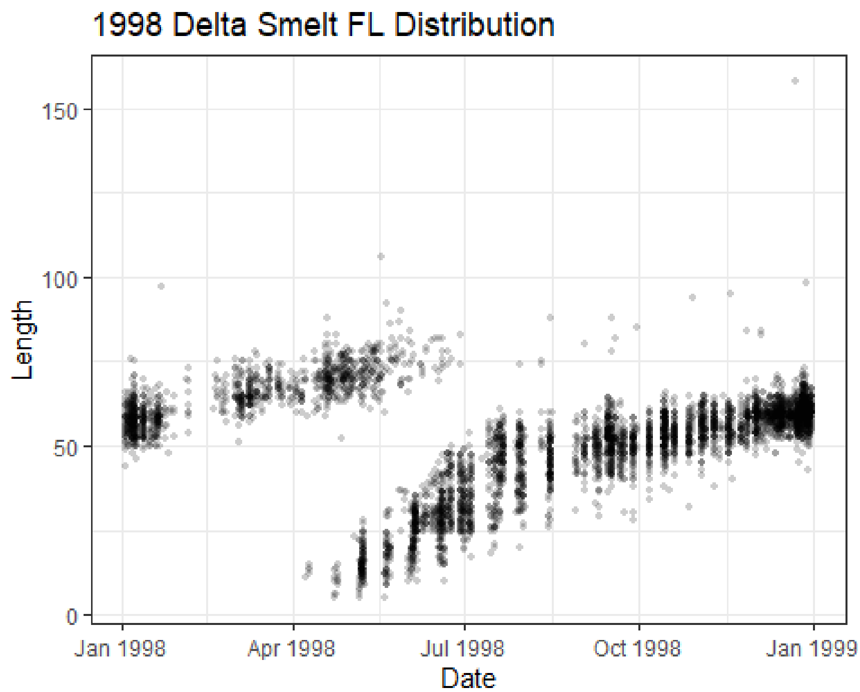


Figure C-66. Distribution of Delta Smelt in 1998 Showing Overlapping 1- and 2-Year-Old Adult Delta Smelt

Table C-93. Adult (> 58-mm) Delta Smelt Occurrence in Bays Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1995	03-05-1996	03-05-1996	03-05-1996	03-05-1996	03-05-1996	03-05-1996	44
1996	01-09-1997	01-09-1997	01-09-1997	02-05-1997	02-05-1997	02-05-1997	3
1997	09-03-1997	09-03-1997	03-02-1998	03-04-1998	03-04-1998	03-04-1998	15
1998	08-16-1998	08-16-1998	12-02-1998	03-03-1999	03-03-1999	03-03-1999	14
1999	03-08-2000	03-08-2000	03-08-2000	03-08-2000	03-08-2000	03-08-2000	1
2016	03-02-2017	03-02-2017	03-02-2017	03-02-2017	03-02-2017	03-02-2017	1

The summary is of the cumulative percentage of catch during the period June 1–May 31. Note that this generally spans two adult cohorts of Delta smelt. Adult Delta smelt can linger for more than a year (i.e., 1+ year old Delta smelt). 2-year old Delta smelt have been observed in the past. This phenomenon of 1+ year old Delta smelt appear to be more common in the 1990s (or whenever smelt were more abundant).

Table C-94. Adult (> 58-mm) Delta Smelt Occurrence in North Delta and Suisun Bay Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1994	06-01-1994	06-20-1994	11-23-1994	04-22-1995	05-06-1995	05-31-1995	2004
1995	06-01-1995	09-25-1995	10-25-1995	05-10-1996	05-16-1996	05-31-1996	14254
1996	06-03-1996	06-03-1996	06-08-1996	05-19-1997	05-27-1997	05-31-1997	932
1997	06-01-1997	06-08-1997	06-20-1997	05-01-1998	05-11-1998	05-30-1998	1670
1998	06-01-1998	11-28-1998	12-15-1998	05-02-1999	05-11-1999	05-29-1999	4745
1999	06-01-1999	10-07-1999	11-08-1999	03-07-2000	04-03-2000	05-31-2000	5624
2000	06-07-2000	10-05-2000	11-08-2000	03-19-2001	04-27-2001	05-31-2001	1660
2001	06-01-2001	07-03-2001	08-23-2001	03-06-2002	03-20-2002	05-25-2002	1510
2002	06-04-2002	09-30-2002	11-14-2002	04-03-2003	05-07-2003	05-31-2003	1688
2003	06-01-2003	08-19-2003	12-09-2003	03-22-2004	04-08-2004	05-13-2004	1529
2004	06-02-2004	10-04-2004	11-08-2004	04-21-2005	05-11-2005	05-31-2005	1562
2005	06-01-2005	06-20-2005	07-05-2005	04-26-2006	05-12-2006	05-31-2006	1211
2006	06-01-2006	06-06-2006	06-19-2006	04-05-2007	04-05-2007	05-22-2007	1017
2007	06-06-2007	09-19-2007	12-10-2007	04-08-2008	04-10-2008	05-30-2008	395
2008	06-06-2008	09-03-2008	12-16-2008	03-18-2009	04-15-2009	05-27-2009	754
2009	06-01-2009	07-24-2009	08-18-2009	04-15-2010	04-22-2010	05-26-2010	700
2010	06-07-2010	07-19-2010	08-16-2010	04-06-2011	04-11-2011	05-25-2011	893
2011	06-01-2011	09-07-2011	10-07-2011	04-17-2012	05-02-2012	05-25-2012	2062
2012	06-01-2012	06-25-2012	07-13-2012	03-07-2013	04-04-2013	05-24-2013	836
2013	06-07-2013	07-22-2013	11-13-2013	04-08-2014	04-10-2014	05-08-2014	594
2014	06-02-2014	07-16-2014	09-02-2014	02-12-2015	03-11-2015	05-06-2015	161
2015	07-01-2015	08-03-2015	09-01-2015	04-04-2016	04-04-2016	05-23-2016	57
2016	06-07-2016	12-08-2016	12-08-2016	03-01-2017	03-08-2017	05-31-2017	402
2017	06-07-2017	07-20-2017	08-09-2017	02-14-2018	03-07-2018	03-22-2018	81
2018	07-09-2018	09-17-2018	10-09-2018	02-11-2019	02-12-2019	03-03-2019	42
2019	11-29-2019	11-29-2019	12-04-2019	03-05-2020	03-16-2020	03-16-2020	17

The summary is of the cumulative percentage of catch during the period June 1–May 31. Note that this generally spans two adult cohorts of Delta smelt. Adult Delta smelt can linger for more than a year (i.e., 1+ year old Delta smelt). 2-year old Delta smelt have been observed in the past. This phenomenon of 1+ year old Delta smelt appear to be more common in the 1990s (or whenever smelt were more abundant).

Table C-95. Adult (> 58-mm) Delta Smelt Occurrence in Central and South Delta Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1994	12-08-1994	12-08-1994	02-08-1995	04-03-1995	05-01-1995	05-01-1995	11
1995	01-04-1996	01-04-1996	01-05-1996	04-01-1996	04-01-1996	04-27-1996	40
1996	01-15-1997	01-15-1997	03-03-1997	04-16-1997	04-16-1997	04-16-1997	13
1997	06-02-1997	06-02-1997	06-02-1997	03-05-1998	03-05-1998	03-05-1998	9
1998	03-01-1999	03-01-1999	03-01-1999	05-10-1999	05-28-1999	05-28-1999	13
1999	06-04-1999	06-08-1999	10-12-1999	03-09-2000	04-03-2000	05-08-2000	40
2000	06-12-2000	06-12-2000	09-13-2000	05-07-2001	05-07-2001	05-07-2001	13
2001	12-03-2001	01-07-2002	01-07-2002	03-04-2002	03-04-2002	04-02-2002	74
2002	06-16-2002	12-26-2002	01-23-2003	04-16-2003	04-16-2003	04-16-2003	46
2003	01-12-2004	01-12-2004	01-12-2004	04-05-2004	04-05-2004	05-03-2004	278
2004	01-03-2005	01-03-2005	01-24-2005	02-18-2005	03-11-2005	03-11-2005	15
2005	01-23-2006	01-23-2006	01-23-2006	04-11-2006	04-24-2006	04-24-2006	10
2006	01-08-2007	01-08-2007	01-08-2007	01-08-2007	01-08-2007	01-08-2007	5
2007	01-07-2008	01-07-2008	01-07-2008	03-17-2008	03-17-2008	03-17-2008	6
2008	01-12-2009	01-12-2009	01-12-2009	04-13-2009	04-13-2009	04-13-2009	12
2009	02-08-2010	02-08-2010	02-08-2010	03-23-2010	03-23-2010	03-23-2010	4
2010	01-10-2011	01-10-2011	01-10-2011	04-04-2011	04-04-2011	04-04-2011	10
2011	02-06-2012	02-06-2012	02-13-2012	04-02-2012	04-02-2012	05-07-2012	38
2012	08-09-2012	01-07-2013	01-07-2013	04-29-2013	04-29-2013	04-29-2013	34
2013	03-10-2014	03-10-2014	03-10-2014	05-05-2014	05-05-2014	05-05-2014	3
2014	12-15-2014	12-15-2014	01-05-2015	02-09-2015	02-09-2015	02-09-2015	17
2015	02-08-2016	02-08-2016	02-08-2016	02-08-2016	02-08-2016	02-08-2016	1
2016	12-15-2016	12-15-2016	12-27-2016	03-01-2017	03-07-2017	03-16-2017	59
2018	01-29-2019	01-29-2019	01-29-2019	01-29-2019	01-29-2019	01-29-2019	1

The summary is of the cumulative percentage of catch during the period June 1–May 31. Note that this generally spans two adult cohorts of Delta smelt. Adult Delta smelt can linger for more than a year (i.e., 1+ year old Delta smelt). 2-year old Delta smelt have been observed in the past. This phenomenon of 1+ year old Delta smelt appear to be more common in the 1990s (or whenever smelt were more abundant).

C.6.3 Larval Delta Smelt

Larval Delta smelt are found in the San Francisco Estuary from March to July (Merz et al. 2011). After hatching in spring, most larvae generally migrate downstream, toward the brackish portion of the San Francisco Estuary (Dege and Brown 2004). They are predominantly found in the upper Napa River, Suisun Marsh, Suisun Bay, the Confluence, lower San Joaquin River, lower Sacramento River, and the Cache Slough Complex; however, larvae were also observed more frequently than other life stages in the south and east Delta. Larvae are observed in the greatest densities in the Confluence (Merz et al. 2011). Optimal temperatures for larval survival are between 59°F–63°F (15°C and 17°C; Bennett 2005). Larval Delta smelt generally occur in low-salinity habitats (Sommer et al. 2011), with their habitat shifting upstream of Suisun Bay in drier years (Sommer and Mejia 2013). Table C-96, Table C-97, and Table C-98 summarize the occurrence of larval (<20-mm) Delta smelt for the three different regions: Bays, Central and South Delta, and North Delta and Suisun Bay.

The current abundance of larval and early juvenile Delta smelt appears to be very low, based on available monitoring. The 2022 Phase 2 of the EDSM program focused on postlarval and early juvenile Delta smelt throughout six regions of the San Francisco Estuary in April to July 2022. A total of 18 postlarval and juvenile fish were caught between April and early June 2022. All fish were caught in the Sacramento Deepwater Shipping Channel, except for 2 that were caught in Suisun Bay. No adults from the earlier releases (see discussion above for *Adult Delta Smelt*) were recaptured during Phase 2 (USFWS EDSM Phase 2 2022).

Table C-96. Larval Delta Smelt (<20-mm) Occurrence in Bays Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1995	05-12-1995	05-12-1995	05-12-1995	05-26-1995	05-26-1995	05-26-1995	228
1996	04-17-1996	04-17-1996	04-17-1996	04-17-1996	04-17-1996	04-17-1996	2007
2006	04-22-2006	04-22-2006	04-22-2006	05-19-2006	05-19-2006	06-17-2006	587
2011	04-25-2011	04-25-2011	04-25-2011	05-10-2011	05-10-2011	05-10-2011	666
2019	04-24-2019	04-24-2019	04-24-2019	04-24-2019	04-24-2019	04-24-2019	13

Note: Cohort year set to calendar year.

Table C-97. Larval Delta Smelt (<20-mm) Occurrence in North Delta and Suisun Bay Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1995	04-27-1995	05-10-1995	05-12-1995	07-19-1995	07-20-1995	08-07-1995	228
1996	04-11-1996	04-27-1996	04-30-1996	06-14-1996	06-26-1996	07-25-1996	2007
1997	04-15-1997	05-13-1997	05-14-1997	06-11-1997	06-11-1997	07-24-1997	1148
1998	04-08-1998	04-24-1998	05-06-1998	06-18-1998	06-20-1998	07-30-1998	229
1999	04-13-1999	04-16-1999	04-30-1999	07-08-1999	07-08-1999	08-03-1999	1378
2000	03-21-2000	04-07-2000	05-03-2000	06-14-2000	06-15-2000	07-11-2000	2007
2001	03-21-2001	04-07-2001	04-07-2001	05-05-2001	05-05-2001	06-30-2001	4193
2002	04-16-2002	04-17-2002	04-17-2002	06-14-2002	06-14-2002	06-29-2002	300

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
2003	03-25-2003	03-26-2003	04-09-2003	06-18-2003	07-01-2003	07-03-2003	363
2004	04-01-2004	04-14-2004	04-14-2004	05-27-2004	06-10-2004	06-22-2004	309
2005	03-16-2005	04-27-2005	04-28-2005	06-08-2005	06-09-2005	07-08-2005	384
2006	04-21-2006	05-18-2006	05-19-2006	06-17-2006	06-29-2006	07-18-2006	587
2007	03-14-2007	03-16-2007	03-16-2007	06-20-2007	06-20-2007	06-20-2007	31
2008	04-14-2008	04-14-2008	04-14-2008	06-09-2008	06-09-2008	06-12-2008	62
2009	04-06-2009	04-08-2009	04-22-2009	06-15-2009	06-15-2009	07-01-2009	168
2010	03-17-2010	04-12-2010	04-26-2010	06-25-2010	07-08-2010	07-08-2010	430
2011	03-15-2011	04-26-2011	04-26-2011	06-21-2011	07-05-2011	07-07-2011	666
2012	03-19-2012	03-19-2012	03-20-2012	06-05-2012	06-06-2012	07-12-2012	948
2013	03-18-2013	03-18-2013	03-19-2013	05-20-2013	05-21-2013	07-03-2013	655
2014	03-03-2014	03-04-2014	03-18-2014	05-12-2014	05-13-2014	05-27-2014	132
2015	03-03-2015	03-16-2015	03-25-2015	05-13-2015	05-13-2015	06-23-2015	42
2016	03-15-2016	03-15-2016	03-28-2016	05-12-2016	05-25-2016	06-22-2016	67
2017	03-13-2017	03-15-2017	03-15-2017	05-24-2017	06-05-2017	07-05-2017	116
2018	03-12-2018	03-12-2018	03-12-2018	03-29-2018	04-11-2018	06-12-2018	33
2019	03-11-2019	03-11-2019	03-12-2019	05-21-2019	06-05-2019	06-05-2019	13
2020	03-17-2020	03-17-2020	03-17-2020	05-11-2020	05-19-2020	05-20-2020	38

Note: Cohort year set to calendar year.

Table C-98. Larval Delta Smelt (<20-mm) Occurrence in Central and Southern Delta Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1994	06-02-1994	06-02-1994	06-02-1994	06-29-1994	06-29-1994	06-29-1994	2
1995	07-03-1995	07-03-1995	07-03-1995	07-03-1995	07-03-1995	07-03-1995	228
1996	04-10-1996	04-10-1996	04-11-1996	06-08-1996	06-09-1996	07-08-1996	2007
1997	03-31-1997	04-14-1997	04-14-1997	05-27-1997	05-27-1997	07-08-1997	1148
1998	06-01-1998	06-01-1998	06-01-1998	06-01-1998	06-01-1998	06-01-1998	229
1999	04-12-1999	04-12-1999	04-28-1999	06-14-1999	06-14-1999	07-06-1999	1378
2000	03-20-2000	04-17-2000	04-18-2000	06-13-2000	06-13-2000	07-10-2000	2007
2001	04-02-2001	04-16-2001	04-30-2001	05-30-2001	06-11-2001	06-13-2001	4193
2002	04-02-2002	04-02-2002	04-02-2002	05-29-2002	06-11-2002	06-24-2002	300
2003	03-24-2003	04-07-2003	04-07-2003	06-17-2003	06-30-2003	07-01-2003	363
2004	03-29-2004	04-13-2004	04-26-2004	05-24-2004	06-07-2004	06-09-2004	309

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
2005	03-15-2005	03-28-2005	03-28-2005	06-06-2005	06-07-2005	07-05-2005	384
2006	05-16-2006	05-16-2006	05-16-2006	05-16-2006	05-16-2006	05-16-2006	587
2007	05-07-2007	05-07-2007	05-07-2007	05-07-2007	05-07-2007	05-07-2007	31
2008	04-14-2008	04-14-2008	04-15-2008	05-28-2008	06-09-2008	06-09-2008	62
2009	04-06-2009	04-06-2009	04-06-2009	05-20-2009	06-16-2009	06-16-2009	168
2010	04-13-2010	04-13-2010	04-13-2010	06-22-2010	06-22-2010	06-22-2010	430
2011	05-23-2011	05-23-2011	05-23-2011	06-06-2011	06-06-2011	06-06-2011	666
2012	03-19-2012	03-19-2012	03-19-2012	06-05-2012	06-18-2012	06-18-2012	948
2013	03-18-2013	03-18-2013	03-19-2013	05-20-2013	06-03-2013	06-17-2013	655
2014	03-17-2014	03-17-2014	03-17-2014	05-12-2014	05-27-2014	05-27-2014	132
2015	03-24-2015	03-24-2015	03-24-2015	05-11-2015	05-11-2015	05-11-2015	42
2016	03-14-2016	03-14-2016	03-14-2016	06-06-2016	06-06-2016	06-06-2016	67
2018	03-19-2018	03-19-2018	03-19-2018	03-19-2018	03-19-2018	03-19-2018	33

Note: Cohort year set to calendar year.

C.6.4 Juvenile Delta Smelt

Juvenile Delta smelt generally are found in the San Francisco Estuary from June/July–December, although, based on a size range of 20–58 mm for juveniles, smaller numbers of juveniles occur before and after this general time period (Table C-99 through Table C-101). Data from the monitoring programs suggest that an important rearing area for juveniles from June to December is in the North Delta Arc (Moyle et al. 2018), from Suisun Bay/Suisun Marsh, through the lower Sacramento River and up into the Cache Slough Complex/Sacramento Deep Water Shipping Channel area (Merz et al. 2011; Sommer et al. 2011). Table C-99, Table C-100, and Table C-101 summarize the occurrence of juvenile (20-58mm) Delta Smelt for the three different regions: Bays, Central and South Delta, and North Delta and Suisun Bay.

The current abundance of juvenile Delta smelt appears to be very low based on available monitoring. The 2022 Phase 3 of the EDSM program began in July and, up to week 12 (September 19–22, 2022), had caught a total of six Delta smelt (three in the lower Sacramento River, two in the Sacramento Deepwater Shipping Channel, and one in Suisun Marsh), with extrapolated population abundance of 2,500 fish or less (USFWS EDSM Phase 3 2022).

Table C-99. Juvenile (20–58-mm FL) Delta Smelt Occurrence in Bays Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1995	07-11-1995	07-11-1995	07-21-1995	09-07-1995	09-07-1995	10-12-1995	27
1996	03-05-1996	03-05-1996	03-05-1996	07-26-1996	07-26-1996	07-26-1996	10
1998	03-04-1998	07-13-1998	07-21-1998	08-16-1998	09-03-1998	12-08-1998	35

1999	03-31-1999	03-31-1999	03-31-1999	07-09-1999	07-09-1999	07-09-1999	3
2000	11-02-2000	11-02-2000	11-02-2000	12-26-2000	12-26-2000	12-26-2000	2
2002	08-15-2002	08-15-2002	08-15-2002	08-15-2002	08-15-2002	08-15-2002	2
2005	01-10-2006	01-10-2006	01-10-2006	01-10-2006	01-10-2006	01-10-2006	1
2006	05-19-2006	05-19-2006	05-19-2006	07-01-2006	07-01-2006	07-01-2006	15
2017	08-23-2017	08-23-2017	08-23-2017	09-12-2017	09-12-2017	09-12-2017	2

Note: The summary is of the cumulative percentage of catch during the period March 1 of the first year to the last day of February of the following year. Note that this may span two separate cohorts of Delta smelt.

Table C-100. Juvenile (20–58-mm FL) Delta Smelt Occurrence in North Delta and Suisun Bay Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1994	03-02-1994	06-05-1994	06-07-1994	12-15-1994	01-04-1995	02-24-1995	8158
1995	03-03-1995	06-21-1995	07-06-1995	01-13-1996	01-16-1996	02-20-1996	8115
1996	03-01-1996	05-24-1996	05-29-1996	12-07-1996	12-10-1996	02-05-1997	5375
1997	03-04-1997	05-31-1997	06-11-1997	12-30-1997	01-09-1998	02-25-1998	2992
1998	03-04-1998	06-05-1998	06-18-1998	12-30-1998	01-08-1999	02-23-1999	3022
1999	03-08-1999	06-04-1999	06-10-1999	12-21-1999	01-05-2000	02-22-2000	4833
2000	03-07-2000	06-01-2000	06-13-2000	12-18-2000	01-30-2001	02-26-2001	5344
2001	03-02-2001	05-05-2001	05-05-2001	10-10-2001	10-10-2001	02-15-2002	2391
2002	03-06-2002	05-15-2002	06-11-2002	10-16-2002	11-06-2002	01-24-2003	888
2003	05-06-2003	06-05-2003	06-17-2003	01-27-2004	01-27-2004	02-24-2004	1284
2004	03-09-2004	05-25-2004	05-26-2004	10-07-2004	11-24-2004	02-24-2005	772
2005	03-02-2005	05-13-2005	05-26-2005	10-03-2005	12-14-2005	02-22-2006	793
2006	05-05-2006	05-20-2006	06-03-2006	01-10-2007	01-22-2007	02-22-2007	1081
2007	03-06-2007	05-10-2007	06-12-2007	08-21-2007	12-12-2007	02-04-2008	184
2008	04-29-2008	06-03-2008	06-09-2008	01-14-2009	01-14-2009	02-13-2009	443
2009	03-18-2009	05-06-2009	05-20-2009	08-26-2009	10-26-2009	01-14-2010	429
2010	03-10-2010	05-10-2010	05-10-2010	08-11-2010	10-04-2010	02-10-2011	763
2011	04-01-2011	05-25-2011	06-07-2011	12-07-2011	01-19-2012	02-22-2012	2222
2012	03-05-2012	05-21-2012	05-23-2012	07-26-2012	09-04-2012	02-06-2013	711
2013	04-08-2013	05-06-2013	05-07-2013	09-03-2013	09-18-2013	02-12-2014	1074
2014	03-12-2014	04-28-2014	05-12-2014	08-14-2014	10-09-2014	01-15-2015	302
2015	04-16-2015	04-27-2015	05-08-2015	09-01-2015	09-01-2015	12-01-2015	162

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
2016	03-09-2016	04-13-2016	04-27-2016	12-28-2016	12-28-2016	02-08-2017	128
2017	03-08-2017	05-08-2017	05-24-2017	09-18-2017	10-10-2017	01-10-2018	513
2018	05-02-2018	07-05-2018	07-17-2018	11-07-2018	12-28-2018	02-25-2019	160
2019	04-29-2019	06-18-2019	07-03-2019	09-17-2019	10-15-2019	01-15-2020	146
2020	05-05-2020	05-11-2020	05-19-2020	09-23-2020	01-06-2021	01-26-2021	35
2021	05-06-2021	05-06-2021	05-06-2021	05-06-2021	05-06-2021	05-06-2021	1

Note: The summary is of the cumulative percentage of catch during the period March 1 of the first year to the last day of February of the following year. Note that this may span two separate cohorts of Delta smelt.

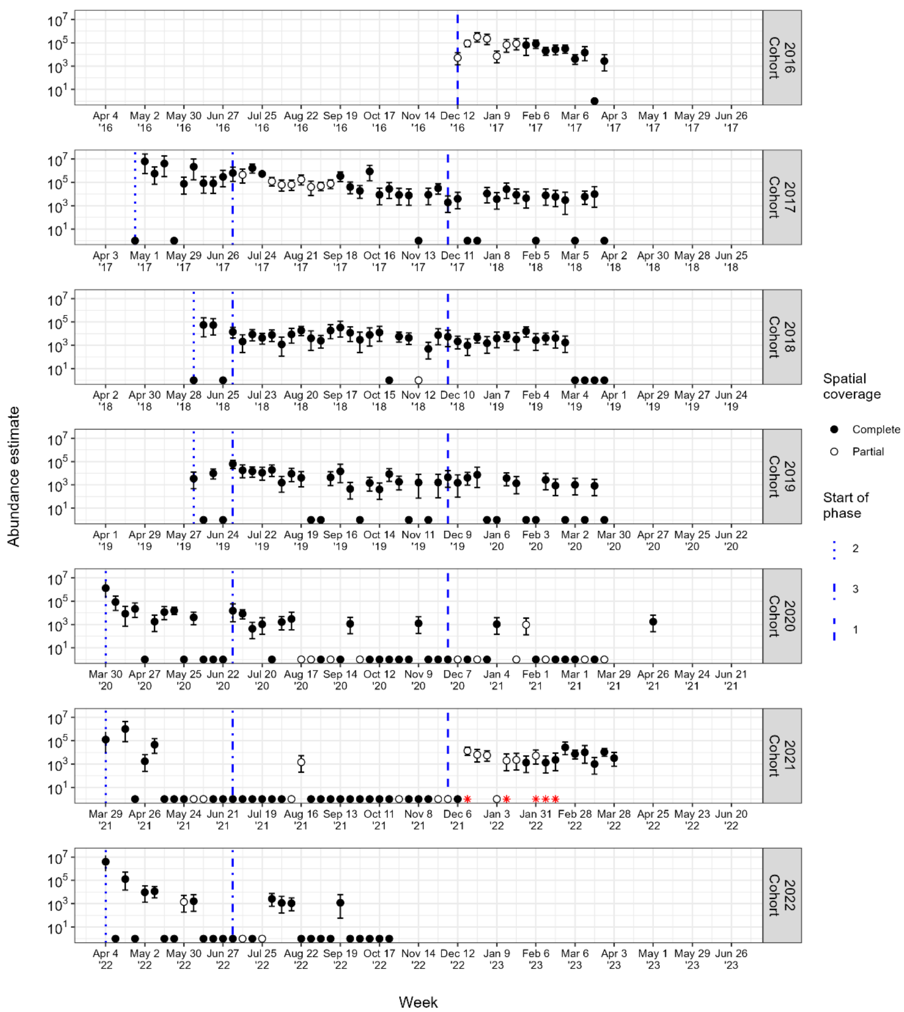
Table C-101. Juvenile (20–58-mm FL) Delta Smelt Occurrence in Central and South Delta Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1994	06-02-1994	06-02-1994	06-06-1994	06-16-1994	07-27-1994	01-10-1995	20
1995	07-03-1995	07-03-1995	07-03-1995	08-18-1995	08-18-1995	08-18-1995	3
1996	05-09-1996	05-09-1996	05-09-1996	07-22-1996	07-22-1996	11-04-1996	26
1997	04-28-1997	04-28-1997	05-13-1997	06-27-1997	07-08-1997	01-12-1998	35
1998	05-04-1998	05-04-1998	05-04-1998	07-10-1998	07-10-1998	07-10-1998	4
1999	04-27-1999	05-10-1999	05-24-1999	06-14-1999	06-24-1999	11-08-1999	219
2000	04-24-2000	05-07-2000	05-15-2000	06-26-2000	06-26-2000	07-21-2000	90
2001	04-30-2001	05-15-2001	05-29-2001	10-04-2001	01-07-2002	02-04-2002	104
2002	05-13-2002	05-13-2002	05-13-2002	06-24-2002	06-24-2002	06-29-2002	99
2003	05-06-2003	05-19-2003	05-19-2003	01-26-2004	02-11-2004	02-23-2004	41
2004	05-10-2004	05-10-2004	05-10-2004	06-07-2004	06-09-2004	07-19-2004	49
2005	05-09-2005	05-09-2005	05-09-2005	01-17-2006	01-17-2006	01-17-2006	6
2006	01-08-2007	01-08-2007	01-08-2007	01-08-2007	01-08-2007	01-08-2007	1
2007	06-04-2007	06-04-2007	06-04-2007	07-03-2007	07-03-2007	07-03-2007	2
2008	05-12-2008	05-12-2008	05-12-2008	06-16-2008	06-30-2008	06-30-2008	15
2009	06-01-2009	06-01-2009	06-01-2009	06-01-2009	06-01-2009	06-01-2009	1
2010	06-14-2010	06-14-2010	06-14-2010	07-29-2010	07-29-2010	07-29-2010	2
2011	06-06-2011	06-06-2011	06-06-2011	06-06-2011	06-06-2011	06-06-2011	1
2012	05-07-2012	05-07-2012	05-21-2012	06-25-2012	07-09-2012	08-06-2012	25
2013	04-22-2013	05-06-2013	05-06-2013	06-10-2013	06-24-2013	06-24-2013	42

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
2014	05-12-2014	05-12-2014	05-12-2014	05-12-2014	05-12-2014	05-12-2014	1
2015	04-28-2015	04-28-2015	04-28-2015	06-08-2015	06-08-2015	06-08-2015	2
2016	05-11-2016	05-11-2016	05-11-2016	12-22-2016	12-22-2016	12-22-2016	4
2017	08-09-2017	08-09-2017	08-09-2017	08-09-2017	08-09-2017	08-09-2017	1

Note: The summary is of the cumulative percentage of catch during the period March 1 of the first year to the last day of February of the following year. Note that this may span two separate cohorts of Delta smelt.

C.6.5 Adult Abundance



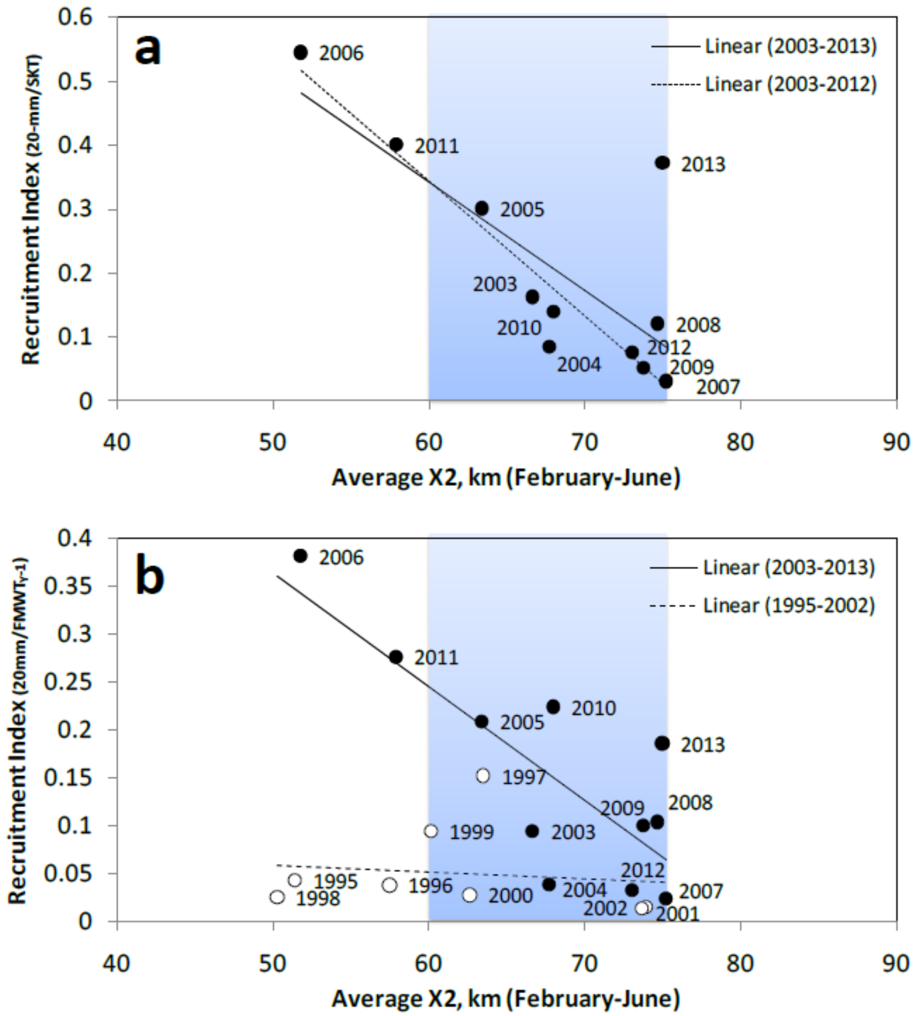
Source: Time series of Enhanced Delta smelt monitoring program (EDSM) weekly Delta smelt abundance estimates (y-axis, log-scale). Phase 1 uses Kodiak trawl to sample adult Delta smelt during spawning and entrainment season. Phase 2 uses 20-mm larval net to sample larval and early juvenile Delta smelt. Phase 3 uses Kodiak trawl to sample rearing subadult Delta smelt. Abundance estimates were calculated using zero-inflated negative binomial model for phase 1 and 3, and using design-based method for phase 2. Red stars indicate weeks with supplemental releases. Note that data from the latest phase has not yet been quality checked. For more information on EDSM, see USFWS et al. (2022; https://doi.org/10.6073/pasta/e1a540c161b7be56b941df50fd7b44c5 (Accessed 2023-01-25).

Figure C-67. Time series of weekly Delta Smelt abundance estimates from EDSM survey: 2016 – 2022 cohorts. Phase 1 of EDSM runs from December through March and focuses on adult Delta Smelt. Phase 2 sampling takes place from April through June and targets post-larval and juvenile Delta Smelt. Phase 3 runs from July through November and targets juvenile and sub-adult Delta Smelt. Abundance estimates were calculated using zero-inflated negative binomial model for phase 1 and 3, and using design-based method for phase 2. Red stars indicate weeks with supplemental releases. Note that data from the latest phase has not yet been QA/QC'ed.

C.6.6 Adult Survival

There are no direct observations of adult survival.

Recruitment of larvae from adults was linearly related to spring X2 for a recent time series (2003-2013, Figure C-68). No relationship was apparent at all before the 2002 step decline when the proportional larval recruitment from then more abundant subadults was generally low (Figure C-68).



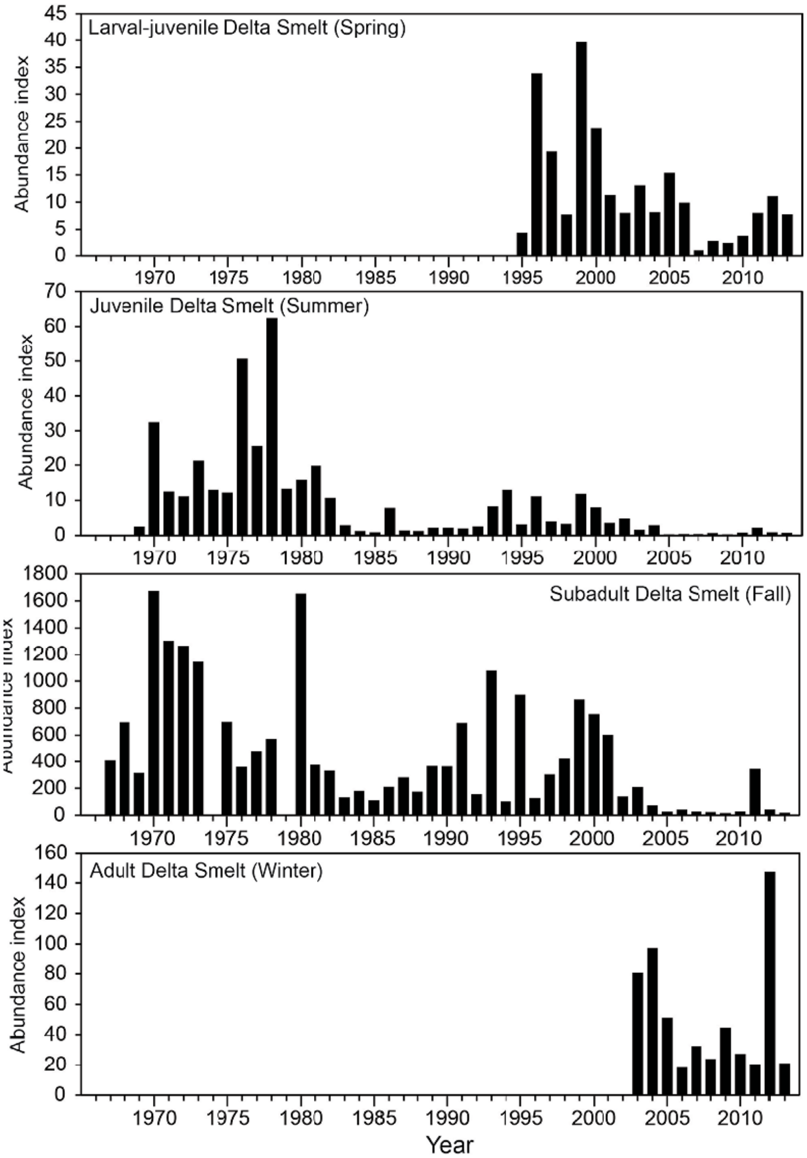
Source: MAST report, figure 82, page 161

Figure C-68. Adult (panel a, SKT) and subadult (panel b, FMWT the previous year) to larvae (20 mm Survey) recruitment indices (abundance index ratios) as a function of spring X2 (February-June). For 20 mm/SKT a linear regression was calculated with and without 2013, which appears to be an outlier. For 20 mm/FMWT the previous year separate regressions were calculated for the POD period (2003- 2013), the period before the POD (1995-2002), and the entire data record (not shown).

C.6.7 Fecundity and Survival of Eggs

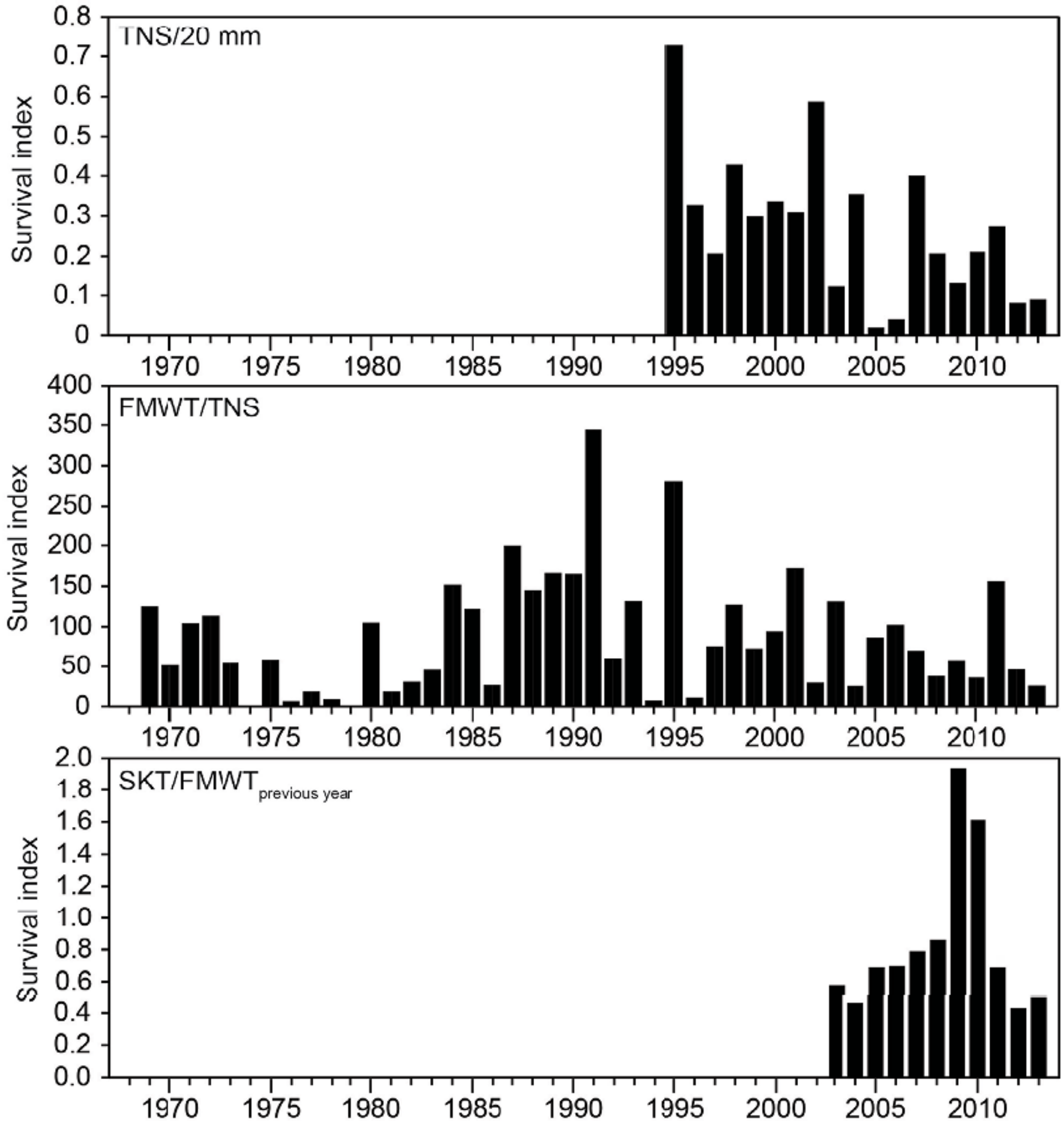
Wild delta smelt adult fecundity was observed to range from 813 to 3919 eggs per clutch based on oocyte developmental stages (Damon et al 2016). No observations of egg survival in the wild have been made.

C.6.8 Larvae Abundance



Source: MAST report, figure 3, page 27.

Figure C-69. Delta Smelt abundance index for life stages of Delta Smelt including the larvae-juveniles (20 mm Survey), juveniles (Summer Townet Survey), subadults (Fall Midwater Trawl), and adults (Spring Kodiak Trawl). The initiation of each individual survey is indicated by the initial bar with subsequent missing bars indicating when an index could not be calculated.



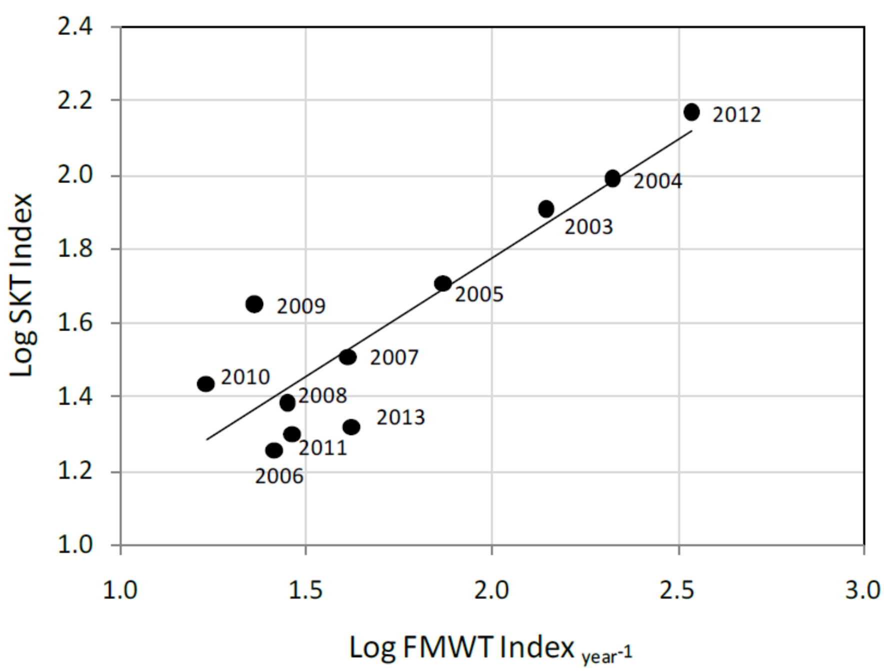
Source: MAST report, figure 51, page 95

Figure C-70. Stage to stage survival indices based on data from Summer Townet Survey (TNS), Fall Midwater Trawl (FMWT), and Spring Kodiak Trawl (SKT)

Table C-102. Summary of relationships of larval recruitment indices (abundance index ratios) for Delta Smelt (response variable) and spring X2 (predictor variable; spring: February-June): n, number of observations (years); SE/Mean, model standard error (square root of mean squared residual) as proportion of mean response, P, statistical significance level for the model; R^2, coefficient of determination. All relationships modeled with least-squares linear models (LM).

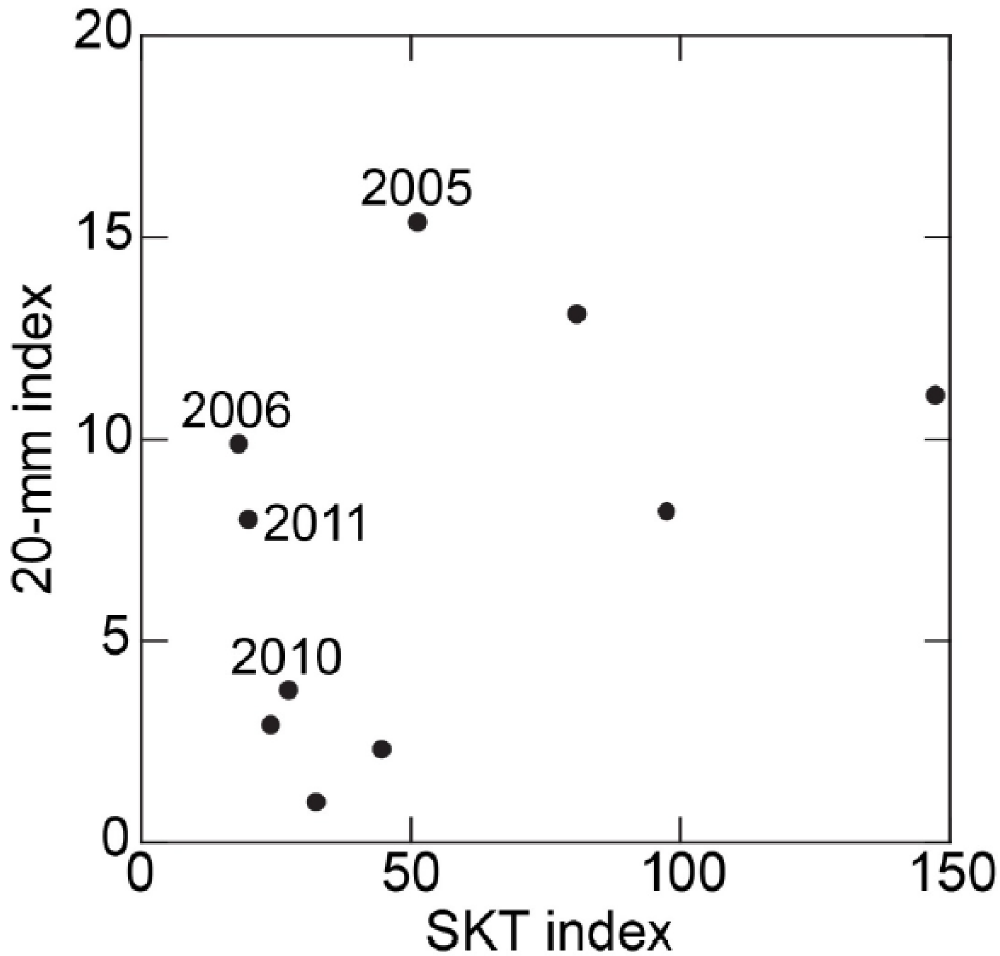
Index Ratio	Period	n	SE / Mean	P	R^2
20-mm/ SKT	2003- 2013	11	0.556	0.006	0.588
20-mm/ SKT	2003- 2012	10	0.270	0.000	0.918
20-mm/ FMWTYear-1	2003- 2013	11	0.469	0.003	0.648
20-mm/ FMWTYear-1	1995- 2002	8	1.012	0.771	0.015
20-mm/ FMWTYear-1	1995- 2013	19	0.981	0.321	0.058

Source: MAST report, table 9, page 162



Source: MAST report, figure 53, page 103

Figure C-71. Relationship of annual indices of Delta Smelt abundance from the Spring Kodiak Trawl (SKT) and Fall Midwater Trawl (FMWT) from the previous year. Year labels correspond to the year of the SKT. The linear regression with all index values log-transformed to address non-normal distributions in the raw data is: Log SKT Index = 0.4997 + 0.6381(Log FMWT Index Year-1), n = 11, $p < 0.001$, $R^2 = 0.79$.



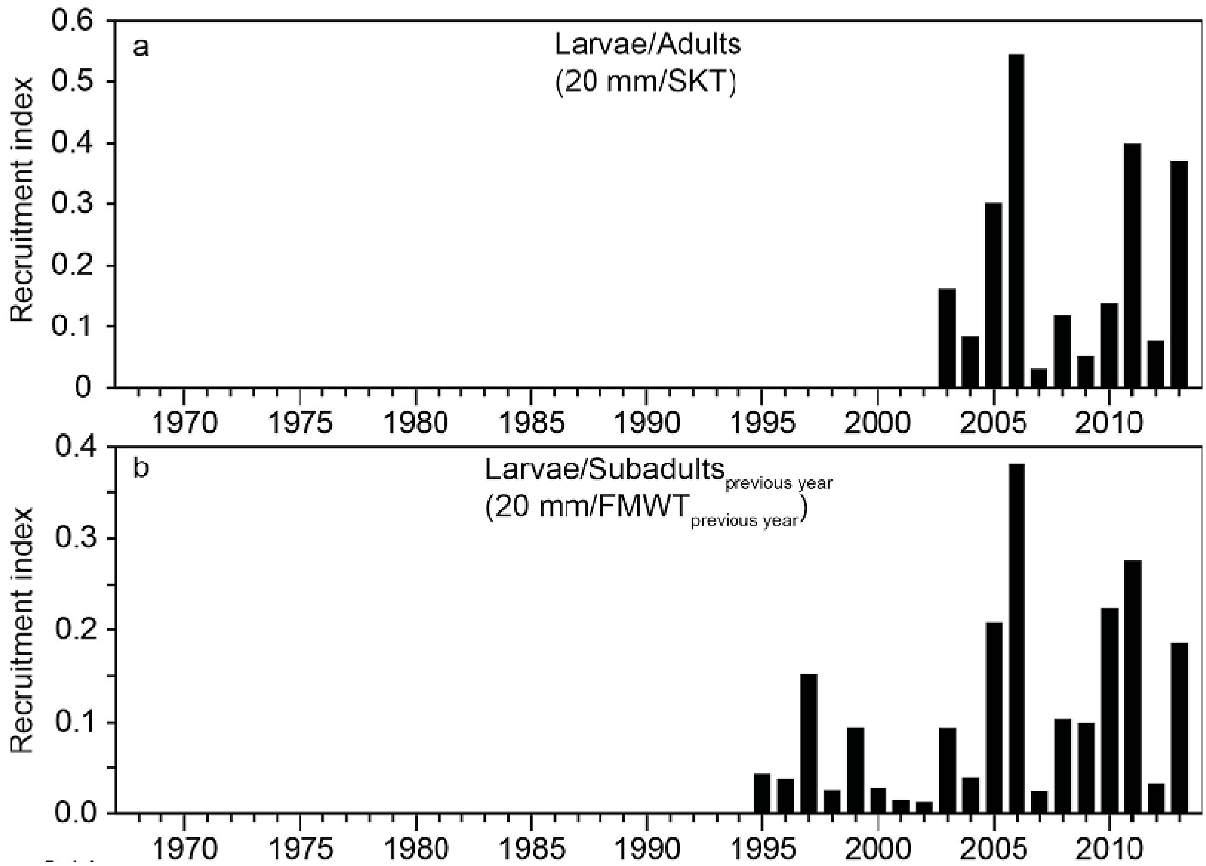
Source: MAST report, figure 54, page 104

Figure C-72. Plot of the Spring Kodiak Trawl (SKT) adult abundance index against the 20 mm Survey larval abundance index 2003-2012. The comparison years of 2005, 2006, 2010, and 2011 are labeled.

C.6.9 Larvae Survival

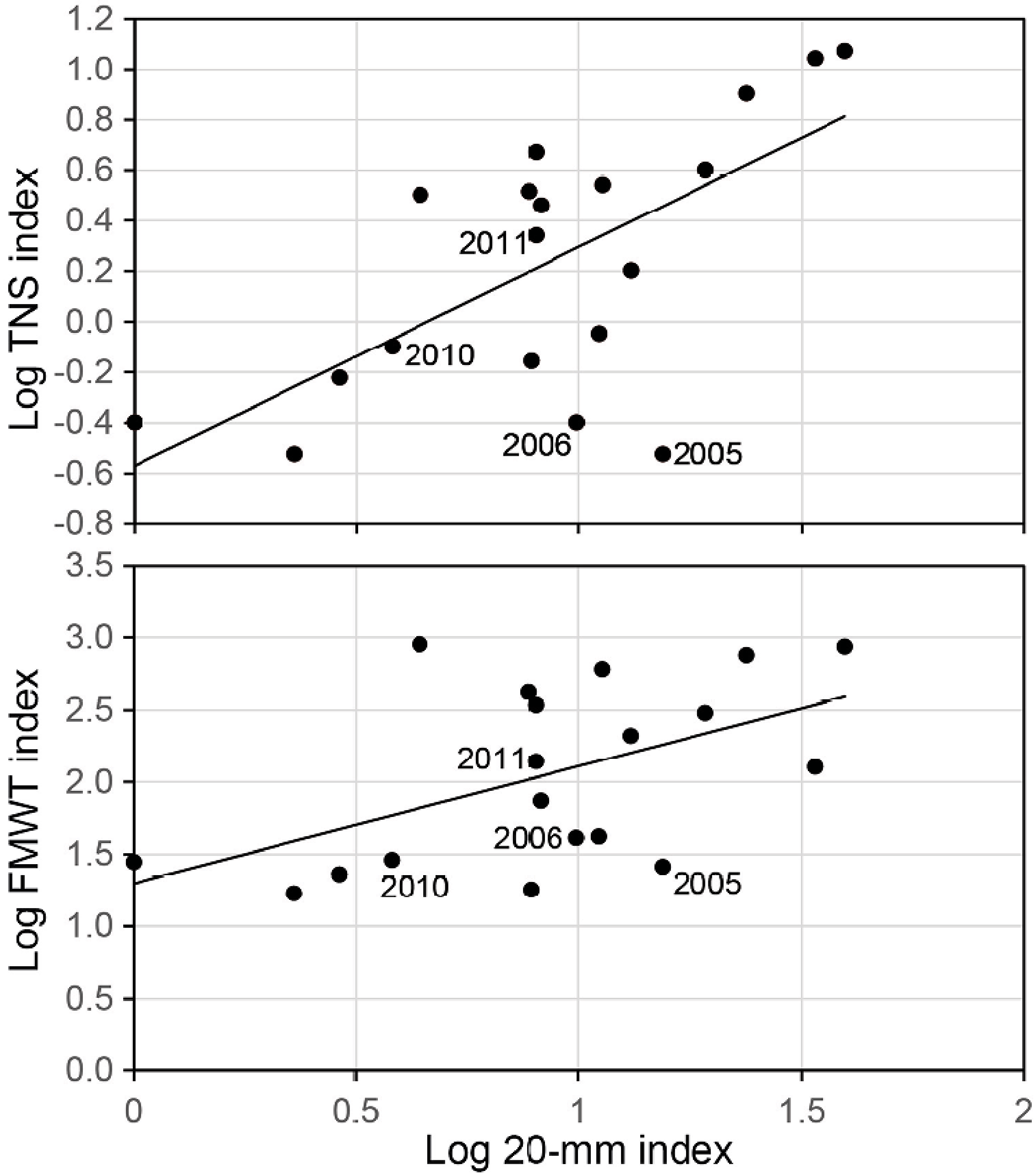
For information on Delta Smelt larvae survival, see recruitment indices figure (Figure C-73).

No observations of Delta smelt larvae are available.



Source: MAST report, figure 52, page 96

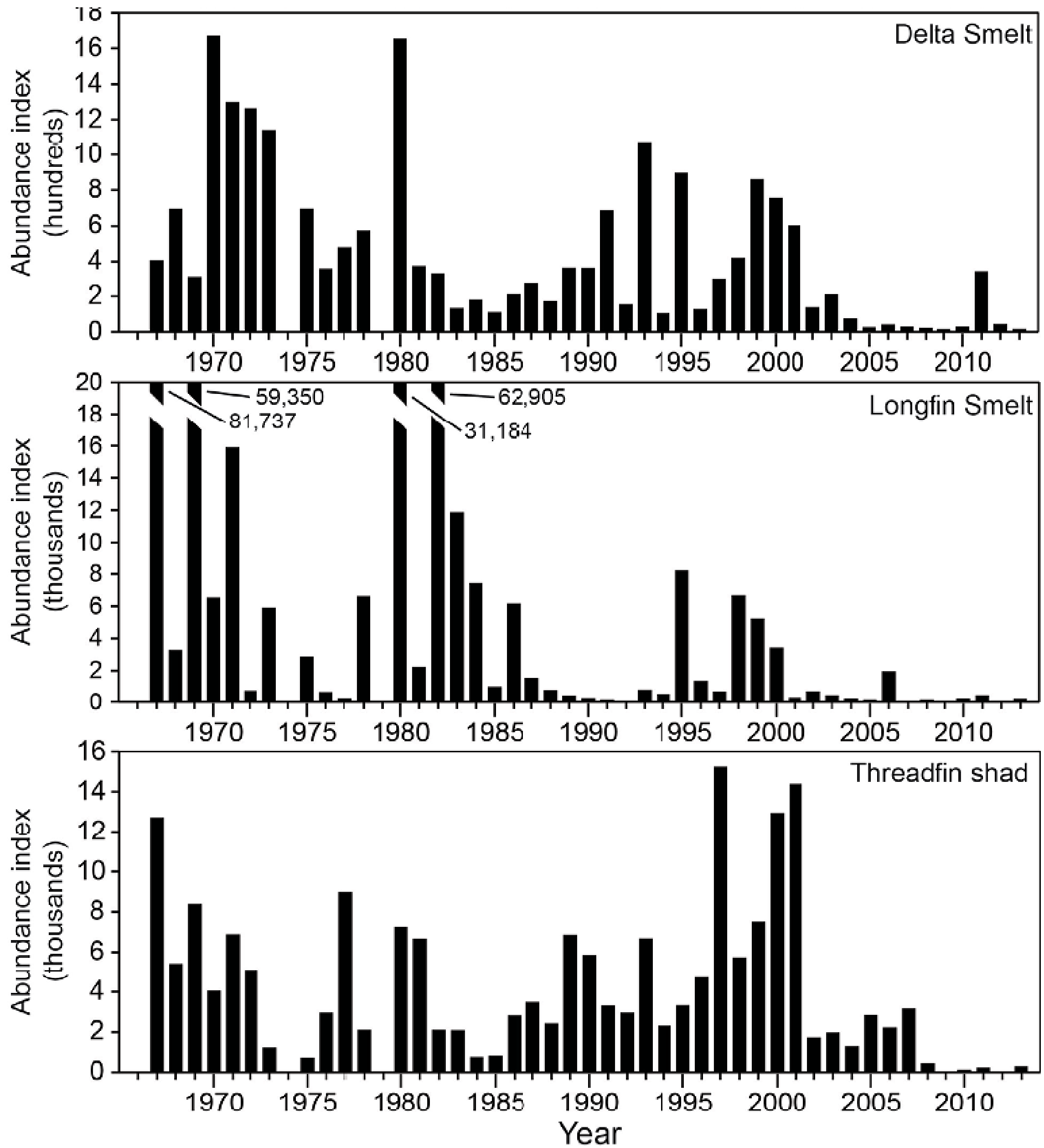
Figure C-73. Delta Smelt recruitment indices based on the annual adult, larval, juvenile, and subadult abundance indices provided by the Spring Kodiak Trawl (SKT, adults), 20 mm Survey (20 mm, larvae), Summer Townet Survey (TNS. juveniles), and Fall Midwater Trawl (FMWT, subadults)



Source: MAST report, figure 56, page 107

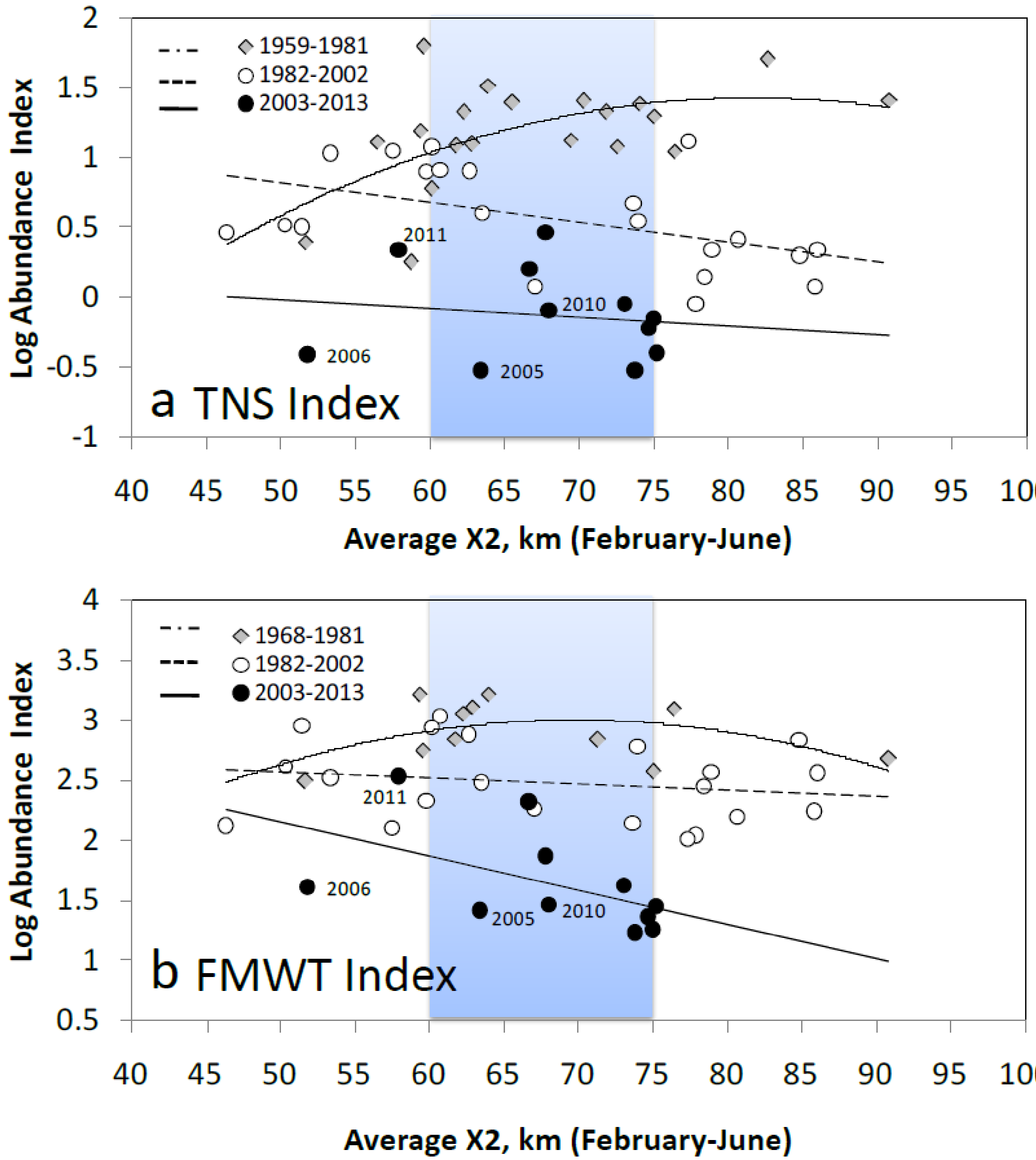
Figure C-74. Relationship of annual index of Delta Smelt abundance from the 20 mm survey (20 mm) with the annual indices from the Summer Townet Survey (TNS) and Fall Midwater Trawl (FMWT) survey. Year labels correspond to the comparison years of interest. The linear regressions with all index values log-transformed to address non-normal distributions in the raw data are: Log 20 mm index = 0.57 + 0.87(Log TNS index), n = 19, $p < 0.05$, $R^2 = 0.44$ and Log 20 mm index = 1.30 + 0.81(Log FMWT index), n = 19, $p < 0.05$, $R^2 = 0.27$.

C.6.10 Juveniles Abundance



Source: MAST report, figure 4, page 28

Figure C-75. Abundance indices from Fall Midwater Trawl for Delta Smelt, Longfin Smelt, age-0 Striped Bass, and Threadfin Shad. Missing bars indicate when an index could not be calculated.



Source: MAST report, figure 23, page 47

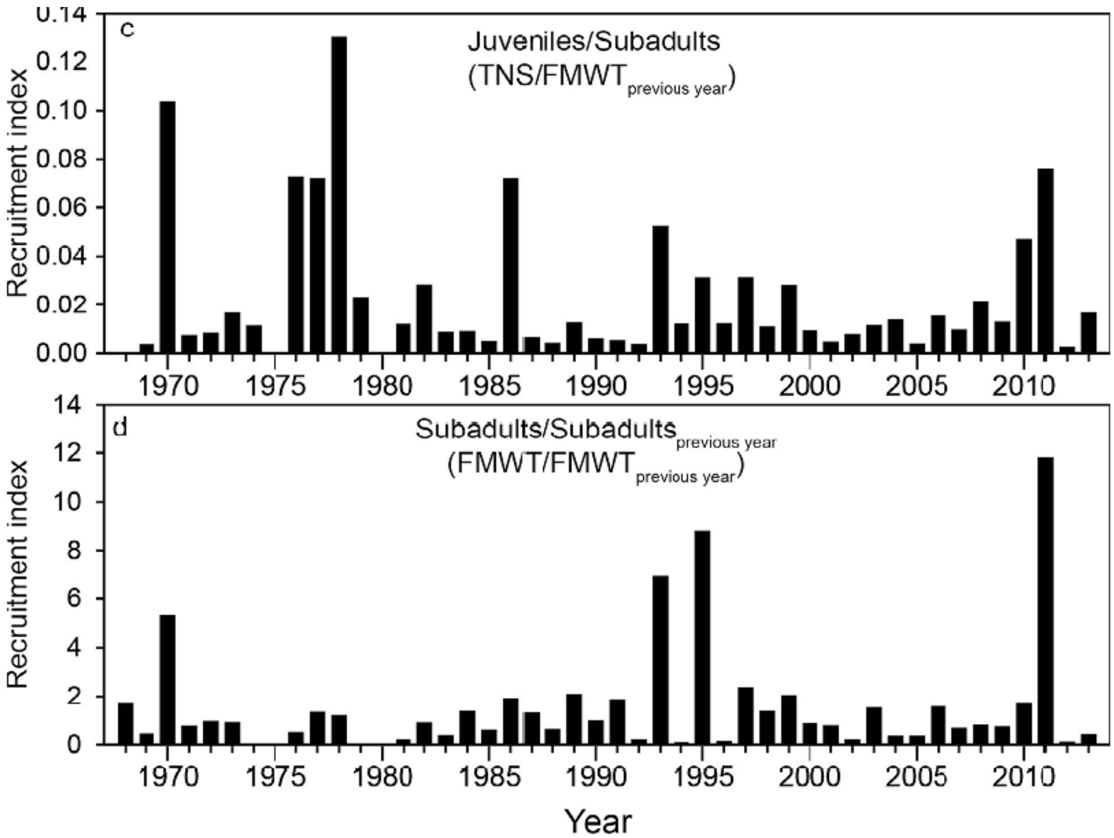
Figure C-76. Plots of the log transformed a) Delta Smelt Summer Townet Survey abundance index and b) Delta Smelt Fall Midwater Trawl Survey abundance index, in relation to monthly averaged daily X2 position from February to June. Lines are either simple linear least squares regression (lines) or quadratic regression (curves).

Table C-103. Summary of relationships between log-transformed annual abundance indices for four Delta Smelt life stages (response variable) and spring X2 (February-June, see text): Survey: see description of monitoring surveys in Chapter 3; Regression: least squares linear or quadratic regression: n, number of observations (years); P, statistical significance level for the model; R^2, coefficient of determination; adjusted R^2, R^2 adjusted for the number of predictor terms in the regression model. Bold font indicates statistically significant relationships.

Life Stage	Season	Survey	Period	Regression	n	P	R^2	Adjusted R^2
Juvenile	Summer	TNS	1959-2013	Linear	52	0.614	0.005	-
Juvenile	Summer	TNS	1959-1981	Linear	20	0.033	0.230	0.187
Juvenile	Summer	TNS	1959-1981	Quadratic	20	0.052	0.295	0.212
Juvenile	Summer	TNS	1982-2002	Linear	21	0.023	0.243	0.203
Juvenile	Summer	TNS	2002-2013	Linear	11	0.689	0.019	-
Subadult	Fall	FMWT	1968-2013	Linear	43	0.290	0.027	0.003
Subadult	Fall	FMWT	1968-1981	Linear	11	0.699	0.017	-
Subadult	Fall	FMWT	1968-1981	Quadratic	11	0.295	0.263	0.079
Subadult	Fall	FMWT	1982-2002	Linear	21	0.394	0.038	-
Subadult	Fall	FMWT	2002-2013	Linear	11	0.107	0.263	0.181

Source: MAST report, table 1, page 49

C.6.11 Juvenile Survival



Source: MAST report, figure 52, page 96

Figure C-77. Delta Smelt recruitment indices based on the annual adult, juvenile, and subadult abundance indices provided by the Spring Kodiak Trawl (SKT, adults), 20 mm Survey (20 mm, larvae), Summer Townet Survey (TNS. juveniles), and Fall Midwater Trawl (FMWT, subadults)

C.7 Longfin Smelt – Bay-Delta Distinct Population Segment

Longfin smelt are a small, euryhaline, anadromous, pelagic fish species that typically reach maturity at the end of their second year (Dryfoos 1965; Merz et al. 2013). Longfin smelt are found throughout the coastal Pacific Ocean from southern Alaska to central California (Moyle 2002) and in some Northern California watersheds (Garwood 2017), with the San Francisco Estuary population being the southernmost self-sustaining population along the Pacific Coast, and comprising the Bay-Delta DPS (Moyle 2002; Merz et al. 2013). Longfin smelt are listed as threatened under the California Endangered Species Act and designated as warranted, but precluded, under the federal Endangered Species Act.

Data from the status and trend fish monitoring surveys and Delta Regional Monitoring Program were used to characterize the distribution and timing of specific life stages of longfin smelt in the San Francisco Estuary by Merz et al. (2013). Overall, longfin smelt were observed from Tiburon in the central San Francisco Bay in the west to Colusa on the Sacramento River in the north, to Lathrop on the San Joaquin River to the east, and to Dumbarton Bridge in south San Francisco Bay to the south. Longfin smelt were frequently observed throughout a large portion of their range, including east San Pablo Bay, Suisun Marsh, Grizzly Bay, Suisun Bay, the Confluence, and the lower Sacramento River. Based on life-stage distribution, adult longfin smelt appear to have a larger upstream and downstream range than rearing juvenile longfin smelt (Merz et al. 2013).

The longfin smelt life cycle typically spans 2 to 3 years (Rosenfield 2010; Merz et al. 2013). Mature adult longfin smelt likely spawn near the low-salinity zone, where brackish and freshwater meet, during January to April (Grimaldo et al. 2017). Spawning habitat could also include freshwater locations in the lower Sacramento River, Cache Slough, eastern Suisun Bay, Suisun Marsh, Napa River, San Joaquin River, and tributaries to San Francisco Bay (Rosenfield 2010; Lewis et al. 2020). Recently, larval longfin smelt have been most prevalent in the Suisun, Confluence, and northern Delta regions and less common in the south Delta and Napa River regions. Larval fish densities in the San Francisco Estuary have substantially declined since 2009 (Eakin 2021). Juvenile fish rear in the upper San Francisco Estuary in brackish waters before migrating downstream to more saline waters, where they remain until adulthood (Hobbs et al. 2006; Rosenfield and Baxter 2007). Juveniles and subadults have been observed to migrate seasonally within the San Francisco Estuary, downstream during summer months, and upstream in the late fall and winter. It is possible that adult longfin smelt mature sexually as they migrate back toward spawning locations in freshwater. A shift in longfin smelt distribution toward freshwater was detected in late fall, continuing into the spring (Rosenfield 2010).

Some longfin smelt may reach sexual maturity in one year (Hieb pers. comm.). Most individuals die after spawning, but a few females may survive to spawn a second time (Moyle 1976). Older smelt spawn earlier in the season than younger ones, which may explain the extended spawning season. Longfin smelt smaller than the current approximate size for maturity (≥ 85-mm FL; i.e., juvenile fish, Figure C-78) are found within the Delta upstream of X2 during winter. Larval growth is slow, requiring almost 3 months to achieve 20-mm total length (c.f., months of first sizable abundance of yolk-sac larvae and 20-mm juveniles, Figure C-78; Lewis et al. 2017).

For the summary herein, three size classes were identified for longfin smelt, defined by FL (mm): larvae (<20-mm FL), juvenile (20-mm to 84-mm FL), and adult (>84-mm FL). Fish with no length measurement were excluded. Note that unmeasured fish that were collected alongside measured fish were converted to have fish length per “deltafish” data documentation.

The following surveys were used to evaluate the occurrence of Delta smelt in the Bay-Delta:

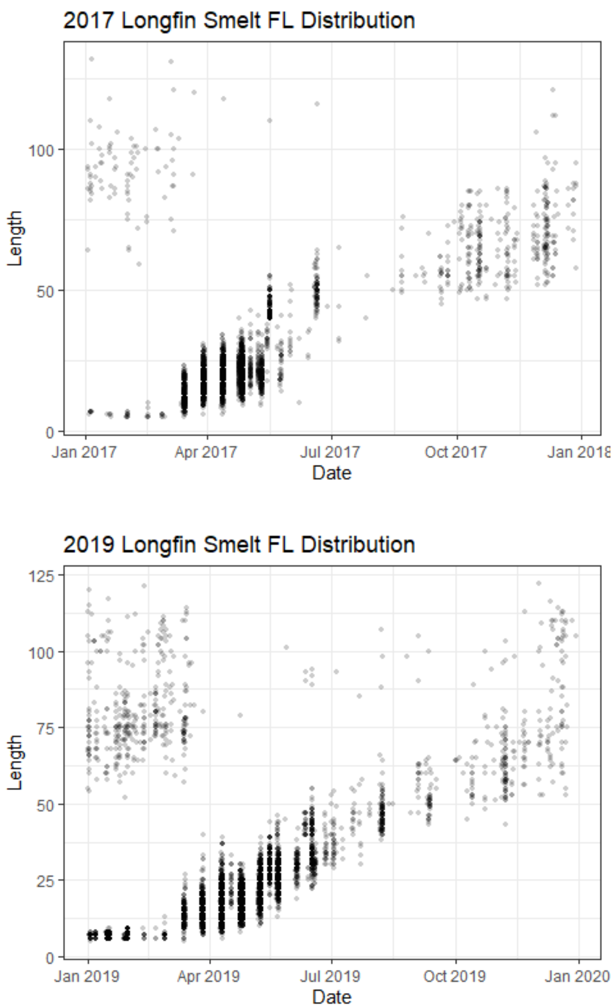
- San Francisco Bay Study (1994–2020)
- Suisun Marsh Study (1994–2021)
- Fall Midwater Trawl (1994–2020)
- Spring Kodiak Trawl (2002–2021)
- Delta Juvenile Fish Monitoring Program (1994–2020)

- Enhanced Delta Smelt Monitoring (2016–2021)
- 20-mm Survey (1995–2021)
- Smelt Larval Survey (2009–2021)
- Summer Townet Survey (1994–2021)

C.7.1 Brood Year Cutoff for the Life Stages

- Larvae: brood year = calendar year
- Juvenile: brood year = calendar year
- Adult: brood year starts on July 1 of current year to June 30 of the following year

Subadult and adult longfin smelt typically are present and caught from January to July, and then again starting October to November.



Source: Mahardja 2021.

Figure C-78. Distribution of Longfin Smelt by Fork Length and Date in Sample Years 2017, 2018, and 2019

The Bay-Delta can be split into three regions to better describe the spatial and temporal patterns of longfin smelt presence within the estuary (79).

The following regional cutoffs were used to evaluate the occurrence of Delta smelt within areas of the Bay-Delta:

1. San Joaquin River at Twitchell Island
2. San Joaquin River at Prisoners Point
3. Franks Tract
4. Holland Cut
5. Middle River

6. Upper San Joaquin River
7. Victoria Canal
8. Grant Line Canal and Old River
9. San Joaquin River near Stockton
10. Old River
11. Disappointment Slough
12. Rock Slough and Discovery Bay
13. Mildred Island

C.7.2 Adult Longfin Smelt

Adult longfin smelt generally are found in the Bay region from July through June of the following year; however, since 2014, the temporal distribution of adults has been more variable, and the sample size has shrunk to <20 individuals (Table C-104). Adult longfin smelt were detected in south San Francisco Bay, suggesting that spawning may occur in the South Bay tributaries (Merz et al. 2013).

From 2011–2019, during October–April, Lewis et al. (2020) observed consistent populations of sexually mature adult longfin smelt in marshes and sloughs of the Coyote Creek watershed in the south San Francisco Bay. Larvae were also observed in April and May in the same area, during the wet years of 2017 and 2019. This finding corroborates Merz et al. (2013) and suggests that spawning in this region is likely during all years, with recruitment success being limited by freshwater outflow. High densities of adult longfin smelt were often detected in restored tidal marshes and their adjacent sloughs, areas where other studies did not sample (Lewis et al. 2020). This is consistent with the hypothesis that shallow tidal wetlands of the many small watersheds throughout San Francisco and San Pablo Bays are used for spawning, rearing, and feeding habitat (Lewis et al. 2020).

Adult longfin smelt are generally found in the Suisun Bay and Marsh region from July through June of the following year. In recent years, occurrence has become more variable, but generally remained within this range (Table C-105).

Adult longfin smelt are generally found in the Central and South Delta regions from November to March (Table C-106). Most longfin smelt become anadromous typically during their second year of life, evidenced by low abundance of adults in the San Francisco Estuary in spring and summer months. Once mature, adults migrate back upstream in fall and winter. Adults were detected upstream of the Confluence, in the upper Sacramento River, Cache Slough, and Sacramento Deep Water Shipping Channel. Adults migrate into the upper Delta regions to spawn (Merz et al. 2013).

Table C-104. Adult (mature and immature adults of >84mm) Longfin Smelt Occurrence in Bays Region (Figure C-79)

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1994	07-06-1994	09-12-1994	11-07-1994	05-03-1995	05-04-1995	05-09-1995	80
1995	07-10-1995	07-10-1995	01-08-1996	06-06-1996	06-10-1996	06-10-1996	203
1996	07-03-1996	08-12-1996	11-06-1996	04-14-1997	05-12-1997	06-10-1997	439
1997	07-09-1997	09-08-1997	11-05-1997	05-11-1998	05-11-1998	06-08-1998	181
1998	11-02-1998	12-03-1998	12-07-1998	05-27-1999	06-09-1999	06-15-1999	173
1999	07-08-1999	07-12-1999	07-12-1999	04-05-2000	05-10-2000	06-13-2000	119
2000	07-07-2000	08-24-2000	12-12-2000	04-16-2001	05-10-2001	06-07-2001	196
2001	07-17-2001	10-25-2001	11-14-2001	04-04-2002	04-04-2002	05-14-2002	154
2002	09-09-2002	12-04-2002	01-08-2003	06-02-2003	06-25-2003	06-25-2003	114
2003	07-17-2003	08-07-2003	10-14-2003	04-15-2004	05-05-2004	05-11-2004	67
2004	09-09-2004	09-09-2004	12-06-2004	06-09-2005	06-09-2005	06-13-2005	62
2005	07-11-2005	10-05-2005	11-08-2005	05-06-2006	05-18-2006	06-14-2006	95
2006	07-19-2006	09-07-2006	11-08-2006	05-14-2007	05-14-2007	06-05-2007	65
2007	07-11-2007	07-11-2007	08-08-2007	03-05-2008	06-05-2008	06-05-2008	15
2008	08-07-2008	11-05-2008	12-02-2008	04-13-2009	05-06-2009	06-03-2009	62
2009	07-13-2009	07-13-2009	07-13-2009	03-08-2010	03-10-2010	05-12-2010	41
2010	07-08-2010	12-06-2010	01-13-2011	05-04-2011	05-04-2011	06-08-2011	39
2011	07-07-2011	10-10-2011	12-07-2011	04-09-2012	05-10-2012	06-07-2012	77
2012	07-05-2012	07-10-2012	09-06-2012	03-11-2013	06-11-2013	06-11-2013	46
2013	07-03-2013	07-03-2013	07-09-2013	02-11-2014	05-19-2014	05-19-2014	19
2014	12-03-2014	12-03-2014	12-03-2014	05-12-2015	05-12-2015	05-12-2015	7
2016	12-12-2016	12-12-2016	12-12-2016	06-21-2017	06-21-2017	06-21-2017	8
2017	10-31-2017	10-31-2017	11-29-2017	02-27-2018	02-28-2018	02-28-2018	16
2018	12-06-2018	12-06-2018	12-06-2018	06-12-2019	06-17-2019	06-17-2019	10
2019	07-22-2019	07-22-2019	08-07-2019	02-03-2020	02-03-2020	02-03-2020	17
2020	09-23-2020	09-23-2020	09-23-2020	11-12-2020	11-12-2020	11-12-2020	5

Note: The summary is of the cumulative percentage of catch during the period July 1–June 31. Note that this generally spans multiple adult cohorts of longfin smelt.

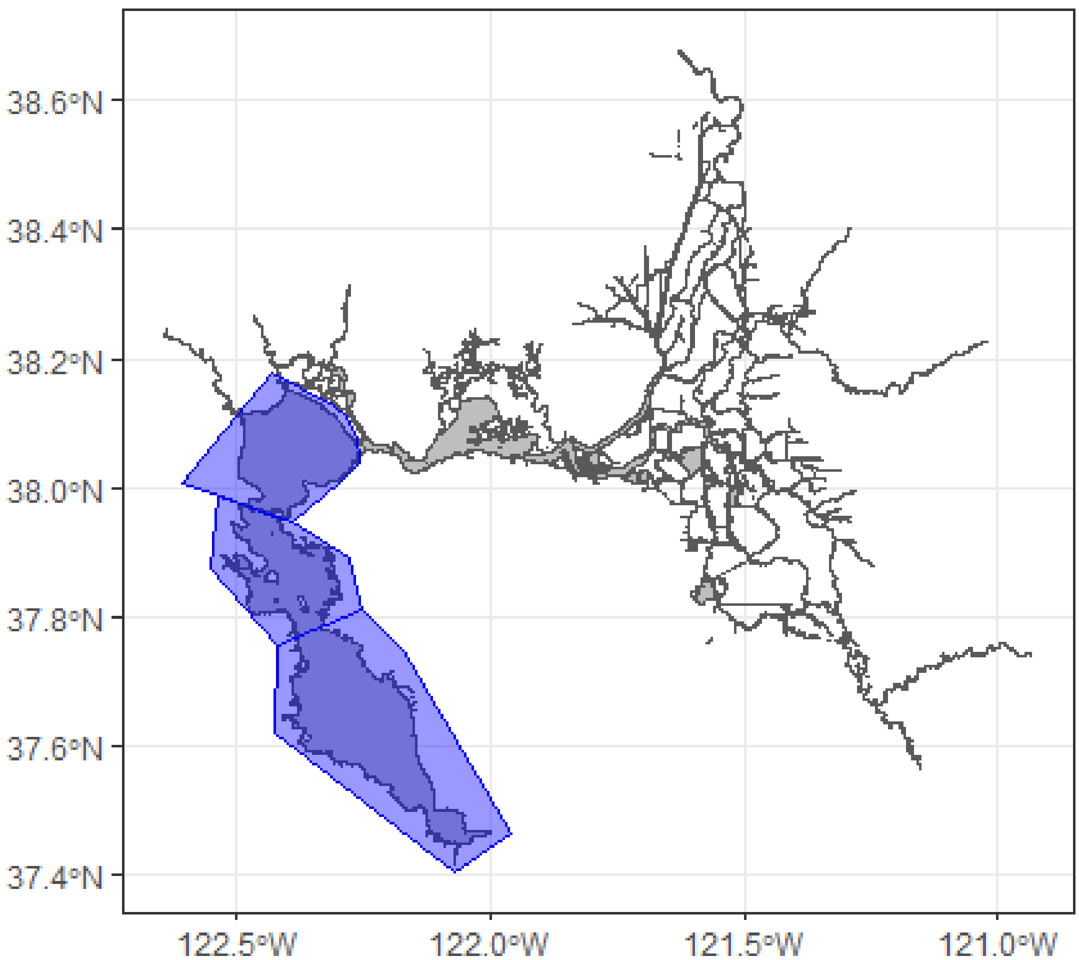


Figure C-79. The Extent of the Defined Bay Region of South Bay, San Francisco Bay, and San Pablo Bay

Table C-105. Adult (mature and immature adults of >84mm) Longfin Smelt Occurrence in North Delta and Suisun Bay Region. (Figure C-80)

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1994	07-03-1994	11-28-1994	12-07-1994	02-10-1995	03-06-1995	06-12-1995	1981
1995	08-09-1995	01-03-1996	01-03-1996	05-13-1996	05-13-1996	06-27-1996	2025
1996	07-10-1996	12-08-1996	12-17-1996	01-23-1997	03-03-1997	06-30-1997	11754
1997	07-15-1997	12-05-1997	12-09-1997	01-12-1998	01-27-1998	06-03-1998	1904
1998	09-16-1998	12-07-1998	12-09-1998	05-19-1999	06-08-1999	06-16-1999	1431
1999	07-07-1999	12-02-1999	12-16-1999	03-06-2000	05-09-2000	06-14-2000	2847
2000	07-11-2000	12-06-2000	12-15-2000	03-19-2001	04-02-2001	06-13-2001	1897

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
2001	07-03-2001	12-12-2001	12-19-2001	01-22-2002	03-04-2002	06-18-2002	6764
2002	07-10-2002	12-19-2002	12-24-2002	01-22-2003	01-31-2003	06-24-2003	1900
2003	07-14-2003	12-13-2003	12-17-2003	01-12-2004	03-02-2004	06-30-2004	4968
2004	07-07-2004	12-07-2004	12-16-2004	01-26-2005	02-14-2005	06-23-2005	1447
2005	07-25-2005	12-07-2005	12-09-2005	02-09-2006	02-22-2006	04-21-2006	732
2006	07-17-2006	11-11-2006	12-12-2006	04-20-2007	05-06-2007	06-13-2007	216
2007	08-13-2007	12-01-2007	12-11-2007	02-12-2008	03-03-2008	04-02-2008	744
2008	10-16-2008	12-08-2008	12-09-2008	03-18-2009	04-09-2009	06-25-2009	389
2009	07-07-2009	12-09-2009	12-16-2009	03-10-2010	03-15-2010	05-27-2010	593
2010	10-07-2010	12-17-2010	12-17-2010	01-12-2011	02-09-2011	06-07-2011	251
2011	08-02-2011	11-01-2011	12-05-2011	03-06-2012	03-13-2012	06-05-2012	252
2012	09-10-2012	12-12-2012	12-17-2012	01-11-2013	02-19-2013	05-13-2013	1089
2013	09-09-2013	11-12-2013	11-13-2013	02-26-2014	03-13-2014	05-15-2014	126
2014	09-03-2014	12-10-2014	12-19-2014	03-03-2015	04-07-2015	06-08-2015	121
2015	07-10-2015	07-10-2015	09-17-2015	02-12-2016	02-22-2016	02-24-2016	20
2016	11-08-2016	12-07-2016	12-19-2016	03-01-2017	03-06-2017	03-22-2017	82
2017	10-10-2017	11-07-2017	12-06-2017	05-03-2018	05-03-2018	05-23-2018	113
2018	08-15-2018	11-08-2018	12-04-2018	03-05-2019	03-15-2019	06-17-2019	181
2019	07-05-2019	10-28-2019	12-04-2019	03-02-2020	03-12-2020	06-11-2020	103
2020	07-07-2020	09-15-2020	10-15-2020	02-12-2021	03-03-2021	04-29-2021	38
2021	09-23-2021	09-23-2021	09-23-2021	09-23-2021	09-23-2021	09-23-2021	1

Note: The summary is of the cumulative percentage of catch during the period July 1–June 31. Note that this generally spans multiple adult cohorts of longfin smelt.

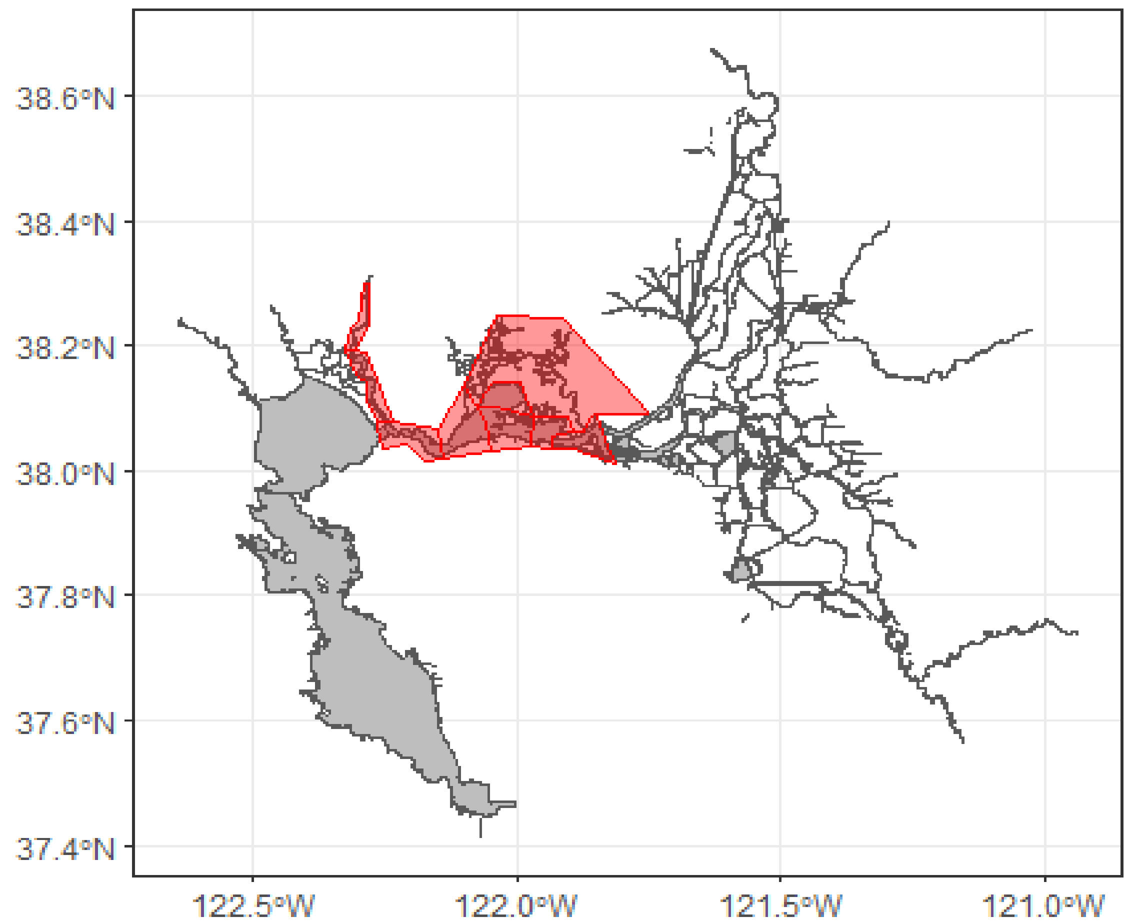


Figure C-80. The Extent of the Defined North Delta and Suisun Bay Region

Table C-106. Adult (mature and immature adults of >84mm) Longfin Smelt Occurrence in Central and South Delta Region (Figure C-81)

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1999	01-07-2000	01-07-2000	01-07-2000	01-07-2000	01-07-2000	01-07-2000	4
2000	12-06-2000	12-06-2000	12-06-2000	01-03-2001	01-03-2001	01-03-2001	5
2001	12-07-2001	12-07-2001	12-07-2001	04-15-2002	04-15-2002	04-15-2002	4
2003	01-05-2004	01-05-2004	01-05-2004	01-05-2004	01-05-2004	01-05-2004	2
2008	01-05-2009	01-05-2009	01-05-2009	01-05-2009	01-05-2009	01-05-2009	1
2009	12-15-2009	12-15-2009	12-15-2009	01-04-2010	01-04-2010	01-04-2010	3
2011	01-03-2012	01-03-2012	01-03-2012	01-03-2012	01-03-2012	01-03-2012	1
2012	01-07-2013	01-07-2013	01-07-2013	01-07-2013	01-07-2013	01-07-2013	2
2016	01-24-2017	01-24-2017	01-24-2017	01-24-2017	01-24-2017	01-24-2017	1

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
2019	12-02-2019	12-02-2019	12-02-2019	12-02-2019	12-02-2019	12-02-2019	1

Note: The summary is of the cumulative percentage of catch during the period July 1–June 31. Note that this generally spans multiple adult cohorts of longfin smelt.

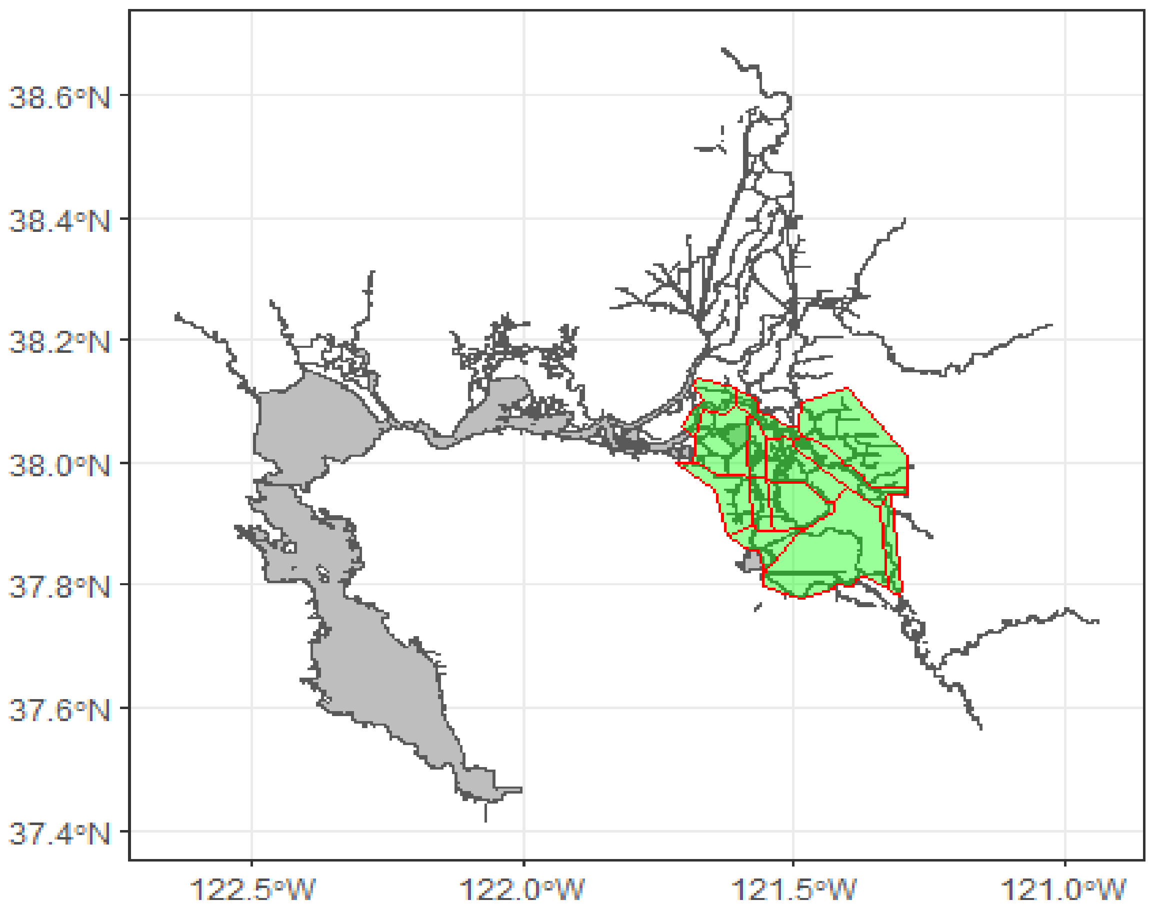


Figure C-81. The Extent of the Defined Central and South Region

C.7.3 Larval Longfin Smelt

Larval longfin smelt are generally found in the Bay region from March–May (Table C-107). Larvae were observed frequently in east San Pablo Bay and Grizzly Bay (Merz et al. 2013). Larvae were also observed in the marshes and sloughs of the Coyote Creek watershed in the south San Francisco Bay in April and May of wet years 2017 and 2019, after adults were observed in the same locations annually. This suggests that recruitment success is limited by freshwater outflow because high frequencies of larvae were not detected in non-wet years. The highest densities of larvae were within shallow, recently restored tidal marshes and their adjacent sloughs, which have not been sampled in other studies (Lewis et al. 2020). Larvae were predominantly found in Suisun Bay during low-flow years, and in the San Pablo and South Bays during high-flow years, reflecting the fluctuation in the low-salinity zone from freshwater outflow (Grimaldo et al. 2020).

The Napa River is also thought to be important spawning habitat; however, Eakin (2021) found that the Napa River had low densities of larvae, compared to Suisun Bay and Marsh and the Delta.

Larval longfin smelt are generally found in the Suisun Bay and Marsh region from January–June (Table C-108). According to the Smelt Larval Survey, larvae remain prevalent in the Suisun region (Eakin 2021). The low-salinity zone occurs within the Suisun Bay, making it an important nursery habitat for several native fish species, including longfin smelt (Meng and Matern 2001; Hobbs et al. 2006; Eakin 2021). Larval detection in the Suisun Bay and Marsh region was consistently high before 2014, becoming more variable after 2014 (Eakin 2021). Larvae were predominantly found in Suisun Bay during low-flow years and in San Pablo and South Bays during high-flow years, reflecting the fluctuation in the low-salinity zone from freshwater outflow (Grimaldo et al. 2020).

Larval longfin smelt are generally found in the Central and South Delta regions from January–June (Table C-109); Merz et al. 2013). Larvae were frequently detected upstream of the Confluence, in the lower Sacramento River, upper Sacramento River, Cache Slough, Sacramento Deep Water Shipping Channel, and lower San Joaquin River. Larvae were caught less frequently in the east and south Delta regions (Merz et al. 2013).

Detection of larval longfin smelt in the south Delta, a region that includes the San Joaquin River and its distributaries, has been relatively low since 2009, and sampling from the Fall Midwater Trawl Survey and Smelt Larval Survey has shown density declines in the years since (Eakin 2021). Historically, increases in larval densities have been positively correlated with freshwater outflows from the Delta (Kimmerer et al. 2009); however, the moderate increases in larval densities observed in the wet years of 2017 and 2019 remained lower than larval densities observed before the observed larval decline in 2014. Specifically, larval densities in the northern Delta region decreased significantly. The increase of potential spawning stock that was seen in 2017 was not reflected in a significant increase in larval density in 2019 (Eakin 2021).

Table C-107. Larval (<20 mm FL) Longfin Smelt Occurrence in Bays Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1995	04-28-1995	04-28-1995	04-28-1995	05-26-1995	05-26-1995	06-09-1995	146
1996	04-14-1996	04-14-1996	04-14-1996	04-17-1996	04-17-1996	05-29-1996	2759
1997	04-18-1997	04-18-1997	04-18-1997	04-18-1997	04-18-1997	04-18-1997	14
1998	04-10-1998	04-10-1998	04-10-1998	05-08-1998	05-08-1998	06-05-1998	398
1999	04-15-1999	04-15-1999	04-15-1999	05-13-1999	05-13-1999	06-25-1999	43
2000	03-24-2000	03-24-2000	03-24-2000	05-04-2000	05-04-2000	09-11-2000	298
2001	03-23-2001	03-23-2001	03-23-2001	04-06-2001	04-06-2001	04-20-2001	26

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
2002	03-22-2002	03-22-2002	03-22-2002	03-22-2002	06-01-2002	06-01-2002	13
2004	04-15-2004	04-15-2004	04-15-2004	04-15-2004	04-15-2004	04-15-2004	1
2005	04-02-2005	04-02-2005	04-02-2005	04-29-2005	04-29-2005	04-29-2005	8
2006	03-24-2006	04-22-2006	04-22-2006	05-06-2006	05-19-2006	05-19-2006	7006
2007	03-30-2007	03-30-2007	03-30-2007	04-13-2007	04-13-2007	04-13-2007	6
2008	03-20-2008	03-20-2008	03-20-2008	03-20-2008	03-20-2008	03-20-2008	3
2009	03-13-2009	03-13-2009	03-13-2009	03-26-2009	04-24-2009	05-08-2009	31
2010	03-17-2010	03-17-2010	03-17-2010	04-14-2010	04-14-2010	05-26-2010	37
2011	03-17-2011	04-25-2011	04-25-2011	04-25-2011	04-25-2011	05-10-2011	2972
2012	03-14-2012	03-14-2012	03-14-2012	05-23-2012	05-23-2012	05-23-2012	7
2013	04-10-2013	04-10-2013	04-10-2013	04-24-2013	04-24-2013	04-24-2013	8
2017	03-15-2017	03-15-2017	03-15-2017	04-26-2017	04-26-2017	05-10-2017	1530
2018	03-28-2018	03-28-2018	03-28-2018	03-28-2018	03-28-2018	03-28-2018	1
2019	03-13-2019	03-13-2019	03-27-2019	04-24-2019	04-24-2019	05-22-2019	1784

Table C-108. Larval (<20 mm FL) Longfin Smelt Occurrence in North Delta and Suisun Bay Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1994	03-18-1994	03-18-1994	03-18-1994	04-24-1994	04-24-1994	04-24-1994	4
1995	04-27-1995	04-27-1995	04-27-1995	05-12-1995	05-25-1995	06-27-1995	386
1996	04-12-1996	04-13-1996	04-16-1996	05-13-1996	05-14-1996	06-29-1996	9816
1997	04-03-1997	04-04-1997	04-04-1997	04-30-1997	04-30-1997	06-01-1997	8349
1998	04-10-1998	04-10-1998	04-10-1998	04-10-1998	04-10-1998	06-19-1998	10706
1999	04-14-1999	04-15-1999	04-15-1999	04-30-1999	05-14-1999	07-23-1999	28318
2000	03-22-2000	03-24-2000	04-06-2000	04-21-2000	04-22-2000	06-17-2000	101153
2001	03-20-2001	03-22-2001	03-23-2001	04-20-2001	04-20-2001	07-12-2001	50238
2002	03-19-2002	03-20-2002	03-21-2002	04-17-2002	04-18-2002	07-31-2002	26821
2003	03-25-2003	03-26-2003	03-26-2003	04-11-2003	04-25-2003	06-07-2003	13420
2004	03-30-2004	04-01-2004	04-01-2004	04-16-2004	04-28-2004	06-10-2004	7478
2005	03-15-2005	03-17-2005	03-18-2005	04-27-2005	04-29-2005	06-15-2005	5600
2006	03-23-2006	03-24-2006	03-24-2006	06-02-2006	06-03-2006	08-16-2006	711
2007	03-14-2007	03-17-2007	03-17-2007	04-25-2007	04-25-2007	05-12-2007	2156

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
2008	03-05-2008	03-18-2008	03-19-2008	04-30-2008	04-30-2008	06-12-2008	12284
2009	01-06-2009	01-22-2009	02-03-2009	04-08-2009	04-21-2009	06-11-2009	19047
2010	01-04-2010	01-19-2010	01-21-2010	04-14-2010	04-14-2010	05-26-2010	26944
2011	01-18-2011	01-31-2011	02-01-2011	05-09-2011	05-11-2011	06-30-2011	17932
2012	01-09-2012	01-10-2012	01-23-2012	03-28-2012	05-08-2012	06-06-2012	16715
2013	01-02-2013	01-29-2013	02-11-2013	04-23-2013	04-24-2013	07-03-2013	47892
2014	01-06-2014	01-21-2014	01-22-2014	03-21-2014	04-03-2014	05-13-2014	5867
2015	01-07-2015	01-08-2015	01-22-2015	04-01-2015	04-08-2015	05-11-2015	1098
2016	01-04-2016	01-20-2016	02-02-2016	04-26-2016	04-26-2016	05-23-2016	1266
2017	01-04-2017	03-16-2017	03-16-2017	05-10-2017	05-11-2017	06-07-2017	1308
2018	01-03-2018	01-18-2018	01-31-2018	04-24-2018	04-24-2018	06-05-2018	4432
2019	01-03-2019	01-17-2019	01-30-2019	05-10-2019	05-10-2019	06-05-2019	4253
2020	01-08-2020	01-21-2020	01-21-2020	04-22-2020	04-23-2020	05-20-2020	3545
2021	01-12-2021	01-26-2021	02-10-2021	04-21-2021	05-05-2021	06-03-2021	5079

Table C-109. Larval (<20 mm FL) Longfin Smelt Occurrence in Central and South Delta Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1996	04-24-1996	04-30-1996	04-30-1996	04-30-1996	04-30-1996	04-30-1996	69
1997	03-31-1997	04-14-1997	04-14-1997	04-28-1997	04-28-1997	05-12-1997	91
1999	04-12-1999	04-12-1999	04-12-1999	04-26-1999	04-26-1999	04-26-1999	6
2000	04-03-2000	04-03-2000	04-03-2000	05-22-2000	06-12-2000	06-12-2000	85
2001	03-19-2001	03-19-2001	03-19-2001	04-30-2001	05-01-2001	05-29-2001	143
2002	03-18-2002	03-18-2002	04-02-2002	04-29-2002	04-29-2002	05-28-2002	1292
2003	03-24-2003	03-24-2003	03-24-2003	04-21-2003	04-21-2003	05-05-2003	135
2004	03-29-2004	03-29-2004	03-29-2004	04-13-2004	04-26-2004	04-26-2004	14
2005	03-14-2005	03-14-2005	03-14-2005	03-14-2005	03-28-2005	06-21-2005	106
2006	04-18-2006	04-18-2006	04-18-2006	05-01-2006	05-01-2006	05-01-2006	9
2007	03-26-2007	03-26-2007	03-26-2007	04-23-2007	04-23-2007	04-23-2007	12
2008	03-17-2008	04-01-2008	04-01-2008	04-28-2008	04-29-2008	05-27-2008	121
2009	01-05-2009	01-20-2009	01-20-2009	03-02-2009	04-06-2009	04-21-2009	437
2010	01-04-2010	01-04-2010	01-04-2010	03-01-2010	03-23-2010	05-10-2010	605

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
2011	01-18-2011	01-31-2011	01-31-2011	02-14-2011	02-28-2011	03-22-2011	297
2012	01-09-2012	01-09-2012	01-09-2012	03-12-2012	03-19-2012	05-07-2012	705
2013	01-02-2013	01-28-2013	01-28-2013	04-08-2013	04-09-2013	06-03-2013	1130
2014	01-06-2014	01-21-2014	01-21-2014	03-18-2014	04-01-2014	04-29-2014	632
2015	01-05-2015	02-02-2015	02-02-2015	04-27-2015	04-27-2015	04-27-2015	110
2016	01-04-2016	01-04-2016	01-04-2016	02-16-2016	03-14-2016	03-29-2016	49
2017	01-17-2017	01-17-2017	01-17-2017	03-13-2017	03-13-2017	03-13-2017	2
2018	01-02-2018	01-02-2018	01-02-2018	02-12-2018	02-12-2018	02-12-2018	16
2019	01-02-2019	01-02-2019	01-02-2019	01-28-2019	02-11-2019	02-11-2019	11
2020	01-06-2020	01-06-2020	01-21-2020	03-17-2020	03-31-2020	12-28-2020	108
2021	01-11-2021	01-25-2021	01-25-2021	04-05-2021	04-20-2021	05-18-2021	218

C.7.4 Juvenile Longfin Smelt

Juvenile longfin smelt are generally found in the Bay-Delta region year-round (January–December); however, during the sampling season of 2021, just one juvenile longfin smelt was captured (Table C-110). Prior to 2014, juveniles were frequently caught in San Pablo Bay, central San Francisco Bay, and subadults (described by Merz et al. 2013 as 41-100mm FL) in the south San Francisco Bay (Merz et al. 2013).

Juvenile longfin smelt are generally found in the Suisun Bay and Marsh region year-round from January to December (Table C-111). Juvenile locations fluctuate between the bays and Suisun Marsh in relation to the low-salinity zone (Merz et al. 2013). The distribution of juveniles tends to follow the low-salinity zone (Dege and Brown 2004), which shifts downstream during wet years and upstream during dry years (Grimaldo et al. 2020). Suisun Bay has been identified as a critical nursery habitat for longfin smelt, providing ideal rearing conditions (Merz et al. 2013).

Juvenile longfin smelt are generally found in the Central and South Delta regions year-round, from January to December; however, in 2020 and 2021 juveniles were only detected until June (Table C-112). The location of longfin smelt when they become juveniles is dependent on spawning location, outflow from the Delta, and spring tides. Juveniles migrate seasonally, downstream during the summer and upstream during the late fall and winter (Rosenfield et al. 2010).

Table C-110. Juvenile (20-84 mm FL) Longfin Smelt Occurrence in Bays Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1994	02-04-1994	02-04-1994	02-04-1994	12-05-1994	12-05-1994	12-05-1994	288
1995	01-05-1995	05-04-1995	05-09-1995	09-11-1995	11-14-1995	12-13-1995	14009

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1996	01-08-1996	01-08-1996	02-14-1996	12-09-1996	12-11-1996	12-12-1996	1390
1997	01-07-1997	02-04-1997	03-04-1997	12-01-1997	12-01-1997	12-09-1997	969
1998	01-06-1998	02-11-1998	05-08-1998	11-02-1998	12-02-1998	12-08-1998	3927
1999	01-13-1999	02-08-1999	04-21-1999	09-07-1999	09-30-1999	11-29-1999	6184
2000	01-24-2000	02-09-2000	03-24-2000	11-17-2000	12-12-2000	12-15-2000	2352
2001	01-10-2001	01-10-2001	01-10-2001	09-10-2001	10-31-2001	12-11-2001	425
2002	02-14-2002	03-14-2002	04-06-2002	11-06-2002	12-04-2002	12-09-2002	638
2003	01-08-2003	01-09-2003	01-09-2003	12-01-2003	12-03-2003	12-18-2003	428
2004	01-07-2004	01-07-2004	01-13-2004	12-06-2004	12-07-2004	12-14-2004	432
2005	01-05-2005	01-05-2005	01-11-2005	10-11-2005	12-13-2005	12-20-2005	402
2006	01-09-2006	04-22-2006	04-22-2006	09-05-2006	10-04-2006	12-11-2006	7929
2007	01-08-2007	01-08-2007	01-08-2007	09-13-2007	10-10-2007	12-05-2007	308
2008	01-28-2008	06-05-2008	06-10-2008	12-02-2008	12-04-2008	12-04-2008	237
2009	01-07-2009	01-12-2009	01-13-2009	07-13-2009	10-12-2009	12-09-2009	243
2010	01-06-2010	01-19-2010	02-09-2010	12-06-2010	12-06-2010	12-09-2010	151
2011	01-12-2011	02-10-2011	03-14-2011	12-05-2011	12-07-2011	12-12-2011	1386
2012	01-05-2012	01-05-2012	01-05-2012	11-06-2012	11-06-2012	12-10-2012	328
2013	01-09-2013	01-09-2013	02-06-2013	12-04-2013	12-09-2013	12-10-2013	334
2014	01-13-2014	01-13-2014	01-13-2014	11-12-2014	12-04-2014	12-09-2014	66
2015	01-07-2015	01-07-2015	01-07-2015	06-09-2015	10-12-2015	10-12-2015	31
2016	05-04-2016	05-04-2016	05-04-2016	09-07-2016	11-29-2016	12-13-2016	32
2017	02-09-2017	03-29-2017	03-29-2017	07-07-2017	10-17-2017	12-13-2017	1083
2018	02-26-2018	02-27-2018	05-29-2018	12-10-2018	12-11-2018	12-11-2018	406
2019	01-14-2019	03-13-2019	03-27-2019	09-12-2019	11-07-2019	12-11-2019	945
2020	01-28-2020	06-23-2020	07-27-2020	11-05-2020	11-05-2020	12-01-2020	321
2021	02-22-2021	02-22-2021	02-22-2021	02-22-2021	02-22-2021	02-22-2021	1

Table C-111. Juvenile (20-84 mm FL) Longfin Smelt Occurrence in North Delta and Suisun Bay Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1994	01-03-1994	01-11-1994	03-08-1994	06-14-1994	06-17-1994	12-31-1994	10263
1995	01-03-1995	04-28-1995	05-12-1995	12-06-1995	12-20-1995	12-28-1995	9228

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1996	01-03-1996	01-04-1996	01-11-1996	06-29-1996	07-29-1996	12-30-1996	15906
1997	01-17-1997	04-04-1997	04-05-1997	12-06-1997	12-20-1997	12-31-1997	11208
1998	01-03-1998	04-10-1998	04-10-1998	11-24-1998	12-15-1998	12-31-1998	24423
1999	01-01-1999	04-15-1999	04-16-1999	08-16-1999	10-05-1999	12-31-1999	41724
2000	01-02-2000	04-06-2000	04-07-2000	06-21-2000	09-13-2000	12-20-2000	64002
2001	01-03-2001	02-06-2001	03-24-2001	05-30-2001	06-03-2001	12-31-2001	25079
2002	01-02-2002	03-22-2002	03-22-2002	06-15-2002	10-20-2002	12-31-2002	20473
2003	01-02-2003	03-26-2003	03-28-2003	05-22-2003	10-13-2003	12-31-2003	8436
2004	01-02-2004	01-27-2004	02-11-2004	08-03-2004	12-09-2004	12-31-2004	4440
2005	01-02-2005	01-05-2005	01-24-2005	06-09-2005	10-07-2005	12-28-2005	2407
2006	01-10-2006	03-24-2006	03-24-2006	10-11-2006	11-15-2006	12-31-2006	1364
2007	01-03-2007	01-09-2007	01-22-2007	05-26-2007	06-07-2007	12-30-2007	1162
2008	01-02-2008	03-19-2008	03-19-2008	06-04-2008	06-18-2008	12-24-2008	11480
2009	01-02-2009	03-12-2009	03-26-2009	06-11-2009	06-16-2009	12-23-2009	2672
2010	01-05-2010	03-16-2010	03-17-2010	05-13-2010	05-25-2010	12-06-2010	4972
2011	01-05-2011	03-16-2011	04-14-2011	06-30-2011	12-05-2011	12-30-2011	4531
2012	01-03-2012	02-07-2012	03-27-2012	06-13-2012	06-27-2012	12-21-2012	1589
2013	01-04-2013	04-09-2013	04-09-2013	06-04-2013	06-11-2013	12-11-2013	20106
2014	01-06-2014	03-19-2014	03-20-2014	05-15-2014	06-18-2014	12-31-2014	1315
2015	01-02-2015	01-06-2015	01-07-2015	05-12-2015	05-26-2015	06-09-2015	434
2016	02-03-2016	03-10-2016	03-30-2016	05-11-2016	05-24-2016	12-27-2016	760
2017	01-03-2017	03-30-2017	03-30-2017	10-18-2017	12-05-2017	12-28-2017	1283
2018	01-04-2018	02-07-2018	03-22-2018	08-09-2018	12-20-2018	12-30-2018	1676
2019	01-01-2019	03-28-2019	04-11-2019	06-06-2019	06-26-2019	12-23-2019	4328
2020	01-03-2020	04-06-2020	04-23-2020	06-17-2020	06-22-2020	12-28-2020	1667
2021	01-04-2021	04-07-2021	04-07-2021	05-19-2021	05-19-2021	08-11-2021	5990

Table C-112. Juvenile (20-84 mm FL) Longfin Smelt Occurrence in Central and South Delta Region

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1994	06-15-1994	06-15-1994	06-15-1994	06-15-1994	06-15-1994	06-15-1994	1
1995	12-04-1995	12-04-1995	12-04-1995	12-04-1995	12-04-1995	12-04-1995	1

Cohort Year	0.0%	5.0%	10.0%	90.0%	95.0%	100.0%	Sample Size
1996	04-25-1996	04-25-1996	04-25-1996	04-30-1996	04-30-1996	04-30-1996	5
1997	04-14-1997	04-14-1997	04-14-1997	05-12-1997	05-12-1997	05-12-1997	8
1999	04-12-1999	04-12-1999	04-12-1999	05-11-1999	05-11-1999	05-11-1999	4
2000	05-01-2000	05-01-2000	05-01-2000	12-06-2000	12-06-2000	12-06-2000	3
2001	04-16-2001	04-16-2001	04-16-2001	06-11-2001	06-11-2001	06-11-2001	6
2002	03-18-2002	04-15-2002	04-15-2002	04-29-2002	05-13-2002	05-28-2002	779
2003	03-24-2003	04-07-2003	04-07-2003	04-21-2003	04-22-2003	04-22-2003	23
2004	04-12-2004	04-12-2004	04-12-2004	06-07-2004	06-07-2004	06-07-2004	5
2005	03-14-2005	03-14-2005	03-14-2005	03-14-2005	03-14-2005	03-14-2005	14
2006	05-01-2006	05-01-2006	05-01-2006	05-01-2006	05-01-2006	05-01-2006	1
2007	06-04-2007	06-04-2007	06-04-2007	06-04-2007	06-04-2007	06-04-2007	1
2008	04-14-2008	04-14-2008	04-14-2008	06-30-2008	06-30-2008	06-30-2008	4
2010	03-29-2010	03-29-2010	03-29-2010	05-10-2010	05-10-2010	05-10-2010	2
2012	03-12-2012	03-12-2012	03-12-2012	04-23-2012	04-23-2012	04-23-2012	6
2013	03-25-2013	04-08-2013	04-22-2013	06-10-2013	06-17-2013	06-26-2013	44
2014	03-18-2014	03-18-2014	03-18-2014	04-28-2014	04-28-2014	04-28-2014	24
2015	04-06-2015	04-06-2015	04-06-2015	04-27-2015	04-27-2015	04-27-2015	9
2017	02-10-2017	02-10-2017	02-10-2017	03-07-2017	03-07-2017	03-07-2017	3
2019	02-19-2019	02-19-2019	02-19-2019	12-04-2019	12-04-2019	12-04-2019	3
2020	04-27-2020	04-27-2020	04-27-2020	04-27-2020	04-27-2020	04-27-2020	1
2021	04-05-2021	04-05-2021	04-05-2021	05-18-2021	05-18-2021	05-18-2021	9

C.7.5 Adult Abundance

For information on adult Longfin Smelt abundance, see Bay Study Age-2 index values in the table below.

C.7.6 Larvae Abundance

No observations available.

C.7.7 Larvae Survival

C.7.8 Juvenile Abundance

Table C-113. Bay Study Age-0 and Age-2 index values by water year 1980 – 2021

Water Year	Bay Study Age-0 index	Bay Study Age-2 index
1980	159,556	1,339
1981	3,049	383
1982	278,517	1,656
1983	28,756	1,891
1984	36,774	4,925
1985	7,341	1,939
1986	18,489	1,384
1987	2,428	1,786
1988	1,409	3,571
1989	1,054	942
1990	713	688
1991	188	351
1992	495	152
1993	6,046	11
1994	2,847	414
1995	354,186	504
1996	5,856	248
1997	7,639	1,075
1998	41,729	89
1999	58,510	748
2000	14,203	704
2001	1,460	1,054
2002	9,653	1,752
2003	2,119	739
2004	2,418	686
2005	4,538	569
2006	12,149	188
2007	2,039	447
2008	3,681	196
2009	647	272
2010	748	197

Water Year	Bay Study Age-0 index	Bay Study Age-2 index
2011	7,833	305
2012	1,284	733
2013	8,495	301
2014	1,247	32
2015	384	120
2016	No index	No index
2017	3,948	40
2018	3,387	No index
2019	16,132	146
2020	6,473	No index
2021	6,222	43

Source: California Department of Fish and Wildlife's San Francisco Bay Study and the Interagency Ecological Program for the San Francisco Estuary, unpublished data.

C.8 Green Sturgeon – Southern Distinct Population Segment

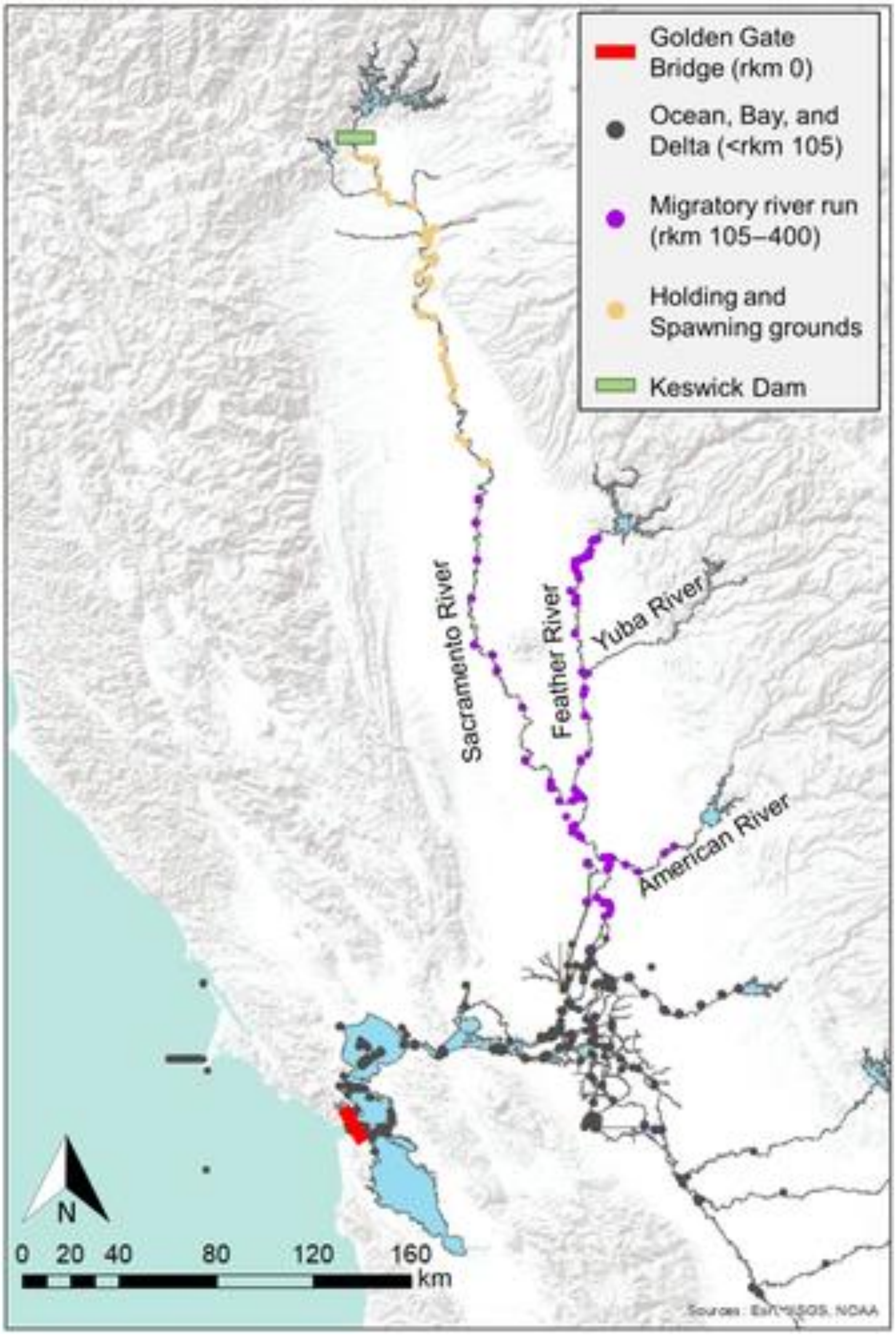
Green sturgeon spend most of their life in the Pacific Ocean, along the western coast of North America, returning to the Sacramento River watershed to spawn every 4 years, on average (Miller et al. 2020; Colborne et al. 2022). Two distinct population segments of North American green sturgeon are recognized, the federally threatened southern Distinct Population Segment (sDPS) and the northern Distinct Population Segment (nDPS), Species of Special Concern The two DPSs are differentiated by genetics and spawning-site fidelity, with the sDPS spawning in the Sacramento River basin, and the nDPS spawning in the Rogue River, in Oregon, Klamath River in Northern California, and additional evidence of nDPS spawning in the Eel River in Norther California (Benson et al. 2007; Stillwater Sciences and Wiyot Tribe Natural Resources Department 2017; National Marine Fisheries Service 2018). Nonspawning green sturgeon adults of the sDPS generally occur in marine waters from Graves Harbor, Alaska, to Monterey Bay, California; however, adult green sturgeon are detected in the San Francisco Estuary and Delta year round (Moser and Lindley 2007; Lindley et al. 2008, 2011; Schreier et al. 2016; Miller et al. 2020). Presently, the only known recurring spawning population of the sDPS green sturgeon occurs in the Sacramento River in Northern California, part of the San Francisco Estuary watershed; however, during the 2011 high-spring outflow and wet water year, green sturgeon were documented to have spawned in the Feather River (Seesholtz et al. 2015) and possibly the Yuba River (Poytress et al. 2015). Seesholtz et al. (2015) found that an area near the Thermalito Afterbay Outlet may be important green sturgeon spawning habitat and that the Feather River has potential to provide a second production area for the sDPS green sturgeon population. Green sturgeon have also been observed in the Stanislaus and San Joaquin Rivers (Anderson et al. 2018; Root et al. 2020). Green sturgeon in the San Francisco Estuary watershed represent the most southerly spawning population of the species (Heublein et al. 2017a).

The majority of green sturgeon spawning occurs in the upper mainstem of the lower Sacramento River. Inmigration takes place during spring, peaking in March (Colborne et al. 2022). Spawning occurs from April–June, but can extend into summer months with periodic late-summer and fall spawning (Heublein et al. 2017b). Many adult green sturgeon spend the summer months in the river near the spawning grounds, with outmigration to the Pacific Ocean occurring bimodally, either in the late spring months or late summer through fall months. Green sturgeon typically remain in the Pacific Ocean between spawning migration events (Erickson and Webb 2007); however, adult green sturgeon (and white sturgeon) are present in the system year-round (Miller et al. 2020).

C.8.1 Adult Delta Migration, River Spawning, and Holding

Since 2004, more than 300 acoustic receivers have been deployed throughout the Sacramento River, Bay-Delta, San Francisco Estuary, and nearshore Pacific Coast to monitor movements of acoustic-tagged fish, including salmonids and sturgeon (Figure C-82). Once entering the San Francisco Estuary at Golden Gate Bridge, green sturgeon travel more than 400 river kilometers (RKM) through the Delta and Sacramento River to the spawning grounds (Figure C-82; Colborne et al. 2022). Colborne et al. (2022) synthesized telemetry detection records between 2006–2018 for 117 paired (i.e., each individual fish detected during up-river and down-river movement) migration events. From 2006–2018, 151 tagged green sturgeon were detected on receivers in the San Francisco Estuary watershed. The mean date of immigration events was March 22, the mean date of outmigration was October 16, and individuals were present in the Sacramento River for an average of 204 days.

Based on adult and egg presence, spawning occurs in water depths of about 8–9 meters (Wyman et al. 2018) from the Glen Colusa Irrigation District Diversion, near Hamilton City, California, up to Keswick Dam in Redding, California (Thomas et al. 2014; Klimley et al. 2015; Poytress et al. 2015).



Source: Colborne et al. 2022.

Figure C-82. Locations of Acoustic Receives Throughout the California Central Valley, San Francisco Estuary, and Nearby Pacific Ocean

After spawning in the spring–early summer, green sturgeon may immediately outmigrate, primarily in June, or after September in the late fall–early winter months. Outmigration may be linked to flow rates based on the observed early and late outmigration groups. It is theorized that when spring flows are suboptimal, many green sturgeon are likely to hold in the river for several months (Colborne et al. 2022). As drought conditions continue, the number of late outmigrations may increase (Colborne et al. 2022). Miller et al. (2020) observed green sturgeon in the Sacramento River during all months of the year, potentially due to late outmigrants overlapping with the earliest inmigrants (Colborne et al. 2022).

Table C-114. Summary of (a) Upstream and (b) Downstream Adult Green Sturgeon Passage at Benicia, 2007–2018

Calendar Year	Total count	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
(a) Upstream							
2007	4	Mar 21	–	–	–	–	May 17
2008	0	–	–	–	–	–	–
2009	3	Mar 12	–	–	–	–	Apr 23
2010	3	Mar 2	–	–	–	–	Apr 25
2011	2	Feb 23	–	–	–	–	Mar 8
2012	17	Mar 6	Mar 6	Mar 9	Apr 29	May 5	May 5
2013	13	Feb 18	Feb 18	Feb 18	Apr 16	May 6	May 6
2014	13	Feb 15	Feb 15	Feb 15	Apr 9	May 5	May 5
2015	20	Feb 18	Feb 18	Mar 12	May 3	May 29	Jun 14
2016	26	Feb 10	Feb 14	Feb 28	Apr 7	Apr 9	Apr 14
2017	16	Feb 24	Feb 24	Feb 25	Apr 12	May 4	May 4
Median Month	-	February	February	February	April	May	May
(b) Downstream							
2007	4	Aug 17	–	–	–	–	Jan 6
2008	0	–	–	–	–	–	–
2009	3	Oct 14	–	–	–	–	Jan 14
2010	3	Dec 7	–	–	–	–	Dec 11
2011	2	Jun 28	–	–	–	–	Jan 23
2012	17	May 24	May 24	May 25	Dec 1	Dec 2	Dec 2
2013	13	Jul 1	Jul 1	Jul 8	Feb 12	Feb 14	Feb 14
2014	13	May 11	May 11	May 27	Dec 5	Dec 6	Dec 6
2015	20	May 20	May 20	Jun 23	Dec 21	Dec 24	Jan 9
2016	26	Apr 15	Apr 23	May 6	Dec 12	Dec 12	Dec 12

Calendar Year	Total count	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2017	16	May 18	May 18	May 28	Mar 18	Mar 24	Mar 24
Median Month	–	May	May	May	December	December	January

Source: Colborne pers. comm.
Note: Dates are based on acoustic detection records, where both upriver and downriver migrations were captured in the detection records. *Upstream migration* was defined as upstream movement starting at Benicia and continuing past RKM 105 to approximately RKM 400. *Downstream migration* was defined as downstream movement from approximately RKM 400 past RKM 105. RKM is measured as a distance from the entrance to the Pacific Ocean marked by Golden Gate Bridge in San Francisco Bay (Colborne et al. 2022). Note: Percentages passing only calculated for years with >10 fish detected migrating.

Table C-115. Downriver Migration Timing Based on Early and Late Groups Identified in Telemetry Analysis

	Early Downriver				Late Downriver			
Year	Count	First Date	Mean Date	Last Date	Count	First Date	Mean Date	Last Date
2007	1	Aug 17	–	–	3	Dec 7	Dec 18	Jan 6
2008	0	–	–	–	–	–	–	–
2009	0	–	–	–	3	Oct 14	Nov 16	Jan 14
2010	0	–	–	–	3	Dec 7	Dec 9	Dec 11
2011	1	Jun 28	–	–	1	Jan 23	–	–
2012	10	May 24	Jun 14	Jul 24	7	Nov 21	Nov 25	Dec 2
2013	3	Jul 1	Jul 7	Jul 12	10	Dec 15	Feb 5	Feb 14
2014	3	May 22	Jun 11	Jul 26	10	Dec 1	Dec 4	Dec 6
2015	4	May 20	Jun 23	Jul 26	16	Oct 15	Dec 14	Jan 9
2016	9	Apr 15	May 21	Jul 7	17	Sep 22	Nov 13	Dec 12
2017	6	May 18	Jun 9	Jul 7	10	Nov 22	Jan 14	Mar 24

Source: Colborne pers. comm.

Unpublished, anecdotal information suggests that green sturgeon are present in the Feather River year round. Seesholtz et al. (2015) found that green sturgeon used the Feather River near the Thermalito Afterbay as spawning grounds in 2011, a wet water year, and the eggs were collected between June 14 and June 22, when the water temperatures were 61°F–63°F (16°C –17°C). This supports the laboratory findings from Van Eenennaam et al. (2005), showing that 61°F (16°C) was the optimal temperature for hatching success and a low chance of embryo deformities.

C.8.2 Sacramento Egg Incubation

Poytress et al. (2015) conducted an egg-mat study between 2008–2012 in a reach of the Sacramento River from the Glenn-Colusa Irrigation District Diversion to Cow Creek in Anderson, California. A total of 268 eggs and five post-hatch larvae were collected at seven sites between April 2 and July 7 of each year (Table C-116) from medium-gravel substrates. This study verified a known spawning site 0.5 kilometer above the Glenn-Colusa Irrigation District Diversion, which is believed to be the lower river limit of green sturgeon spawning. The uppermost site where eggs were collected was ~25 kilometers below Cow Creek. Table C-116 presents physical habitat data for all years of the study. The temperature range that eggs were sampled at was 53°F–59°F (11.8°C–14.8°C).

Table C-116. Site-Specific Physical Habitat Data for All Years Sampled

Site	Eggs or larvae (n)	Depth (m)	Temperature (°C)	Discharge (m^3/s)	Turbidity (NTU)	Column Velocity (m/s)	Substrate class
RKM 426	26	10.1±1.8	12.9±0.8	396±115	4.3±1.5	0.8±0.4	Gravel/ cobble
RKM 424.5	154	6.8±1.8	12.9±1.0	275±52	4.7±5.2	0.6±0.1	Medium gravel
RKM 407.5	3	6.5±2.9	13.9±0.7	269±10	3.8±0.6	0.8±0.2	Small gravel
RKM 391	4	1.2±0.7	14.8±0.9	323±17	3.4±0.8	NA[a]	Small gravel[b]
RKM 377	81	4.6±1.2	14.1±1.2	311±58	3.8±2.4	1.0±0.1	Medium gravel
RKM 366.5	1	6.2±0.0	11.8±0.5	290±0	4.9±0.0	0.3±0.0	Medium/ large gravel
RKM 332.5	4	7.3±0.2	14.0±1.8	331±87	9.7±11.0	1.2±0.5	Small gravel

Source: Poytress et al. 2015.
[a] Tailrace of Red Bluff Diversion Dam; no velocity measurements were taken during years of dam operation.
[b] Tailrace of Red Bluff Diversion Dam; substrate class was assessed by direct observation.

The optimal incubation temperature range for green sturgeon eggs is between 14°C–17°C; acceptable temperatures are between 52°F–70°F (11°C–21°C; Table C-83). Deformed hatched embryos increased at incubation temperatures between 63°F–68°F (17°C–20°C) and hatched embryo length was shorter at 52°F (11°C). Temperatures of 74°F (23°C) and above resulted in total mortality before hatch, and temperatures below 52°F (11°C) were not studied. Suboptimal temperatures are between 63°F–68°F (17°C–20°C), resulting in increased embryo deformities that could affect future survival (Van Eenennaam et al. 2005). Optimal temperatures for sturgeon spawning (below 63°F [17°C]) extend from Keswick Dam to below the Red Bluff Diversion Dam in most years. During years of low reservoir storage and outflow, temperatures at the downstream extent of green sturgeon spawning habitat near Red Bluff Diversion Dam may be suboptimal (above 64°F [17.5°C]) in the late spring (Heublein et al. 2017b).

temperature °C	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
temperature °F	46.4	48.2	50.0	51.8	53.6	55.4	57.2	59.0	60.8	62.6	64.4	66.2	68.0	69.8	71.6	73.4	75.2	77.0	78.8	80.6	82.4
egg				b	b	b	b	b	b	b	b	b	b	b	b,f	b,f	b,f	b,f	b,f	b	b
larvae							e	e	e	c	f	dd,f	dd,f	dd,f	dd,f	dd,f	dd,f	dd,c,f	f	f	f
juvenile				a	a	a	a	a	a	a	a	a	a	a	a	a	a,d	a	a	a	a
spawning adult			g	g	g	g	g	g	g,h	g,h											

- optimal temperature
- acceptable temperature
- impaired fitness; avoid prolonged exposure; increasing chance of lethal effects
- likely lethal
- lethal
- unknown effect upon survival and fitness

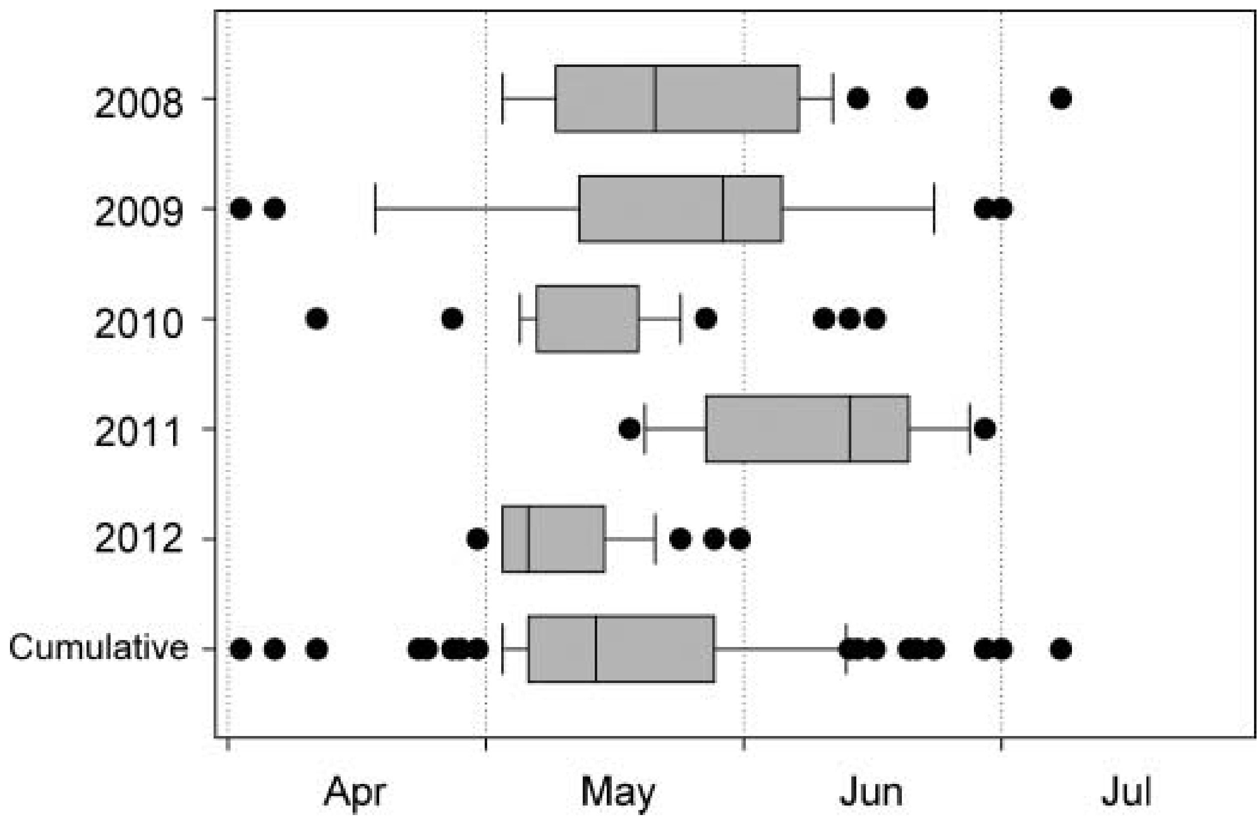
Source: Heublein et al. 2017b.

Figure C-83. Temperature Ranges for Green Sturgeon Life Stages Including Optimal, Lethal, and Unknown

Table C-117. Green Sturgeon Eggs from Upper Sacramento River Egg Mat Surveys

Brood Year	First	5%	10%	90%	95%	Last
2008	May 2	May 2	May 2	Jun 10	Jun 13	Jul 7
2009	Apr 2	Apr 23	Apr 23	Jun 23	Jun 23	Jul 1
2010	Apr 11	May 5	May 5	May 24	Jun 13	Jun 16
2011	May 18	May 18	May 27	Jun 20	Jun 29	Jun 29
2012	Apr 29	Apr 29	May 2	May 20	May 23	May 30
Median Month	April	May	May	June	June	June

Source: Poytress pers. comm.



Source: Poytress et al. 2015.

Figure C-84. Box Plots Displaying the Median and 10th, 25th, 75th, and 90th Percentiles with Outliers (Black Dots) of Annual Green Sturgeon Spawning Events (n = Egg Counts) on the Sacramento River for 2008 (n=42), 2009 (n=56), 2010 (n=105), 2011 (n=11), 2012 (n=59), and Cumulatively (n=273)

Larval green sturgeon are suspected to remain near their spawning grounds for about 16 days post hatch, when they begin a first nocturnal migration to disperse from their hatching site (Kynard et al. 2005; Poytress et al. 2012). It is hypothesized that larval green sturgeon spend a period of time foraging in the upper river and may move upstream during the late summer and fall, rather than moving downstream to feed (Poytress et al. 2012). A secondary nocturnal downstream winter migration is thought to occur at 110–181 days post hatch, until water temperatures drop to about 46°F (8°C), indicating that juveniles migrate downstream to overwinter (Kynard et al. 2005).

C.8.3 Juveniles

Green sturgeon are typically defined as juveniles from when they are able to feed exogenously (Klimley et al. 2015) up to when they are capable of entering estuarine and marine waters at about 90 centimeters in length (Miller et al. 2020). Not much is known about juvenile green sturgeon movements, and it is not clear when juvenile green sturgeon leave their birthplace upriver and migrate downstream to rearing habitats in the Delta. Gruber et al. (2022) recently estimated that juveniles would reach the migrant readiness stage at 180 days post hatch, based on research by Kynard et al. (2005). Based on larval presence at the Red Bluff Diversion Dam rotary screw trap, juveniles would be ready to migrate 164 days later. The timing of juvenile outmigration is reliant on their hatch date and can vary from early- to mid-October to January (Gruber et al. 2022). Juveniles were detected making continuous and stepped migrations from the upper Sacramento River in Red Bluff, California, to the Delta. New research suggests that increases in reach discharge, paired with co-occurring turbidity and individual migrant readiness, may influence the initiation of juvenile downstream migration (Gruber et al. 2022). Juveniles likely spend the next 2–4 years rearing in the Delta and San Francisco Estuary (Thomas et al. 2019; Moyle 2002).

During spring 2008 and 2010, Klimley et al. (2015) released six green sturgeon juveniles that were roughly 30 centimeters long at Santa Clara shoals in the Bay-Delta and tracked them by boat for 5 days. The fish were observed moving within the area local to where they were released. Their movements did not appear to be tidally influenced and occurred both day and night. In 2013, an additional 31 tagged individuals, ranging in FL from 30–53 centimeters, were released at Santa Clara shoals (Thomas et al. 2022). They exhibited a diversity of movements, including moving around the Delta, moving into the saltier waters of the Carquinez Straits and San Pablo Bay, moving into San Pablo Bay, and then returning to the Delta, exiting the San Francisco Estuary after migrating through, and moving back and forth between the San Francisco Estuary and the Pacific Ocean. It was found that all 31 tagged fish spent the most amount of time, an average of 87.7 of 290 days in the central Delta, where they were released (Thomas et al. 2022). This is consistent with Miller et al. (2020), who found that large juveniles were generally detected throughout the San Francisco Estuary and Delta, with some individuals detected close to Golden Gate Bridge. Juveniles were detected most frequently in the Delta, peaking in the late winter and early spring. Some individuals were also detected in the central San Francisco Bay, San Pablo Bay, and Suisun Bay, especially in spring and summer (Miller et al. 2020). This is consistent with findings that juvenile green sturgeon are able to detect and seek out saline waters as early as 6 months post hatch (Poletto et al. 2013). The findings by Thomas et al. (2022) suggest that juvenile green sturgeon are flexible in their movements in a highly variable environment.

Table C-118. Red Bluff Diversion Dam Juvenile Green Sturgeon Presence

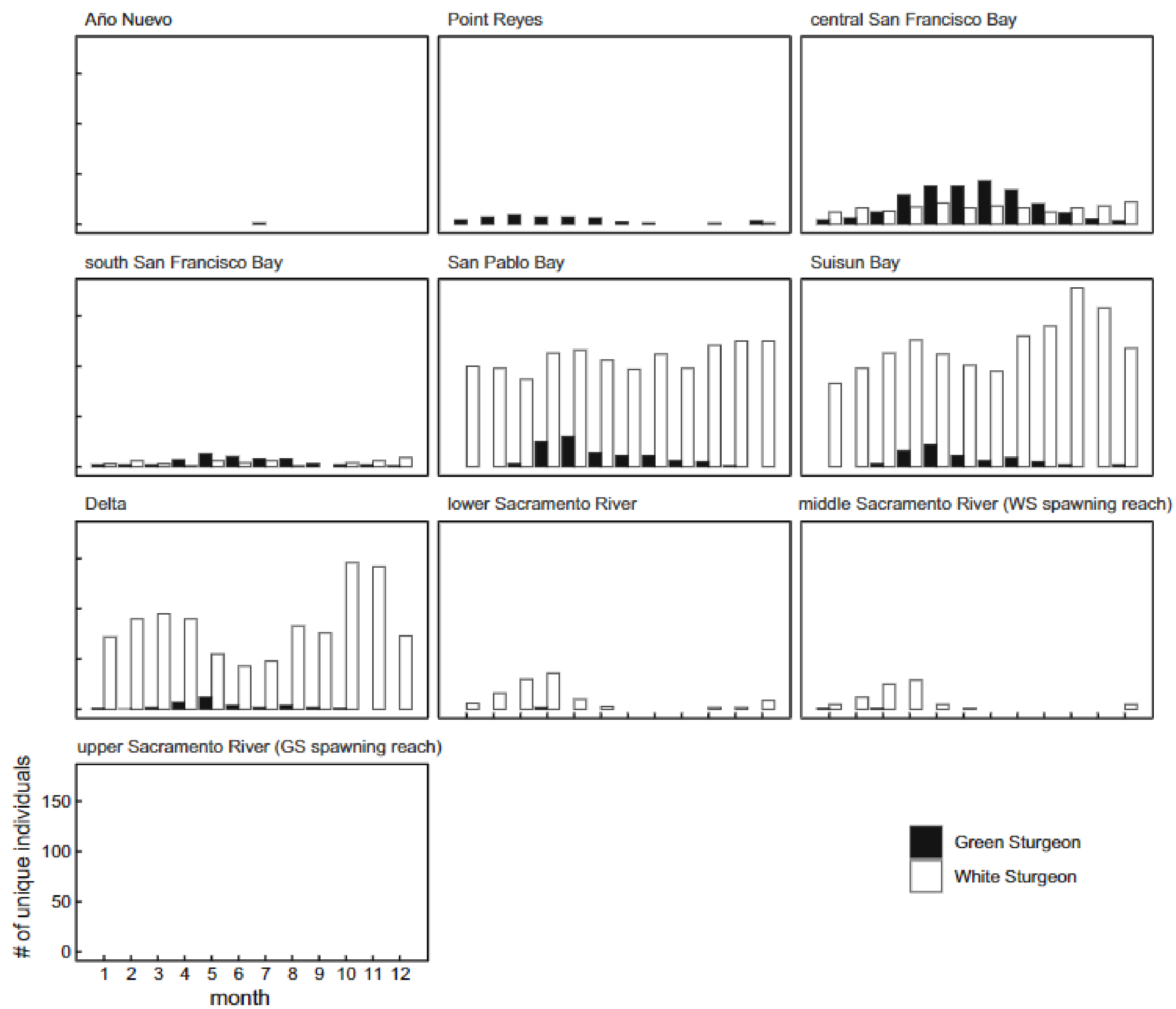
Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2002	May 7	May 7	May 7	Jul 15	Jul 16	Jul 16
2003	Jun 13	Jun 17	Jun 18	Jul 10	Jul 15	Nov 11
2004	May 4	May 17	May 19	Jul 1	Jul 8	Jul 29
2005	May 7	Jun 28	Jun 29	Jul 20	Jul 29	Aug 13
2006	Jun 10	Jun 22	Jun 23	Jul 27	Jul 28	Aug 25
2007	May 11	May 11	Jun 9	Jul 15	Jul 24	Jul 24
2008	–	–	–	–	–	–
2009	May 11	Jun 11	Jun 11	Jul 7	Jul 10	Jul 16
2010	May 26	Jun 2	Jun 12	Jul 29	Jul 31	Aug 29
2011	May 16	May 23	May 24	Jul 21	Jul 25	Aug 27

Brood Year	First	5% Passing	10% Passing	90% Passing	95% Passing	Last
2012	May 1	May 9	May 10	May 30	May 31	Jun 26
2013	May 2	May 9	May 13	Jul 9	Jul 29	Aug 20
2014	May 3	May 5	May 6	May 24	Jun 6	Aug 4
2015	Apr 14	Apr 22	Apr 23	Jun 11	Jun 21	Jul 6
2016	Apr 28	May 5	May 5	Jun 2	Jun 22	Sep 21
2017	May 27	Jun 1	Jun 4	Jul 14	Jul 21	Sep 9
2018	May 10	May 12	May 12	Jun 1	Jun 7	Jun 22
2019	May 13	May 21	May 23	Jun 23	Jul 6	Sep 12
Median Month	May	May	May	July	July	August

Source: Poytress pers. comm.
Note: No fish were caught in 2008; COVID-19 disrupted sampling from March 28–July 1. The majority of the fish in the data set were larvae (99.6%); some juveniles appeared during the October and November sampling period in a few years.

C.8.4 Bay Subadult and Adult Residence

Subadult and adult green sturgeon are characterized by total lengths of over 90 centimeters (Miller et al. 2020). The San Francisco Estuary provides foraging habitat for subadults and non-spawning adults in the summer months (National Marine Fisheries Service 2018). Subadult green sturgeon have been detected from the Delta to Point Reyes, suggesting that subadult initial migration preference is northward up the Pacific Coast (Miller et al. 2020). Subadult green sturgeon were detected most often in the San Francisco, San Pablo, and Suisun Bays (Figure C-85), with peaks in spring and summer months. Occasionally, subadults were detected in the central and lower Sacramento River, but not in the upper Sacramento River. Detections of individual subadult green sturgeon in coastal waters and San Francisco Bay waters suggest that subadults are going in and out of the San Francisco Estuary before making their adult migration into coastal waters (Miller et al. 2020). Pre-spawning adult green sturgeon return to migrated through the San Francisco Estuary to spawning grounds in late winter and early spring, moving through the Bay and Delta quickly to reach their spawning grounds (Israel and Klimley 2008). Post-spawning green sturgeon spent an average of 7 days in the San Francisco Bay before returning to the ocean (Miller et al. 2020).



Source: Miller et al. 2020.
Note: Most subadults were detected in the central San Francisco Bay.

Figure C-85. Subadult Green Sturgeon Presence Across all Months by River Reach

The University of California, Davis, reviewed telemetry data between 2010–2018, looking at tagged green sturgeon. Fish were considered Bay residents if they entered the Bay through the Golden Gate, but did not pass the Benicia Bridge.

Table C-119. Cumulative Proportion of Occupancy by Resident Bay Subadult Green Sturgeon

Month	Total count	Cumulative Proportion
Jan	9	0.02
Feb	10	0.05
Mar	18	0.09

Month	Total count	Cumulative Proportion
Apr	42	0.19
May	59	0.33
Jun	62	0.48
Jul	64	0.64
Aug	59	0.78
Sep	38	0.87
Oct	27	0.94
Nov	18	0.98
Dec	7	1.00

Source: Colborne pers. comm.

C.8.5 Delta Subadult and Adult Residence

Subadult green sturgeon were more frequently detected in the San Francisco Estuary than Delta waters, although they were occasionally detected in the Delta, primarily in the spring months (Figure C-85) (Miller et al. 2020). It is assumed adult green sturgeon migrate directly to their spawning grounds, spending an average of 3 days in the Delta during the upstream migration (Miller et al. 2020). Post spawning, the adult green sturgeon appear to hold in the rivers near the spawning sites until fall or winter. It is assumed they use cues of increasing flow rates and decreasing temperatures to begin their outmigration (Israel and Klimley 2008). There is no evidence of tagged adult green sturgeon exhibiting permanent residency in the Delta (Colborne et al. 2022).

The University of California, Davis, reviewed telemetry data between 2010–2018, looking at tagged green sturgeon. Fish were considered Bay residents if they entered the Delta by passing under the Benicia Bridge, but did not pass upstream of RKM 105.

Table C-120. Cumulative Proportion of Occupancy by Resident Bay Subadult Green Sturgeon

Month	Total Count	Cumulative Proportion
Jan	3	0.02
Feb	17	0.10
Mar	17	0.19
Apr	21	0.29
May	27	0.43
Jun	21	0.54
Jul	18	0.63
Aug	25	0.75

Month	Total Count	Cumulative Proportion
Sep	20	0.85
Oct	17	0.94
Nov	7	0.97
Dec	5	1.00

Source: Colborne pers. comm.

C.8.6 Adult Post-Spawn Delta Residence

Post-spawning adults were observed to prefer the mainstem of the Sacramento River for outmigration (Miller et al. 2020). Studies have found that post-spawning adult green sturgeon reside in the river near their spawning grounds for several months, with variations in outmigration from early summer through December (Heublein et al. 2009; Miller et al. 2020). Two distinct outmigration groups have been observed, one in early summer and one in winter (Colborne et al. 2022). Miller et al. (2020) observed an adult green sturgeon remaining in the spawning grounds for nearly a year before outmigrating, a behavior previously unseen. It is speculated that longer holding in the spawning grounds could be a response to environmental conditions that change from year to year. It could also be a feature of the sDPS, individual variation, driven by food requirements before their long journey back to sea, or a response to drought conditions that delayed the flow conditions that trigger outmigration (Miller et al. 2020).

The University of California, Davis, reviewed telemetry data between 2012–2017, looking at tagged green sturgeon. Fish were considered post-spawn Delta residents if they entered the Delta by passing downstream of RKM 105, but did not pass downstream of Benicia Bridge.

Table C-121. Cumulative Proportion of Occupancy By Resident Bay Subadult Green sturgeon

Year	Count	Mean Duration (days)	Shortest Period (days)	Longest Period (days)	Mean Arrival Date	Mean Departure Date
2012	15	18	0	86	Sep 12	Sep 30
2013	12	6	1	13	Jan 16	Jan 22
2014	13	20	2	176	Oct 28	Oct 17
2015	20	50	3	248	Oct 14	Dec 3
2016	23	18	2	153	Sept 11	Sept 28
2017	15	12	0	62	Oct 16	Oct 28

Source: Colborne pers. comm.
Note: Considered the same group of fish as green sturgeon with both upriver and downriver migrations (above) defined as when green sturgeon were below RKM 105 and above the Benicia Bridge (38.03994, -122.123) row of receivers.

C.9 References

C.9.1 Printed References

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