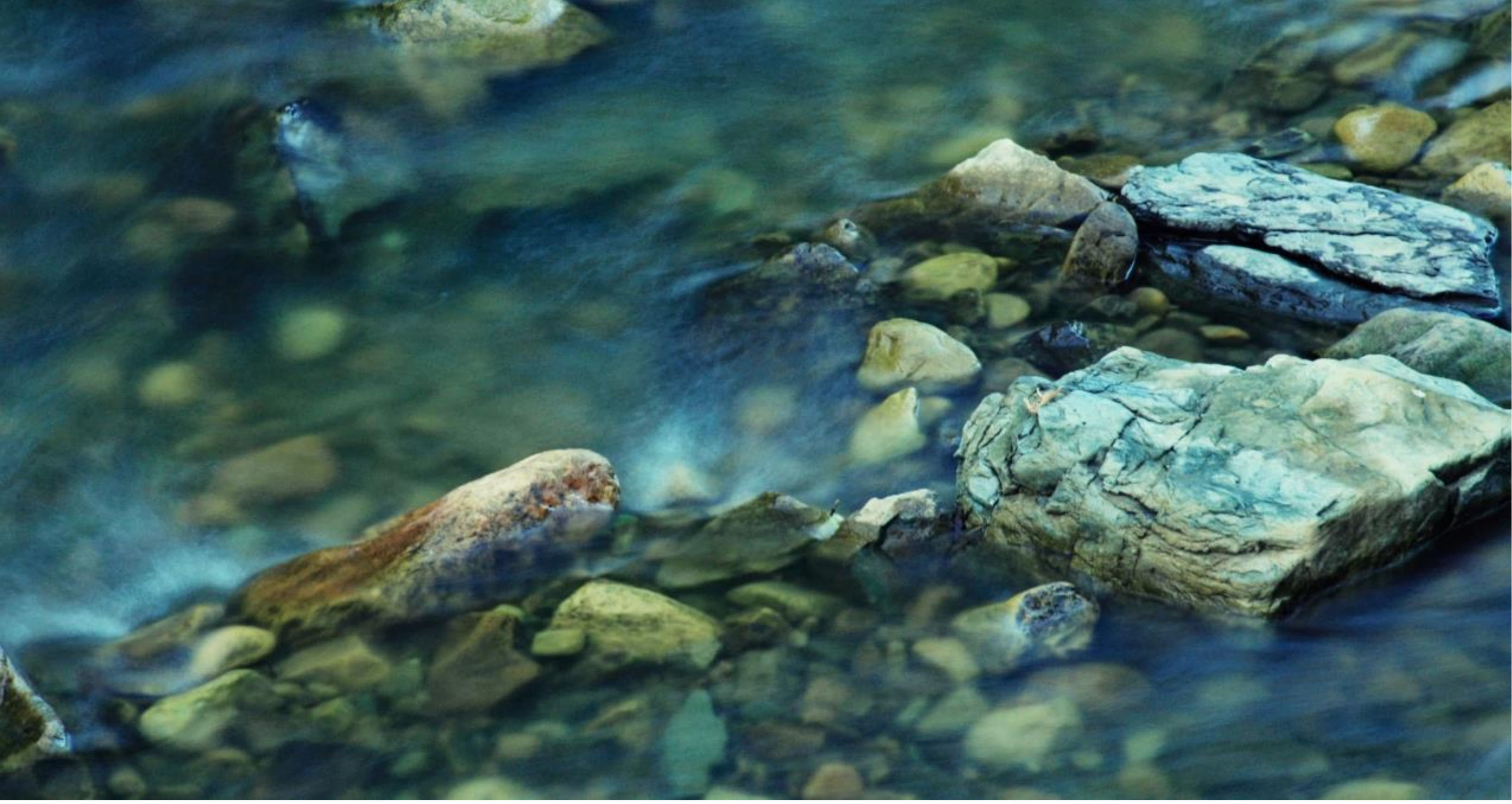

August 2020

Brood Year 2019 Winter-Run Chinook Salmon Operations and Monitoring Assessment

Prepared for NOAA Fisheries

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Project Number: 190912-01.01
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APPENDICES

Appendix A SacPAS Fish Modeling Details

Appendix B Migration Timing on the Middle Sacramento

ABBREVIATIONS

ACID	Anderson-Cottonwood Irrigation District
BY	brood year
CDEC	California Data Exchange Center
CDWR	California Department of Water Resources
cfs	cubic feet per second
CM	conceptual model
CRR	cohort replacement rate
CNFHC	California-Nevada Fish Health Center
CVFED	Central Valley Floodplain Evaluation and Delineation
CVPIA	Central Valley Project Improvement Act
Delta	Sacramento-San Joaquin River Delta
DO	dissolved oxygen
DOY	day of year
GCID	Glenn-Colusa Irrigation District
JPE	juvenile production estimate
JPI	juvenile production index
kcfs	thousands of cubic feet per second
km^2	square kilometer
LAD	length-at-date
LSNFH	Livingston Stone National Fish Hatchery
m^2	square meter
mg/L	milligrams per liter
mm	millimeter
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NTU	nephelometric turbidity unit
PNI	proportion of natural influence
RBDD	Red Bluff Diversion Dam
RKM	river kilometer
RM	river mile
RST	rotary screw trap
SacPAS	Central Valley Prediction and Assessment of Salmon
SAIL	Salmon Assessment of Indicators by Life Stage
SIT	Science Integration Team
SRTTG	Sacramento River Temperature Task Group
TCP	temperature compliance point

USBR	U.S. Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service
WRCS	winter-run Chinook salmon
WRO	Water Rights Order
WUA	weighted usable area

Executive Summary

Anchor QEA, LLC, evaluated the relative success of the 2019 brood year (BY) of Sacramento River winter-run Chinook salmon (WRCS; *Oncorhynchus tshawytscha*) (BY 2019) to inform how water management strategies implemented in 2019 resulted in conditions needed to support the productivity of WRCS. The analyses were conducted using readily available environmental, habitat, and biological data and conceptual models (CMs). The CMs were developed as part of the Salmon Assessment of Indicators by Life Stage (SAIL) effort to characterize specific environmental and management factors that drive WRCS responses within discrete geographic domains and life stages. They provide a framework to assess the relative success of the BY 2019 cohort by providing life-stage-specific hypotheses on how fish responses are influenced by environmental and habitat conditions that are controlled in part by water management operations. The assessment was conducted for the Sacramento River Science Partnership through funding provided by National Oceanic and Atmospheric Administration (NOAA) Fisheries.

This assessment focused on freshwater life stages of BY 2019 in the mainstem Sacramento River, including adult spawning and egg-to-fry survival in the upper Sacramento River and juvenile rearing and out-migration through the upper and middle sections of the Sacramento River. The upper Sacramento River is defined as the reach from just below Keswick Dam at river mile (RM) 302 to Red Bluff Diversion Dam (RBDD) at RM 242. Environmental and habitat conditions experienced by returning adults in the upper Sacramento River were evaluated for the period from January through September 2019, which encompasses the period of adult holding and spawning. Eggs and juveniles in this reach were evaluated for the period from June 2019 through March 2020, which encompasses that portion of the life cycle beginning with redd occupation until juvenile migrants were no longer observed passing RBDD. The middle Sacramento River is defined as the reach from RBDD to the Sacramento-San Joaquin River Delta (Delta) entry point at Sherwood Harbor near Sacramento (RM 55). Rearing and out-migrating juveniles in this reach were evaluated for the period from July 2019 through March 2020. This period encompasses the portion of the life cycle from when juveniles were first observed passing RBDD through their last date of passage at Sherwood Harbor based on trawling operations.

The assessment framework identified numerous variables associated with many habitat attributes and environmental drivers that can potentially affect WRCS survival and productivity. To aid data interpretation, results of the assessment are organized into a summary table (Table ES 1). Table ES 1 provides a snapshot summary of each variable considered in the assessment, the factors that influenced life stage-specific survival of BY 2019 fish, and data gaps for certain variables. Green shaded cells in the table indicate fish responses, habitat attributes, or environmental drivers that were better than the 10-year average or were expected to benefit BY 2019 fish. Yellow shaded cells indicate responses, attributes, or drivers that were similar to the 10-year average or were expected to

have a neutral effect on BY 2019 fish. Red shaded cells indicate conditions that were worse than the 10-year average or are expected to not benefit BY 2019 fish.

The results presented in Table ES 1 are summarized in two ways. First, fish responses to conditions experienced during the 2019 to 2020 assessment period are described. Second, the responses are discussed in the context of the viable salmonid population parameters developed by NOAA Fisheries. This is to help inform, in general terms, progress made toward achieving WRCS population viability given the management actions implemented for BY 2019.

Table ES-1
Summary of BY 2019 Responses to Environmental Drivers and Habitat Attributes in the Upper Sacramento River and Middle Sacramento River During Various Life Stages

Geographic Region	Upper Sacramento			Middle Sacramento
CM Variables[1]	**Adult Spawning**	**Egg-to-Fry Emergence**	**Rearing-to-Out-Migrating Juveniles**	**Rearing-to-Out-Migrating Juveniles**
Fish Response				
Adult Survival (Abundance)		-	-	-
Adults to Hatchery		-	-	-
Adult Fecundity		-		
Pre-Spawn Mortality		-	-	-
Egg-to-Fry Survival	-		-	-
Growth (FL)	-	-		ND
JPI (fry-equivalent)	-	-		-
Fry-to-Smolt Survival[2]	-	-		
Migration Timing	-	-		
Natural Smolt Survival[2]	-	-	-	
Natural JPE	-	-	-	
Hatchery Smolt Survival	-	-	-	
Hatchery JPE	-	-	-	
Habitat Attributes				
Redd Dewatering			-	-
Juvenile Stranding	-	-		-
Water Temperature				
DO				ND
In-Stream Habitat Capacity[3,4]				See Note 4
Habitat Refuge	ND	ND	ND	ND
Food Quality/Availability	ND	ND	ND	ND

Geographic Region	Upper Sacramento			Middle Sacramento
CM Variables[1]	**Adult Spawning**	**Egg-to-Fry Emergence**	**Rearing-to-Out-Migrating Juveniles**	**Rearing-to-Out-Migrating Juveniles**
Pathogens/Disease	ND	ND		
Hatchery Pathogens/Disease				
Toxicity/Contaminants	ND	ND	ND	ND
Substrate Size/Sedimentation*	ND	ND	-	-
Predation/Competition	-	ND	ND	ND
Fishery/Recreation Disturbance*	ND	ND	-	-
Migration Cues		-		
Entrainment Risk	-	-	ND/NE	ND/NE
Environmental Drivers				
Air Temperature				
Keswick Dam Releases*/Flows				See note 5
Fish Assemblage*	NE	NE	NE	NE
Hatchery Influence		-	-	-
Depth/Shallow Water[3]				
Food Production	ND	ND	ND	ND
Turbidity				
Mobilized Substrate	ND	ND	ND	ND
Contaminant Loading*	ND	ND	ND	ND
Irrigation Diversions*	NE	NE	NE	NE
Floodplain Connectivity[6]	-	-		
Shasta and Trinity Storage*/Hydrology				

Notes:
Green indicates conditions better than 10-year average or expected to have beneficial effects on BY 2019.
Yellow indicates conditions similar to 10-year average or expected to have neutral effects on BY 2019.
Red indicates conditions lower than the 10-year average or expected to have less beneficial effects on BY 2019.

1. Windell et al. 2017
2. Fry-to-smolt and natural smolt survival rate were calculated by a new method (O'Farrell et al. 2018) in 2019 that resulted in lower rates than in previous years, as discussed in Sections 6 and 7.
3. Evaluated based on spawning and in-stream rearing habitat WUA inputs to the CVPIA SIT Salmon Population Model for WRCS.
4. Habitat capacity in the middle Sacramento River was generally better than the 10-year average, except between mid-October and mid-December 2019 near Verona when habitat capacity was similar to the 10-year average.
5. Flows in the middle Sacramento River were both above and below the 10-year average during juvenile rearing and out-migration depending on the location and month.
6. Evaluated based on floodplain rearing habitat WUA inputs to the CVPIA SIT Salmon Population Model for WRCS.

* Management action
-: Not applicable to life stage
ND: No data were available
NE: No data were evaluated

Data Availability

Data were available to inform approximately one-third of the habitat attribute variables and one-half of the environmental driver variables identified in the SAIL CMs. The key habitat attributes (water temperature, redd dewatering, dissolved oxygen [DO], habitat capacity) and environmental drivers (Keswick Dam releases/flows, turbidity) had data available and were included in the assessment. Other attributes and drivers that may be important that did not have data available for the assessment included those that could have been impacted by the 2018 Carr Fire (sedimentation, toxicity, mobilized substrate, and contaminant loading) and those that are identified in the SAIL CMs as influencing egg-to-fry survival and fry-to-smolt survival (fish access to the floodplain, predators, pathogens or disease, contaminants, and suspended sediments).

Fish Responses, Habitat Attributes, and Environmental Drivers

The biological responses to conditions provided by the 2019 to 2020 water management operations were generally positive, except for egg-to-fry survival and fish growth (as measured by fork length) in the upper Sacramento River. Fry-to-smolt survival and natural-origin smolt survival were lower only due to a change in the methods used to calculate those metrics. Based on the variables that could be assessed, BY 2019 fish experienced habitat attributes and environmental drivers that were better than or similar to the 10-year average or were expected to benefit BY 2019 fish (green and yellow cells in Table ES 1). This was the case in both the upper and middle Sacramento River reaches during spawning, egg incubation and fry emergence, fry and juvenile rearing, and migration to the Delta. The exceptions to this overall pattern were as follows: 1) air temperature was higher than average in the upper Sacramento River during egg incubation and fry emergence; 2) floodplain access was limited in the upper and middle Sacramento River reaches; and 3) flows in the middle Sacramento River reach were lower than normal during the second half of the BY 2019 out-migration due to 2020 being a below normal water year (WY). In 2019 there was also a concern about impacts to habitat conditions in the upper Sacramento River from runoff due to effects from the 2018 Carr Fire, which is discussed in this report.

Adult Spawning

Adult spawning responses to conditions provided by the 2019 to 2020 water management operations were positive, as shown by the following data:

- The total number of mainstem in-river spawners observed was 7,852 fish, compared to the 10-year average of 2,909 in-river spawners. Escapement was composed of 2,873 hatchery-origin fish (36.6%) and 4,979 natural-origin fish (63.4%).
- Fecundity was high and estimated to be 5,424 eggs per female spawner, compared to an average fecundity over the last 10 years of 4,782 eggs per female spawner.
- Pre-spawn mortality was slightly higher than the 10-year average (1.3% vs 1.1%).

- A total of 515 WRCS redds were documented during aerial surveys in 2019, which is higher than the 10-year average of 215 redds. Both carcass and redd surveys showed that in 2019 there was a greater distribution of spawners downstream of Highway 44 at Redding (RM 296), compared to the 10-year average.

Environmental conditions during the time adults were holding and spawning in the upper Sacramento River (January through September 2019) were beneficial, as shown by the following data:

- Flow levels were optimal for creating the maximum spawning habitat.
- The temperature criterion (56°F) at Balls Ferry Bridge (RM 275) was met approximately 99% of the required time within the spawning season, and the pilot temperature criterion of 53.5°F at Clear Creek (RM 292) was met 98% of the time during spawning.
- Turbidity was generally less than 10 nephelometric turbidity units (NTU), although there were occasional short periods (days) where turbidity spiked to between 20 and 90 NTU.
- DO was generally above 10 milligrams per liter (mg/L) when adults were present. However, there were three periods prior to spawning when adults experienced lower DO levels between 5 and 9 mg/L.

Findings related to the key management questions for adult spawning showed positive fish responses or improving over recent conditions experienced during the drought, as follows:

- Was pre-spawn mortality low in 2019 given the beneficial flow and temperature conditions?
  - Yes, pre-spawn mortality was 1.3%. Although this is slightly higher than the 10-year average of 1.1%, it was lower than the most recent high in 2015 of 2%.
- Was the estimated hatchery influence on the 2019 spawning population higher than recommended?
  - Yes; although decreasing from the recent past, there is still a higher than desired influence of hatchery-origin fish in the BY 2019 spawning population. Hatchery-origin fish made up 36.6% of the spawning population in 2019. This proportion is higher than the 10-year average of 32.6. Also, the proportion of natural influence (PNI) metric in 2019 was 0.46, which is below the recommended value of greater than or equal to 0.67.

Egg-to-Fry Emergence and Survival

Egg-to-fry emergence and survival responses to conditions provided by the 2019 to 2020 water management operations were positive, except for egg-to-fry survival, as shown by the following:

- There were an estimated 26.5 million eggs produced, which is much higher than the 10-year average of 8.4 million eggs and much higher than BYs 2011 and 2017, which experienced comparable wet WYs and produced approximately 2.1 and 1.5 million eggs, respectively.
- Egg-to-fry survival was estimated at 18%. Although this was higher than estimates during recent drought years (BY 2013 to BY 2015) when survival ranged from 4% to 15%, it was much

lower than comparable wet WYs (BYs 2011 and 2017) where survival was 49% and 44%, respectively, and was lower than average egg-to-fry survival over the past 10 years (25%).

  - A comparison of the number of mainstem spawners to egg-to-fry survival indicated that survival decreased as the number of spawners increased, indicating a potential density-dependent effect on egg-to-fry survival.
  - The mechanism(s) that caused the lower egg-to-fry survival observed for BY 2019 were not apparent in the variables evaluated beyond there being a potential density dependence effect. This suggests that egg-to-fry survival was affected either in the egg stage or the fry stage (between emergence and passage at RBDD) by density dependence or another variable that was not monitored.
- An alternate predictive modeling method for estimating egg-to-fry survival is currently available in the Central Valley Prediction and Assessment of Salmon (SacPAS) and was used to compare to the juvenile production index (JPI) back-calculated survival rate. This method estimated the egg-to-fry survival rate for BY 2019 to be between 20.9% and 24.5%. The temperature-only component of mortality in this model ranged from 5.6% to 13.2%.

Environmental conditions during egg-to-fry emergence in the upper Sacramento River (June through November 2019) were beneficial, as shown by the following:

- Flows during this time were similar to the 10-year average, except in the late May through mid-June period when there was a small storage management release, causing flows at Bend Bridge (RM 257) to increase and be higher than normal at approximately 15,000 cubic feet per second (cfs).
- Only five redds were dewatered during incubation as flow from Keswick Dam began to decline from a steady summer flow of approximately 11,000 cfs from early July through late August.
- Water temperatures at the Balls Ferry and Clear Creek monitoring and compliance locations were generally below normal, except during mid-July when water temperatures reached close to 54°F. The rest of the emergence period experienced temperatures less than 54°F.
- In June, July, and August 2019, turbidity was low, averaging 3.4 NTU below Keswick Dam and 3.1 NTU above the confluence with Clear Creek. Starting in early September and continuing through mid-November, there were four events where turbidity levels up to 50 NTU were recorded above Clear Creek, which could have affected late-emerging fry.
- DO, which is critical to egg development, remained above 10 mg/L during egg incubation.

Findings related to the key management question for egg-to-fry emergence and survival showed a negative fish response that is likely related to density dependence and a factor not monitored, as follows:

- Was egg-to-fry survival better than the 10-year average given the beneficial habitat attributes and environmental drivers during egg incubation and emergence?

- No, BY 2019 egg-to-fry survival was 18%, which is lower than the 10-year average of 25% and the average survival since 2002 of 24%.

Rearing-to-Out-Migrating Juveniles in the Upper Sacramento River

Rearing-to-out-migrating juvenile fish responses to conditions provided by the 2019 to 2020 water management operations in the upper Sacramento River were positive, except smaller-sized fish than average were observed passing RBDD, as shown by the following:

- Although egg-to-fry survival was lower than average (see summary for egg-to-fry emergence and survival in the preceding section), production was high due to the large number of spawners and higher-than-average fecundity. This resulted in the number of BY 2019 fry and fry-equivalents passing RBDD (4,762,142 fish) being higher than any year since 2009.
- Median passage at RBDD occurred on September 29, which is approximately 10 days earlier than normal. The date of last passage of juveniles was March 23, which is approximately 34 days earlier than the 10-year average. Most juveniles passed RBDD between mid-August and early December.
- The series of pulse flow releases from Keswick Dam that occurred from mid- to late October 2019 appeared to cause the juveniles to migrate past RBDD earlier than the 10-year average.
- Juveniles that were moving out of the upper Sacramento River earlier than the 10-year average were also smaller than the 10-year average when passing RBDD. Fork length averages for the entire season were smaller for BY 2019 (47.5 to 71.2 millimeters [mm]) than the 10-year average (54.6 to 77.1 mm). A total of 1,611 WRCS fry were rescued from stranding sites in the upper Sacramento River region (Keswick Dam to RBDD; RM 302 to RM 229). This is far fewer than the 7,766 juvenile WRCS that were rescued from stranding sites in 2018 (Israel and Johnson 2020), especially considering the much greater number of BY 2019 fry. This may indicate that late-migrating fry that might have otherwise been stranded were instead pushed downstream by pulse flows.

Environmental conditions during the time most of the juveniles were rearing in and out-migrating from the upper Sacramento River (mid-August to early December) were beneficial, except for access to floodplain habitat, as shown by the following:

- A series of pulse flow releases from Keswick Dam that occurred from mid- to late October 2019 appeared to cause the juveniles to migrate past RBDD earlier than normal. Four pulses with peaks of approximately 9,000 cfs occurred between October 14 and October 23, 2019. A fifth and lower pulse of 8,200 cfs occurred on October 30 and 31, 2019.
- All other flows during the rearing period were near normal, indicating that the amount of in-stream rearing habitat available to juveniles was also like other years. However, access to floodplain habitat was limited for BY 2019 due to flows that did not allow access to floodplain channels. Habitat modeling by the Central Valley Project Improvement Act (CVPIA) has shown

that a negligible amount of floodplain rearing habitat is available for salmonids at flows below 25,000 cfs. Maximum WY 2020 winter flows between December 2019 and March 2020 that were experienced by BY 2019 juveniles peaked at 18,000 cfs, indicating that negligible floodplain rearing habitat was available.

- Water temperatures when most of the juveniles were rearing were generally similar to or below the 10-year average and were below 57°F. Exceptions occurred at the end of August through early September 2019 when water temperatures rose to 59°F and again in late September when water temperatures rose to 58°F.
- DO was generally greater than 10 mg/L during this time period.
- The highest turbidity recorded was 280 NTU at Bend Bridge in late August 2019, which may have encouraged the downstream migration of juveniles since passage was occurring 12 to 13 days earlier than normal during late August and early September 2019.

Findings related to the key management questions for rearing-to-out-migrating juveniles in the upper Sacramento River showed positive fish responses, as follows:

- Did fry production increase for BY 2019?
  - Yes, the number of fry and fry-equivalents (juvenile production index [JPI]) at RBDD was 4,762,142 fish, which is the highest since 2006.
- Did pulse flows in the fall change migration patterns and stimulate earlier movement downstream?
  - Yes, it appears that the pulse flows stimulated migration and resulted in earlier cumulative migration at various quantiles and smaller-sized fish at RBDD.
- Was rearing habitat (in-river and floodplain) higher than normal for BY 2019?
  - No, the amount of in-river rearing habitat was similar to the average, except for during the pulse flows, and flows were not high enough to connect floodplain habitat.
- Were environmental conditions necessary for good productivity and survival met?
  - Yes, environmental conditions, including water temperature, DO, flows, system hydrology, and migration cues were generally better than the 10-year average for BY 2019 rearing and out-migrating juveniles. Turbidity and air temperature were similar to the 10-year average.
- Did the rearing and migration periods overlap for natural-origin WRCS and hatchery releases?
  - No, because of a difference in timing of natural-origin WRCS migrations and hatchery-origin WRCS release dates, there was likely minimal co-occupancy of habitats and interactions between the two sources of fish.

Rearing-to-Out-Migrating Juveniles in the Middle Sacramento River

Rearing-to-out-migrating juvenile fish responses to conditions provided by the 2019 to 2020 water management operations in the middle Sacramento River were positive, as shown by the following:

- Estimated production of natural-origin juvenile WRCS from BY 2019 that entered the Delta was 854,941 fish, which is the highest since BY 2013 and continues a trend of increasing production starting with BY 2015.
- Fry-to-smolt survival (47%) and the survival of natural-origin smolts (39%) in the middle Sacramento River reach were lower than normal for BY 2019. However, this was attributed to a change in the methods used to calculate those rates starting with BY 2019. Additional years of estimating fry-to-smolt and smolt survival based on the new method will be needed before these two rates can be placed into an overall trend. Natural-origin smolt survival calculated using the previous method (used for BYs 2013 to 2018) produced a value of 48%, which is greater than the average of 42% for BYs 2013 to 2018.
- The early migration observed in the upper Sacramento River continued in this section of the river, with median cumulative passage of juveniles occurring 5 to 10 days earlier than normal between RBDD and Knights Landing (RM 90) and 57 days earlier than normal between Knights Landing and Sherwood Harbor.
- Environmental conditions during the time juveniles were rearing in and out-migrating from the middle Sacramento River were generally beneficial. Overall, a majority of the WRCS juveniles were present in the middle Sacramento River from the beginning of September 2019 (when 5% passage at RBDD had occurred) until early February 2020 (when 95% passage at Sherwood Harbor had occurred). Most juvenile fish were present near Vina Bridge (RM 218) and Hamilton City (RM 199) between the beginning of September and mid-December and near the town of Verona (RM 78) between the end of September and beginning of February. Flows in the middle Sacramento River near Vina Bridge and Hamilton City were both lower than and higher than the 10-year average. Between the beginning of September and early October flows were above the 10-year average, whereas between mid-October and mid-December flows and were generally below the 10-year average except during the fall pulse flows. On average through this time period, flows were lower than the 10-year average, and the amount of in-stream rearing habitat in this area was greater than the 10-year average. However, the CVPIA model estimates of floodplain habitat indicated that flows were not high enough to allow juveniles access to floodplain habitats; therefore, the amount of floodplain habitat available to BY 2019 fish was negligible.
- Flows in the middle Sacramento River near Verona between the end of September and mid-December 2019 were above or similar to the 10-year average, whereas flows between mid-December 2019 and early February 2020 were lower than the 10-year average. The amount of in-stream rearing habitat between mid-October and mid-December was similar to

the 10-year average, whereas the amount of in-stream rearing habitat between mid-December and early February was higher than the 10-year average. The CVPIA model estimated amount of accessible floodplain habitat based on the below average flows was lower than the 10-year average.

- Water temperatures at Verona were generally lower than the 10-year average from the end of September 2019 through early February 2020.
- Turbidity at Verona spiked up to 150 NTU in mid-October to early November 2019. This spike may have been associated with the fall pulse flow releases from Keswick Dam, although the pulses themselves resulted in small changes in flow amplitude this far downstream compared to upstream locations. Another turbidity spike occurred starting in early December 2019, with maximum turbidity reaching 350 NTU. The December increase in turbidity recorded at the Verona gage corresponded with the rapid movement of WRCS juveniles between Knights Landing and Sherwood Harbor.

Findings related to the key management questions for rearing-to-out-migrating juveniles in the middle Sacramento River showed mixed fish responses, as follows:

- Did the earlier migration observed in the upper Sacramento River continue through the middle Sacramento River?
  - Yes, passage timing was earlier than the 10-year average at Knights Landing and substantially earlier at Sherwood Harbor.
- Did water management actions taken in 2019 result in increased BY 2019 smolt survival through the middle Sacramento River?
  - No, but the BY 2019 smolt survival rate was calculated using a new method, which accounts for the decrease.
- Was there floodplain access for BY 2019? If so, were growth rates higher in the middle Sacramento River?
  - No, the flows were not high enough to access the floodplains due to the below normal 2020 WY, which is not a result of a management action. Fish size was not measured at sampling points, so no data were available to assess growth.

Discussion

The SAIL CMs provided an effective framework to assess the relative success of the BY 2019 cohort by providing life-stage-specific hypotheses on how fish responses are influenced by environmental and habitat conditions that are controlled in part by water management operations. The assessment results are discussed within the context of water management operations and a viable salmonid population in this section.

Conditions influenced by water management decisions led to optimal flow levels for creating the maximum spawning habitat and meeting the temperature criterion (56°F) at Balls Ferry approximately 99% of the required time within the spawning season and also meeting the pilot temperature criterion of 53.5°F at Clear Creek 98% of the time during spawning.

Pulse flows were implemented over the last 2 weeks of October as an additional management action in 2019. The early migration in the upper Sacramento River is attributed to the fall pulse flows that appeared to cause BY 2019 cumulative passage to occur earlier than average at RBDD. Before the pulse flows occurred, median passage at RBDD occurred 10 days earlier than average. After the fall pulse flows, migration was accelerated as 95% cumulative passage occurred 20 days earlier than average, and 100% passage occurred 34 days earlier than average. The early migration continued through the middle section of the river, where median cumulative passage between RBDD and Knights Landing occurred between 5 and 10 days earlier. Median cumulative passage at Sherwood Harbor, the entry to the Delta, occurred 57 days earlier than average. There was a turbidity spike recorded at the Verona gage associated with high flows in early December that is likely responsible for the extremely fast migration between Knights Landing and Sherwood Harbor. The effects of the early arrival of BY 2019 to the Delta are currently unknown. The early arrival could influence the length of time the fish spend in the Delta, timing of ocean entry, and survival. It will be important to follow this cohort through to escapement in 2022 to determine if the apparent benefits provided to BY 2019 during spawning, rearing, and migration extended to adulthood.

Flows in the upper and middle Sacramento River during juvenile rearing and migration were not high enough to access the floodplain habitat. These low flows were due to the below normal 2020 WY and not water management actions. The lack of floodplain access could be part of the reason BY 2019 continued their early migration throughout the upper and middle sections of the river to the Delta. Being able to access the floodplains at lower water levels in the future would likely provide additional growth opportunities for juvenile fish.

In the context of a viable salmonid population, the WRCS population appears to be recovering from the drought years and showing signs of improved viability. The number of adult spawners for BY 2019 (7,852 in-river spawners) was the highest observed since 2006, and their fecundity was high, resulting in approximately 26.5 million eggs being produced, which is the highest since 2006 and higher than the 10-year average (8.4 million).

The large return of in-river spawners in 2019 translated to a cohort replacement rate (CRR) of 5.2 for BY 2016 fish that returned to spawn in 2019, indicating that each adult spawner from 2016 produced approximately five spawners in 2019. The CRR estimate assumes that all spawners are produced 3 years earlier. This is the first time since 2015 that CRR has been greater than 1, indicating a growing population. The rate has been below 1 in 5 of the last 10 years, indicating the population is not replacing itself and is decreasing in size. A population that is consistently failing to replace itself is an indicator of increased extinction risk. It is expected that most BY 2019 adults will return to the Sacramento River in 2022 to spawn, and it remains to be seen if the high overall abundance of BY 2019 will translate into a CRR greater than 1 in 2022.

The hatchery influence on BY 2019 spawners was lower than during the drought years but was still higher than normal. However, genetic studies conducted to evaluate the impact of increased hatchery supplementation during the drought have so far found no evidence to suggest differences in adult reproductive success by origin. The genetic studies also found that run timing diversity is being preserved. There was no evidence that selection for early or late spawn timing, or run timing, is occurring. Therefore, it appears that the diversity of phenology phenotypes in the WRCS population are not being altered in a significant way by the hatchery program at this time.

The number of naturally produced fry and fry-equivalents (JPI; 4,762,142) at the RBDD was the highest since 2009. Similarly, the number of natural-origin juveniles entering the Delta (juvenile production estimate [JPE]; 854,941) was the highest since 2013. Juveniles arrived at the RBDD early and were smaller than average. The fish continued moving quickly through the system and arrived at the Delta entry point 57 days earlier than the 10-year average. It is unknown if these positive fish responses will carry through the life cycle and result in a strong escapement and CRR in 2022 and continue to strengthen population viability through time.

Additional Data Needs

To facilitate future cohort assessments, Anchor QEA identified the following data needs in the upper and middle Sacramento River reaches:

- Develop methods to better identify redds in the reach below Keswick Dam, where the water is deep and visibility is impacted by turbidity from water released from the dam. The number and location of redds are input parameters for the SacPAS survival model and are also important for managing water temperatures during egg incubation and emergence.
- Implement regular monitoring of floodplain access. A BY 2018 analysis conducted by Cordoleani et al. (2020) indicated that juveniles who accessed floodplain areas had higher growth than fish that remained in the mainstem Sacramento River. This 1 year of study should be repeated to better inform water management actions that could support floodplain access and fish growth and track how this growth affects migration through the Delta.
- Consistent with a recommendation by Johnson et. al. (2017), collect weight, body condition, and length data at the rotary screw traps (RSTs) to evaluate the juvenile fish health and condition as they migrate and pass various locations and assess how management actions influence fish condition.
- Collect data on other factors that could influence egg-to-fry survival, fry-to-smolt survival, and smolt survival, including predators, pathogens or disease, contaminants, and suspended

sediments. These data are needed to better understand what is driving fish responses so that water can be used efficiently.

Next Steps

Overall, the approach developed to assess BY 2019 was informed by a well-thought-out CM framework and a large amount of readily available data for the primary variables of interest. This allowed the assessment to be conducted efficiently. A robust analytical framework has been established for assessing BY responses to water management actions each year. The assessment can be easily replicated annually to accomplish the following: 1) potentially inform adjustments in water management operations to benefit WRCS; and 2) build a time series for trend analysis. This report constitutes the beginning of a time series of analytical results to assess population status and responses to water management operations and progress toward WRCS population viability through time.

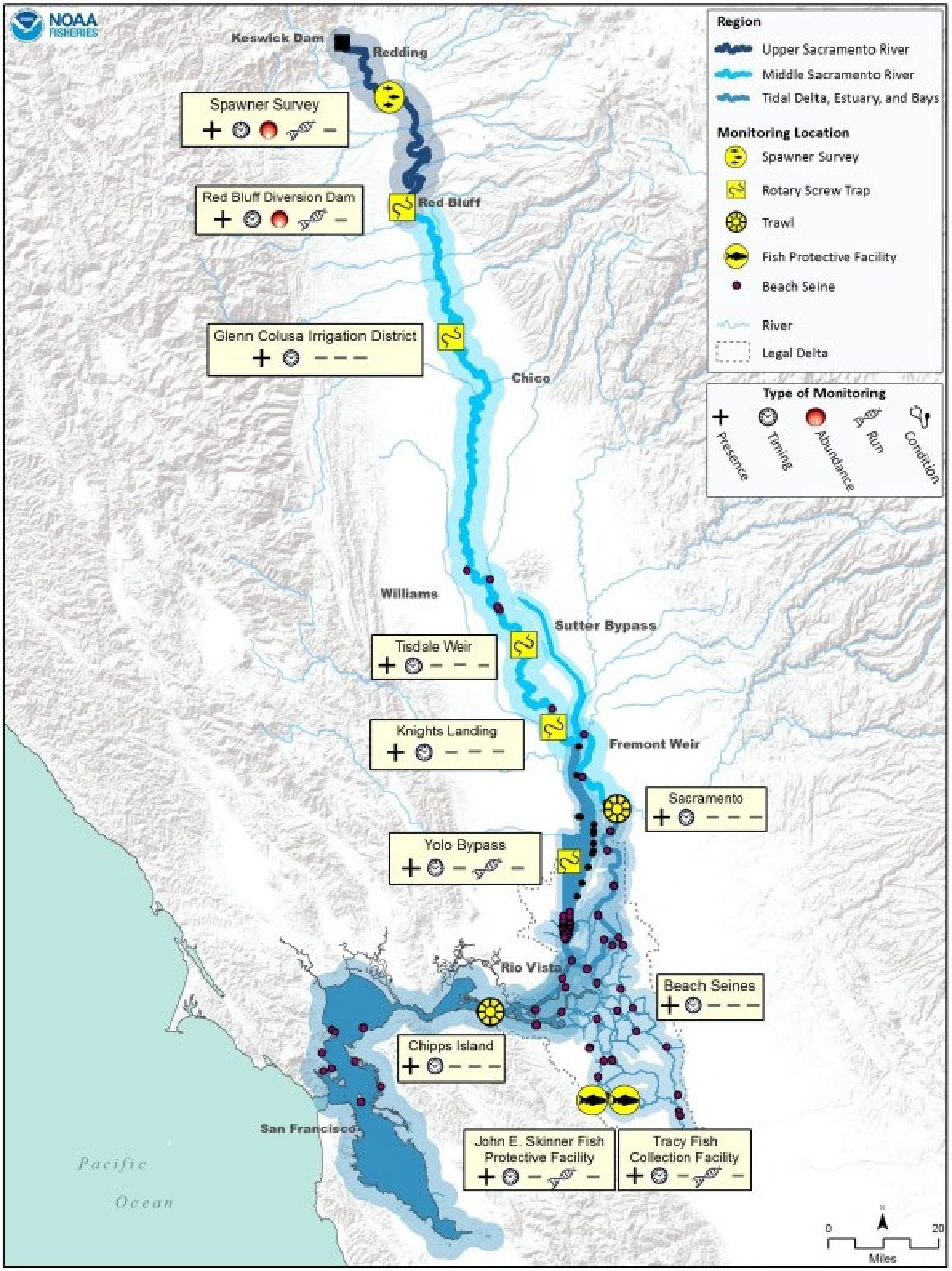
1 Introduction

The purpose of this assessment is to evaluate the relative success of the 2019 brood year (BY) of Sacramento River winter-run Chinook salmon (WRCS; *Oncorhynchus tshawytscha*). This assessment identifies if and how existing management strategies provided conditions that supported salmon survival using available environmental, habitat, and biological response data. BY 2019 WRCS were evaluated in the context of the Salmon Assessment of Indicators by Life Stage (SAIL) conceptual models (CMs) (Windell et al. 2017). The SAIL CMs provide a framework to assess the relative success of the BY 2019 cohort by providing life-stage-specific hypotheses on how fish responses are influenced by environmental and habitat conditions, as well as current and previous management actions. The management actions implemented in 2019 were designed to provide suitable conditions for WRCS that support overall population productivity. To relate the data analyzed in this assessment for each life stage and reach to management objectives, Anchor QEA formulated a series of questions in Sections 4.3, 5.3, 6.3, and 7.3 to present key findings that inform each question.

This assessment focuses on freshwater life stages from 2019 adult returns through BY rearing and out-migrating juveniles in the upper and middle Sacramento River (Figure 1). The upper Sacramento River is the reach just below Keswick Dam at river mile (RM) 302 to the Red Bluff Diversion Dam (RBDD) at RM 242. Environmental and habitat conditions experienced by returning adults in the upper river are considered for the period from January through September 2019. Eggs and juveniles in the upper river are evaluated from the estimated beginning of redd occupation in June 2019 through the last migrants past RBDD in March 2020. The middle Sacramento River is defined as the reach from RBDD to the Delta entry point at Sherwood Harbor (RM 55). Rearing and out-migrating juveniles in the middle river are evaluated from first passage below RBDD in July 2019 through the last detected passage at the trawls in Sherwood Harbor in March 2020.

This report is organized by life stage down to the point of Delta entry, and an assessment of life stages in the Delta and early ocean residence using the SAIL CM framework could be added in the future. Recommendations for additional monitoring, research, or documentation to better evaluate impacts on WRCS in the future are also provided.

Figure 1
Sacramento River Reaches and Delta



Map of Sacramento River and Delta from Windell et al. (2017).

2 SAIL Conceptual Models

The SAIL CMs were developed by a team of scientists formed by California's Central Valley Interagency Ecology Program. The CMs provide a scientific framework for evaluating existing information on endangered WRCS and provide recommendations to improve the management value of life stage monitoring.

The overall SAIL CM for WRCS is composed of seven separate CMs. The seven CMs are organized among four geographic regions by the following life stages: egg-to-fry emergence, rearing juvenile to out-migrating juvenile, ocean juvenile to ocean adult, migrating adult to holding adult, and holding adult to spawning adult. Life stages are associated with geographic regions, which were identified based on significant changes in the ecosystem in conjunction with locations of key monitoring points (Windell et al. 2017). The four geographic regions are the upper Sacramento River, middle Sacramento River, Bay-Delta, and Ocean (Figure 1).

Within the CMs, the following hierarchical tiers were created to describe the environmental pathways that affect each life stage within a geographic region:

- **Tier 1: Landscape Attributes:** Local to system-wide features that change slowly over long periods of time and directly influence environmental drivers
- **Tier 2: Environmental Drivers:** Features that occur over a broad range of temporal and spatial scales, occur within the geographic range of the species, and directly influence habitat attributes
- **Tier 3: Habitat Attributes:** Features that also have a broad range of spatial and temporal scale but directly affect the species' demographic responses
- **Tier 4: Fish Responses:** Factors that are associated with the transition to a subsequent life stage (i.e., life stage input, survival, timing and migration, and condition and growth) and are directly influenced by habitat attributes

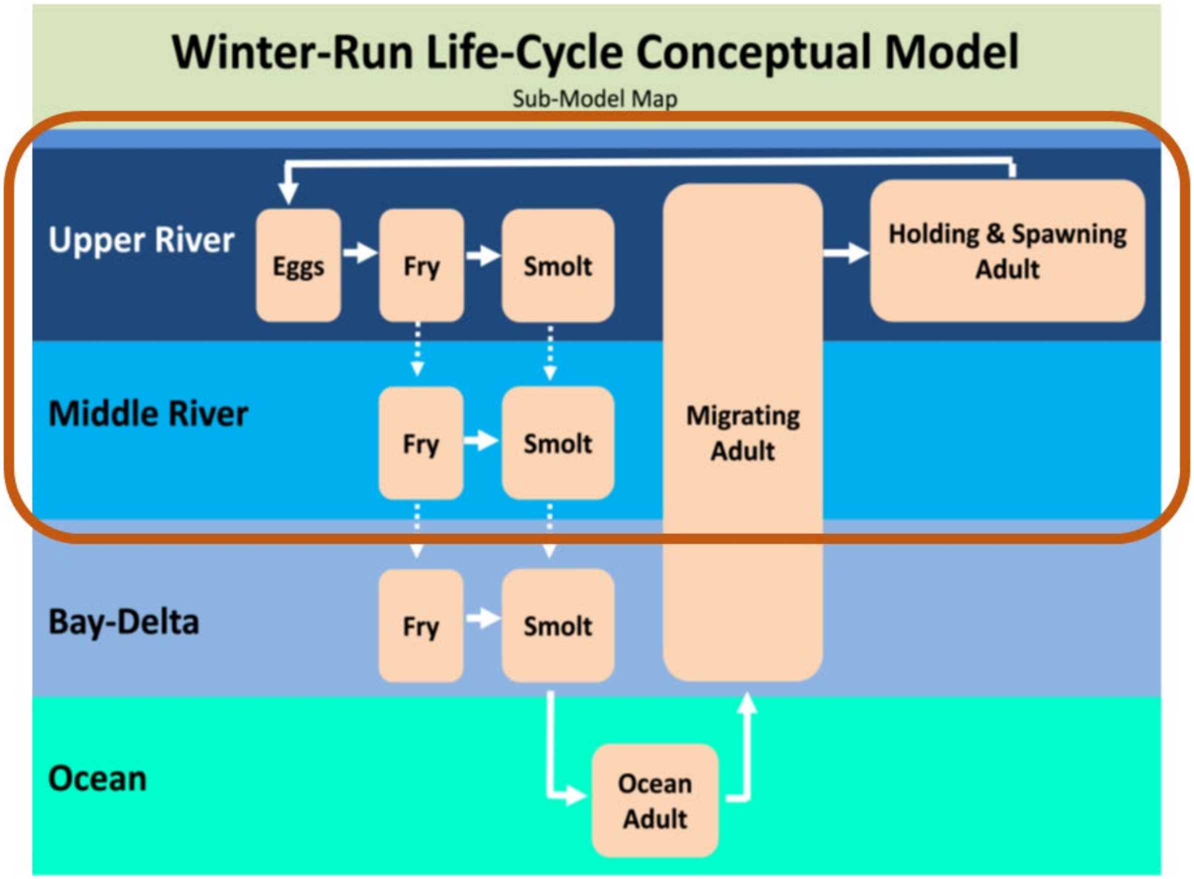
This assessment primarily focuses on how environmental drivers and habitat attributes influence fish response because environmental drivers and habitat attributes are more likely than landscape attributes to vary on an annual timescale and therefore affect BYs differently. Examples of environmental drivers include flow released from Keswick Dam (RM 302), hatchery influence, contaminant loading, air temperatures, and predator-prey interactions. Habitat attributes include food and refugia availability, water temperature, dissolved oxygen (DO) levels, and disease prevalence. Fish responses encompass life history trade-offs such as growth, condition, survival, and migration timing. In addition, some CM variables may be under direct management control. These management actions are included within the CMs to account for their influence on fish responses. Examples of features under management control in the Sacramento River system include

Shasta Reservoir cold-water storage, Keswick Dam flow releases, irrigation diversions, recreational fisheries, and hatchery supplementation.

CMs used in a previous, similar cohort assessment by Israel et al. (2015) have been expanded upon by the SAIL CMs. This assessment focuses on the conditions and responses experienced by BY 2019 in the upper and middle Sacramento River, starting with the holding-adult-to-spawning-adult life stage (Figure 2). Using available environmental, habitat, and fish response data, the conditions experienced by BY 2019 during egg-to-fry emergence and rearing-to-out-migrating juvenile life stages are examined to better understand the relatively successful outcome of BY 2019 in comparison to other recent BYs. This document steps through SAIL CMs by life stage to accomplish the following:

- Identify the biological responses observed for each life stage and put the BY 2019 observations into context by comparing them to the historical trends.
- Describe the environmental and habitat conditions that occurred during each life stage and put them into the context of recent historical conditions, including similar water year (WY) conditions.
- Pose specific questions about causes of the biological responses observed and link the causes to the relevant SAIL hypotheses for how environmental drivers or habitat attributes likely contributed to the observed biological response.
- Summarize findings based on available data that address each given hypothesis, including identifying the relevant management actions or existing data gaps that influenced the findings.

Figure 2
Winter-Run Life-Cycle Conceptual Model



Sacramento River WRCS depiction of the different life stage and geographic domains developed into CMs, taken from Windell et al. (2017). The orange box shows emphasis on life stages in the middle and upper river that are covered in this assessment.

3 Data Sources

Available data sources that were used in the assessment are summarized in Table 1. Most of the habitat attributes and environmental drivers data and figures used in this assessment were obtained directly from the Central Valley Prediction and Assessment of Salmon (SacPAS) website (SacPAS 2020). Juvenile abundance and survival estimates were obtained from the National Marine Fisheries Service (NMFS) juvenile production estimate (JPE) letters. Fish survey and summary data tables were provided by California Department of Fish and Wildlife (CDFW) Region 1 to Anchor QEA directly through Evan Sawyer of NMFS. Anchor QEA also made use of data downloaded or reviewed online from the CalFish and California Data Exchange Center (CDEC) websites. Several individuals from NMFS, U.S. Fish and Wildlife Service (USFWS), U.S. Bureau of Reclamation (USBR), and the California-Nevada Fish Health Center (CNFHC) provided reports with data used in this assessment. A Delta Science Fellowship final report by Neil Thompson and Central Valley Project Improvement Act (CVPIA) habitat modeling outputs by Flow West were also used to inform some variables. All additional background references used in this document are provided in Section 9.

Table 1
Sources of Data Used in the BY 2019 WRCS Assessment

CM Variables	Data Summary	Data Source
Fish Response		
Adult Survival (abundance)	Carcass survey, WRCS summary data file	Provided by Evan Sawyer (NMFS). Carcass survey data from CalFish,[1] WRCS summary table from Doug Killam (CDFW)[2]
Adults to Hatchery	WRCS summary data file, GrandTab	Provided by Evan Sawyer (NMFS), from Doug Killam (CDFW),[2] GrandTab from CalFish[1]
Adult Fecundity	LSNFH fecundity estimate	NMFS JPE letters[3]
Pre-Spawn Mortality	WRCS summary data file	Provided by Evan Sawyer (NMFS), from Doug Killam (CDFW)[2]
Egg-to-Fry Survival	JPE letters	NMFS JPE letters[3]
Rearing Growth (FL)	RBDD RST fork length	SacPAS,[4] (data courtesy of USFWS RBDD)
JPI (fry-equivalent)	JPE letters, USFWS reports	NMFS JPE letters,[3] reports by USWFS [2020a][5]
Fry-to-Smolt Survival[2]	JPE letters	NMFS JPE letters,[3] O'Farrell et al. 2018
Migration Timing	Multiple RSTs	SacPAS,[4] (data courtesy of USFWS Lodi and RBDD and CDFW), GCID
Smolt Survival	JPE letter	NMFS JPE letters[3]

CM Variables	Data Summary	Data Source
JPE	JPE letter	NMFS JPE letters[3]
Hatchery Smolt Survival	JPE letter	NMFS JPE letters[3]
Hatchery JPE	JPE letter	NMFS JPE letters[3]
Habitat Attributes		
Redd Dewatering	Stranding surveys, data file	Provided by Matt Johnson (CDFW)[6]
Juvenile Stranding	Stranding surveys, data file	Provided by Matt Johnson (CDFW)[6]
Water Temperature	River gages	SacPAS,[4] CDWR CDEC Station Map[7]
DO	River gages	SacPAS,[4] CDWR CDEC Station Map[7]
Habitat Capacity	Habitat WUA	CVPIA SIT Salmon Population Model data website[8]
Habitat Refuge	No data available	-
Food Quality/Availability	No data available	-
Pathogens/Disease	CNFHC reports	Study reports and testing results provided by Scott Foott (CNFHC)[9,10]
Hatchery Pathogens/Disease	LSNFH, CNFHC reports	Amanda Cranford (NMFS),[11] Study reports and testing results provided by Scott Foott (CNFHC)[9,10]
Toxicity/Contaminants	No data available	-
Substrate Size/Sedimentation	No data available	-
Predation/Competition	No data available	-
Fishery/Recreation Disturbance	Not evaluated	-
Entrainment Risk	No data available	-
Environmental Drivers		
Air Temperature	Historical weather data	National Weather Service[12]
Keswick Dam Flows/Migration Cues*	River gages	SacPAS,[4] CDWR CDEC Station Map[7]
Fish Assemblage	No data available	-
Hatchery Influence	Reports and academic studies	LSNFH report[11] provided by Amanda Cranford (NMFS) and a Delta Science Fellowship final report by Neil Thompson (NMFS)[13] provided by Josh Israel
Depth/Shallow Water	Habitat WUA	CVPIA SIT Salmon Population Model data website[8]
Food Production	No data available	-
Turbidity	River gages	SacPAS[4]
Mobilized Substrate	No data available	-

CM Variables	Data Summary	Data Source
Contaminant Loading	No data available	-
Irrigation Diversions	No data available	-
Floodplain Connectivity	Habitat WUA, weir overtopping	CVPIA SIT Salmon Population Model data website,[8] SacPAS[4]
Shasta and Trinity Storage/Hydrology	Reports, river and reservoir gages	SRTTG annual report[14] provided by Evan Sawyer (NMFS), SacPAS[4]

Notes:

1. CalFish 2020
2. Killam [unpublished]
3. NMFS 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020
4. SacPAS 2020
5. USFWS 2020a
6. Johnson 2020
7. CDWR 2020
8. CVPIA 2020
9. Foott et al. 2019
10. USFWS 2020b
11. LSNFH 2020
12. NWS 2020
13. Thompson 2019
14. SRTTG 2019

4 Adult Spawning in the Upper Sacramento River

This section describes the assessment findings for adult spawning in the upper Sacramento River. A summary of findings is provided, followed by the analysis each of fish response and habitat attributes and environmental drivers.

WRCS escapement in 2019 was the highest since 2006, with 7,852 mainstem in-river spawners and a system-wide estimate of 8,033 returning adults. Based on carcass fork length data, spawners were primarily age-3 fish produced by BY 2016 return spawners. BY 2016 fish were spawned after the worst effects of the drought were over, and juvenile freshwater life stages experienced below normal to wet WY conditions in 2016 to 2017. Returning adults in 2019 experienced environmental and habitat conditions that were better than or equal to the 10-year average, and pre-spawn mortality was 1.3%, which is greater than the 10-year average of 1.1% but less than the highest level of 2.0% observed within the past 10 years in 2015. Releases of flows from Keswick Dam (RM 302) resulted in a maximum amount of spawning habitat and a source of cool water to the upper Sacramento River that benefited the adult spawners.

The proportion of hatchery spawners estimated from spawner surveys in BY 2019 was 37%. This proportion was lower than recent drought years but is higher than the 10-year average (33%). The proportion of natural influence (PNI), which is a metric of hatchery-associated genetic risk, was 0.46 for BY 2019, which is below the recommended value of greater than or equal to 0.67 for this system (LSNFH Supplementation Report 2019). However, preliminary results from a genetic study of hatchery influence found no evidence of differences in reproductive success by origin or a reduction in run timing diversity, or that hatchery broodstock relatedness resulted in reduced offspring survival (Thompson 2019).

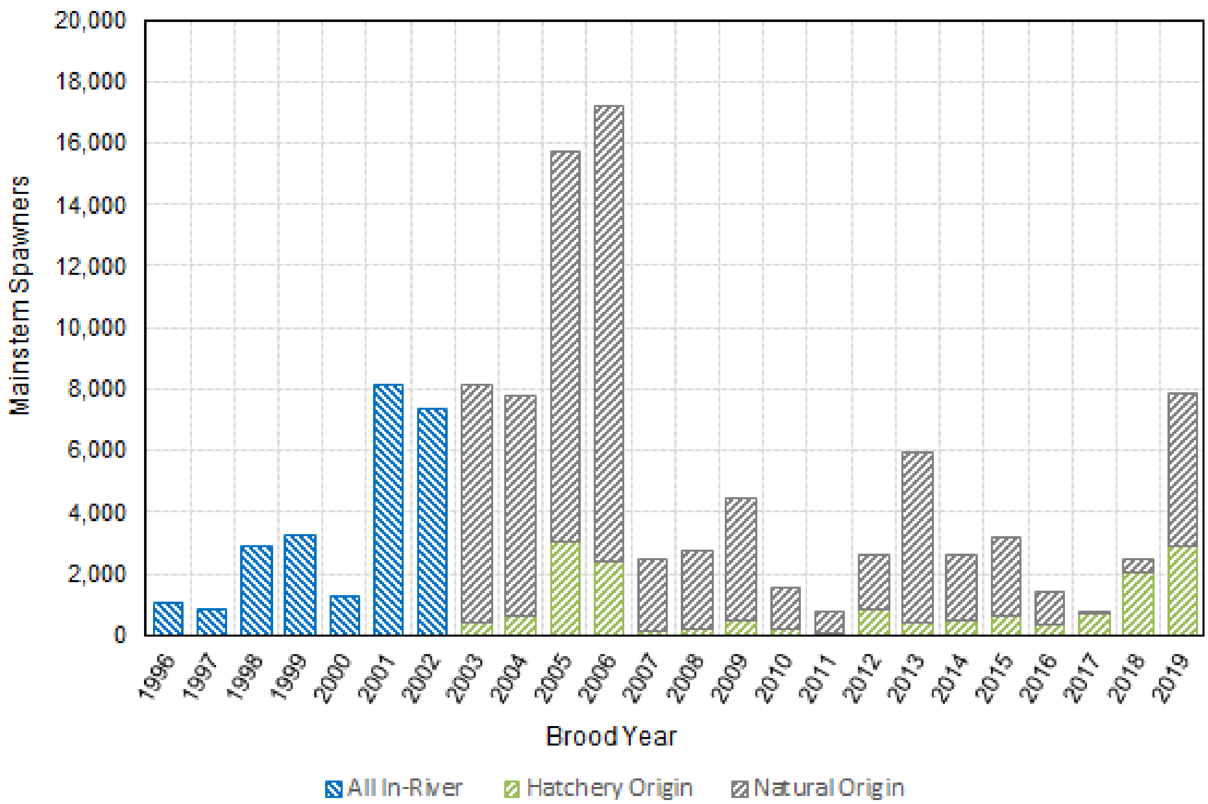
4.1 Fish Response

4.1.1 Adult Survival (Escapement)

The total number of mainstem in-river spawners observed in 2019 was 7,852. This included 2,873 hatchery-origin fish (36.6%) and 4,979 natural-origin fish (63.4%) (Figure 3). Since 1996, the total number of in-river spawners of both hatchery and natural origin has averaged 4,679 fish. This average is influenced by 2 years of substantially higher escapement that occurred in 2005 and 2006 when over 15,000 fish returned each year. The 10-year average of in-river spawners is 2,909 fish. In 2019, a total of 180 natural-origin fish were collected for hatchery broodstock, and one fish was documented during a tributary survey (Azat 2019). This resulted in a system-wide estimate of 8,033 total adult spawners in 2019. Since 2010, 173 fish on average have been taken annually for hatchery broodstock, and between zero and two WRCS have been documented spawning in tributaries annually.

Prior to 1980, returns of over 15,000 fish were common, but during the 1980s average in-river escapement fell below 5,000 (Azat 2019). This was the result of a steady decline of WRCS and other salmonids after the construction of RBDD (RM 242) in the 1960s (Stene 1994). This led to the opening of the RBDD gates annually for WRCS passage starting in 1987 and establishment of the hatchery conservation program in 1989 (Stene 1994; Thompson 2019). The number of returning hatchery-origin spawners has been estimated annually since 2003 and averaged 924 fish per year in that period. Natural-origin spawners averaged 4,227 fish during that same period (Figure 3).

Figure 3
Estimated Total Mainstem In-River Spawners of Natural and Hatchery Origin



Estimated total mainstem in-river spawners of natural and hatchery origin (data from Killam [unpublished]). All in-river spawners are shown in blue for years 1996 to 2002. Natural-origin spawners (grey) and hatchery-origin spawners (green) are shown for 2003 to 2019.

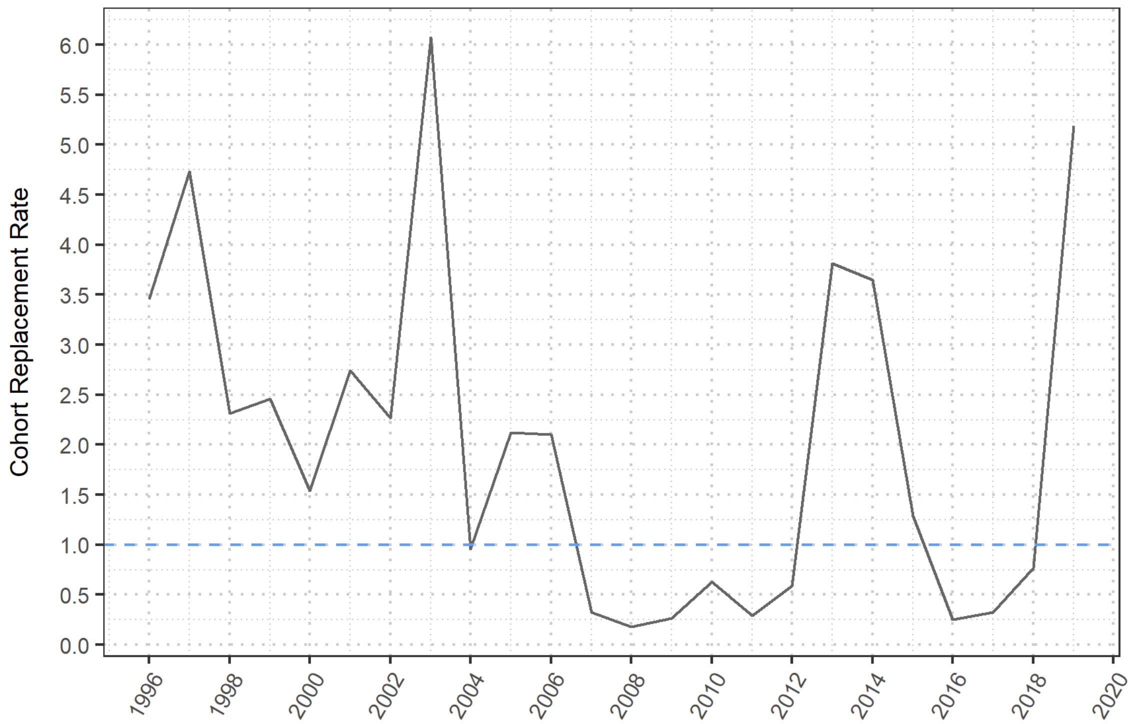
In 2011 and 2017, which were characterized as wet WYs, the total number of mainstem in-river spawners was 738 and 795 fish, respectively. In 2011, 10.7% of the fish were hatchery-origin. In contrast, in 2017 many BY 2014 and BY 2015 hatchery-origin juveniles supplemented during the drought likely returned because hatchery-origin fish comprised 82.4% of the total that year. Hatchery influence is discussed in more detail in Section 4.1.4.

In 2019, 62% of in-river fish were estimated to be females, including 1% jills, and 5% were estimated to be jacks. The percent jills was lower than the 10-year average of 4% and much lower than in the recent similar WY, 2017, when jills were 17.2% of returning females. This may have been due to the higher percentage of hatchery-origin return spawners that year that may be more likely to return as age-2 fish (Thompson 2020). The percent of jacks observed in 2019 was notably less than the 3-year average from 2016 to 2018 of 31% and the 10-year average of 14%. A spike in percent jacks from 2016 to 2018 corresponded with a 3-year drop in the percentage of in-river adults that were females. The spawner age of BY 2019 fish is discussed in more detail in Section 4.1.2.

4.1.2 Cohort Replacement Rate

Assuming all age-3 fish return as adult spawners, the cohort replacement rate (CRR) can be calculated by dividing the number of current BY spawners by the number of spawners 3 years prior. Using this calculation, the CRR for 2019 was estimated as 5.2 (Killam [unpublished]). This was the first year with a replacement rate greater than 1.0 since 2015 (Figure 4). It reflects 3 years of recovery from drought conditions that occurred from 2012 to 2016 and from severe to extreme drought conditions that occurred in the upper Sacramento River region from 2013 to 2015 (Simeral 2020). CRRs were below 1.0 in WYs 2011 and 2017, which were classified as wet like WY 2019.

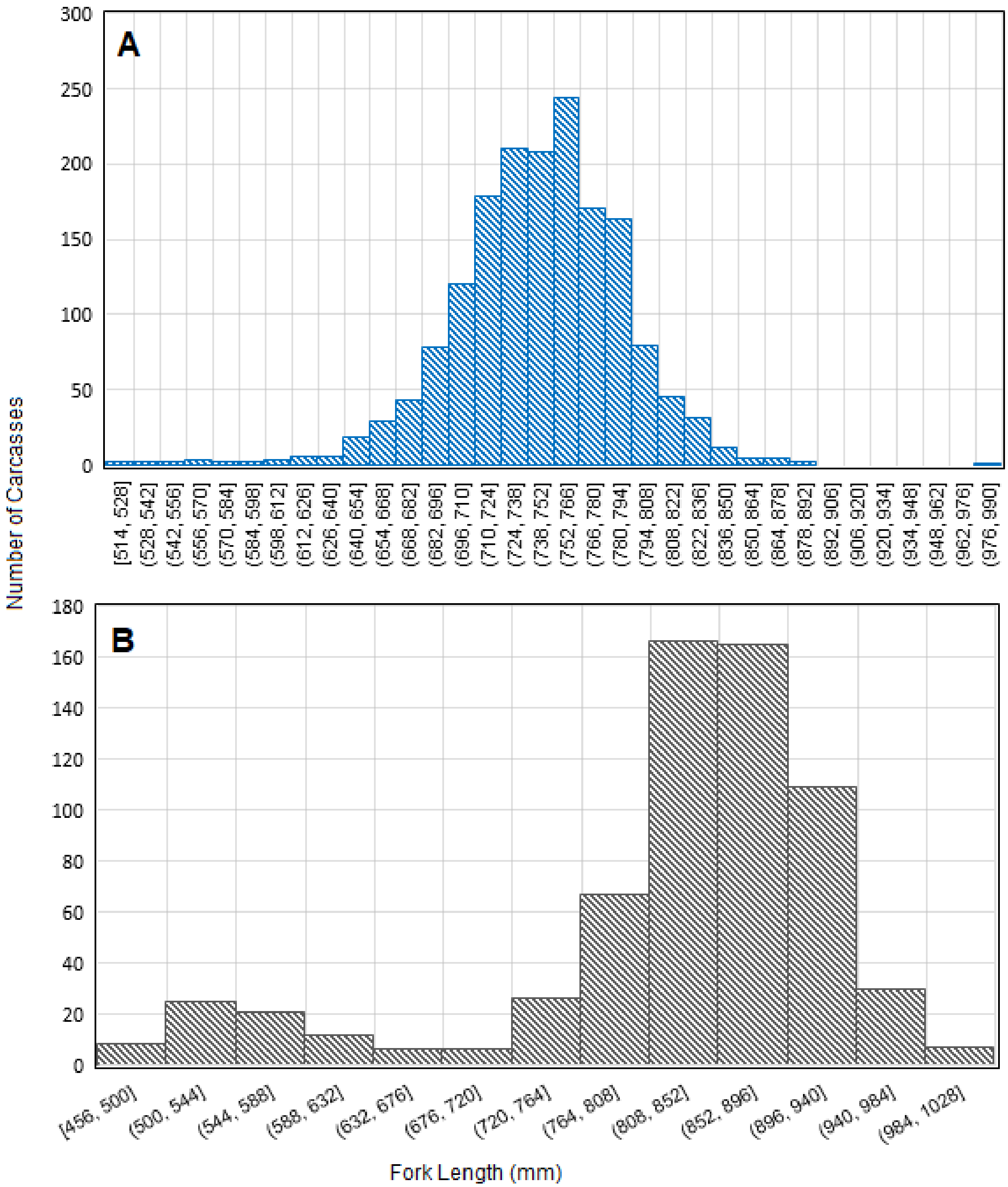
Figure 4
Winter-Run Chinook Salmon Annual Cohort Replacement Rate



WRCS annual CRR is indicated with a black line. The blue dashed line shows a replacement rate of 1.0, defined as one returning spawner per one adult spawner 3 years prior. Replacement rates greater than 1.0 indicate an increasing population. Data from Killam (unpublished).

Approximately 85% to 100% of Sacramento River WRCS are documented to return from the ocean as age-3 fish. The distribution of fork lengths from female carcasses sampled in 2019 confirms that returning adults in 2019 primarily belong to a single age-3 cohort (Mean [standard deviation] = 744 millimeters [mm] [46mm]), though at least one likely age-4 female (>950 mm) was documented (Thompson 2020; Figure 5, panel A). Fork length data from male carcasses sampled in 2019 indicates that approximately 89% of returning males were of the same age cohort, whereas approximately 11% of carcasses appeared to be jacks (<700 mm; Figure 5, panel B).

Figure 5
Carcass Fork Length Distribution for 2019



Carcass fork length distribution for 2019 upper Sacramento River WRCS returning females (A) and males (B). Data from CalFish (2020).

4.1.3 Fish Condition

Pre-spawn mortality was estimated to be 1.3% in 2019. This is slightly greater than the 10-year average of 1.1% but less than the highest level of 2.0% observed within the past 10 years in 2015. The mortality rate in 2019 fell between the mortality observed in similar WYs, 2011 and 2017, where pre-spawn mortality was estimated as 0.6% and 1.7% in those years, respectively.

As discussed in Section 4.1.1, in 2019, 180 adult fish (60 females and 120 males) were collected for hatchery broodstock from the fish trap at the Keswick Dam (USFWS 2019), representing 2.2% of the total mainstem run. All collected fish were found to be in good body condition (NOAA 2019). Annual fecundity is estimated from female fish spawned at Livingston Stone National Fish Hatchery (LSNFH). For 2019 spawners, fecundity was estimated to be 5,424 eggs per female based on data from 56 hatchery females that contributed to BY 2019 progeny. Average fecundity over the last 10 years was estimated to be 4,782 eggs per female (Voss and Poytress 2017; NMFS 2017, 2018, 2019, 2020), and fecundity estimate for 2019 represents a 13% increase over the 10-year average. Preliminary results from genetic studies on the WRCS population have found fecundity to be the only significant predictor of female and male reproductive success (Thompson 2019).

4.1.4 Hatchery Influence

Because of declines in Sacramento River WRCS from BY 2013 through BY 2017, it was decided to support the natural population by increasing hatchery supplementation. In 2014 and 2015, the number of in-river spawners taken as LSNFH broodstock (12.8% and 7.5% of the total mainstem run, respectively) was increased along with releases of hatchery-origin juveniles. As of 2019, natural-origin fish represented 31% of hatchery broodstock. The number of hatchery fish contributing to the natural spawning population was 2,873 (36%), which was higher than the 10-year average of 32.6%. Both the number of natural-origin fish in the hatchery broodstock and the number of hatchery-origin fish in the natural spawning population contributed to the PNI calculation for the WRCS population. The PNI metric is an important indicator of genetic risk to the natural population associated with hatchery fish. In 2019, PNI was 0.46, which is well below the recommended PNI for Sacramento WRCS of greater than or equal to 0.67, indicating a greater than recommended risk of hatchery influence occurred in 2019.

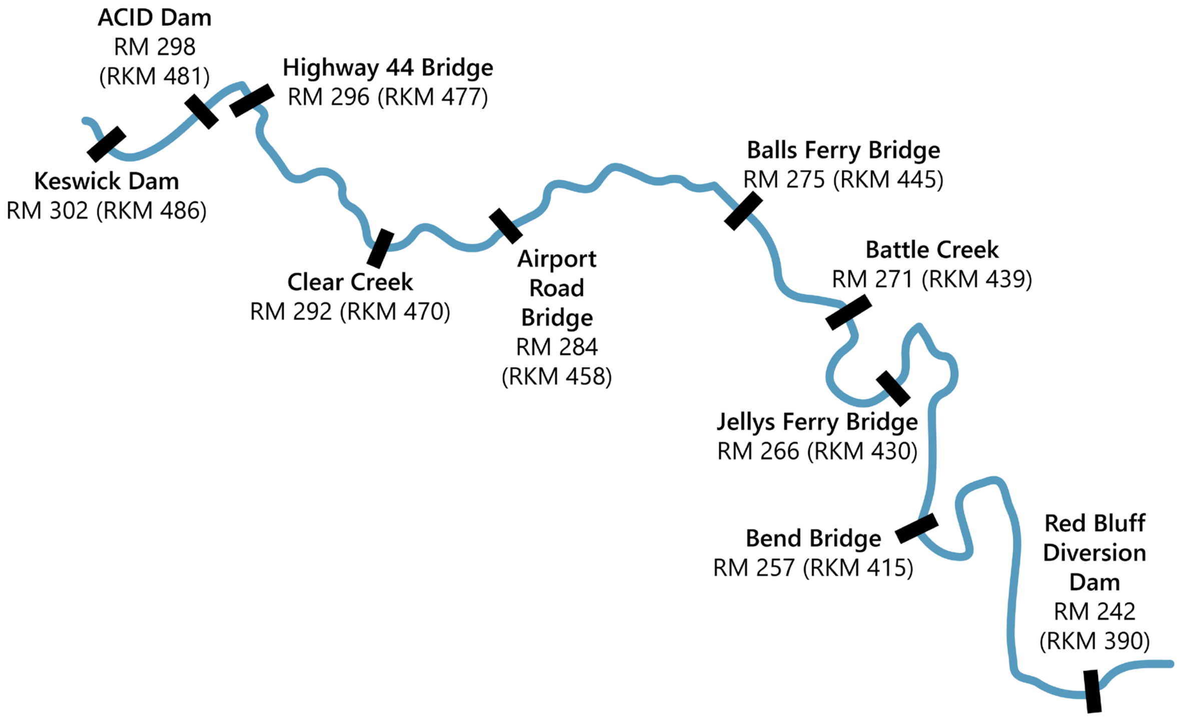
Additional research assessing the influences of the hatchery program on the natural WRCS population is ongoing. To date, genetic studies have found no evidence to suggest there are differences in adult reproductive success by origin or that hatchery broodstock relatedness is resulting in reduced offspring survival (Thompson 2019). Further genetic findings on run timing are discussed in Section 4.1.5.

4.1.5 Migration Timing

WRCS generally leave the ocean and begin arriving in the Sacramento River from December through April. Adults return before they are fully mature and are assumed to be 85% to 100% age-3 fish (O'Farrell et al. 2012; Crozier et al. 2019). Since monitoring began in 1970, spawning has begun in April and continued through September (Azat 2019; Crozier et al. 2019). Over the last 10 years (2010 through 2019), aerial redd surveys of the upper Sacramento River have observed the first WRCS redds from the second week of May through mid-June. Carcass surveys during the same period have detected the first 1% of fresh female carcasses between May 1 and May 17. Carcass surveys between Keswick Dam and Balls Ferry Bridge (RM 275; Figure 6) showed that the 2019 adults began spawning approximately 1 week later than the 20-year average but at the same time as the 10-year average (Figure 7). Peak spawning also occurred approximately 1 week later than the 20-year average but at the same time as the 10-year average. The greater percentage of total spawning that occurred later in the season from late July until late August 2019 is consistent with the 10-year average (Figure 7); however, there appears to have been a trend toward later peak spawning since 2010 (Figure 8).

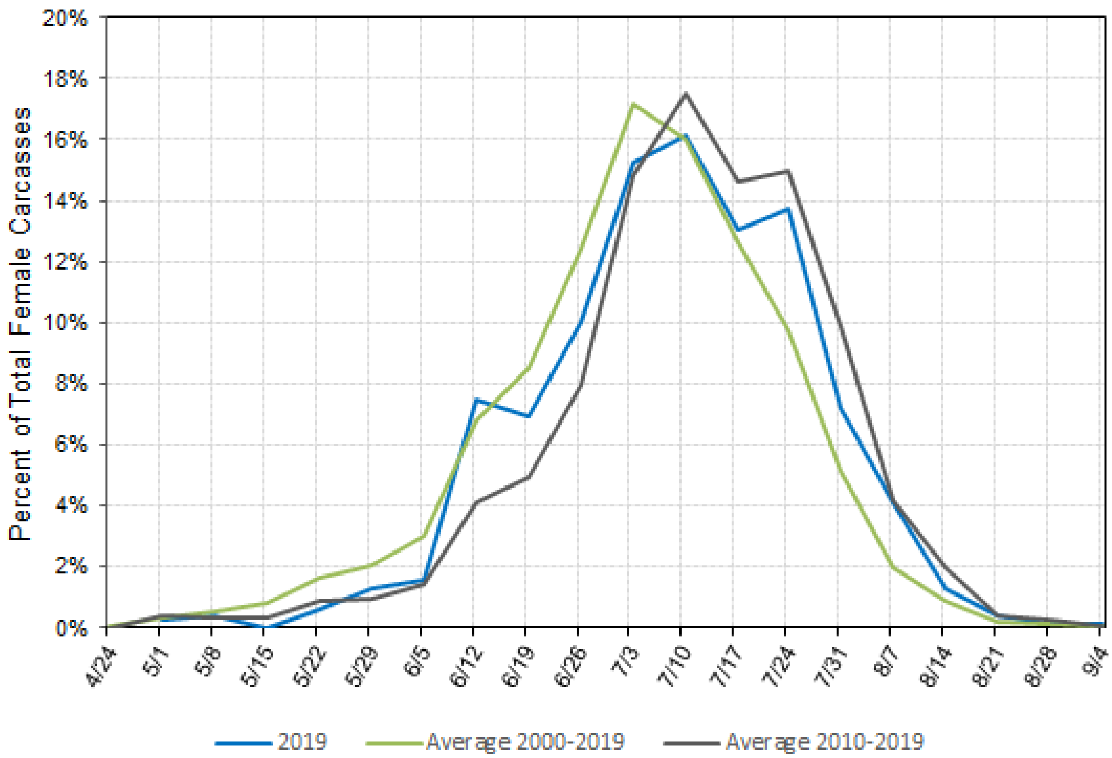
Preliminary genetic study results of hatchery influence on the natural WRCS population have so far found that run timing diversity is being preserved (Thompson 2019). There was no evidence that selection for early or late spawn timing, or run timing, is occurring. Therefore, it appears that the diversity of phenology phenotypes in the WRCS population is not being altered in a significant way by the hatchery program at this time (Thompson 2019).

Figure 6
Diagram of the Upper Sacramento River with Key Landmarks and RM



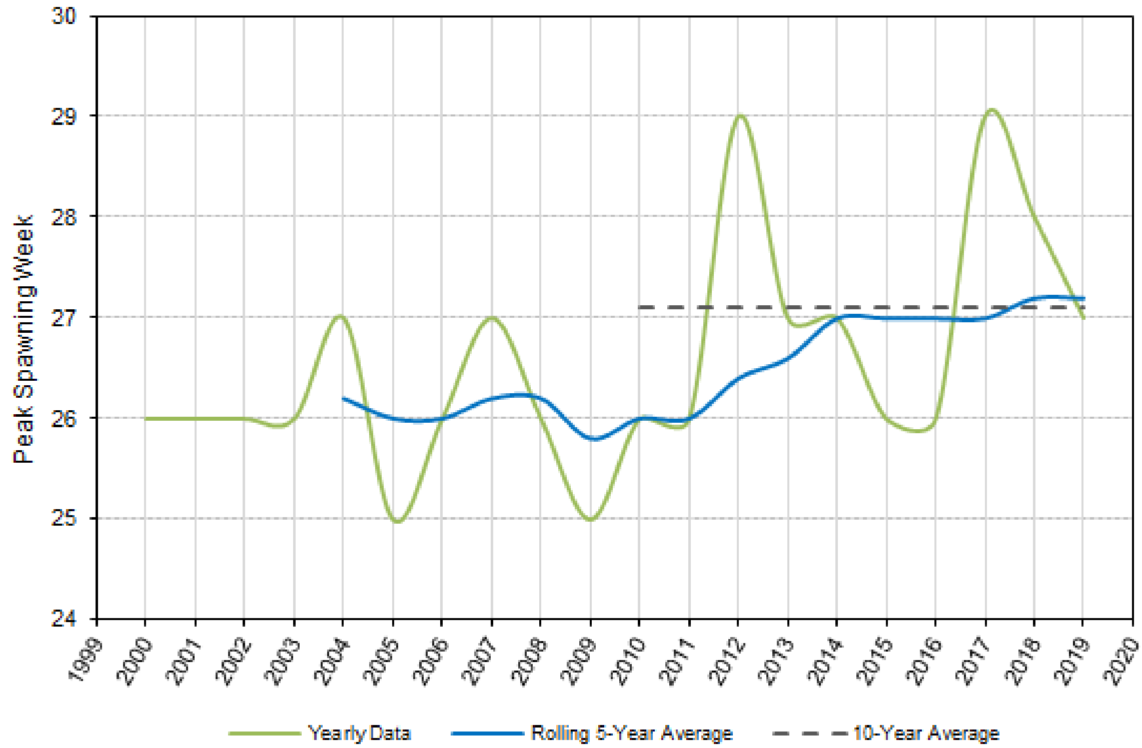
Redrawn from Anderson (2018).

Figure 7
Percent Spawning by Week for 2019



Estimated percentage of spawning by week for 2019 from carcass surveys. Average timing for years 2000 to 2019 (20-year average) and 2010 to 2019 (10-year average) are also shown. Data from CalFish (2020).

Figure 8
Peak Spawning Week from 2000 to 2019



Trend toward later peak spawning based on carcass data over the last 20 years. Data from CalFish (2020).

4.2 Habitat Attributes and Environmental Drivers

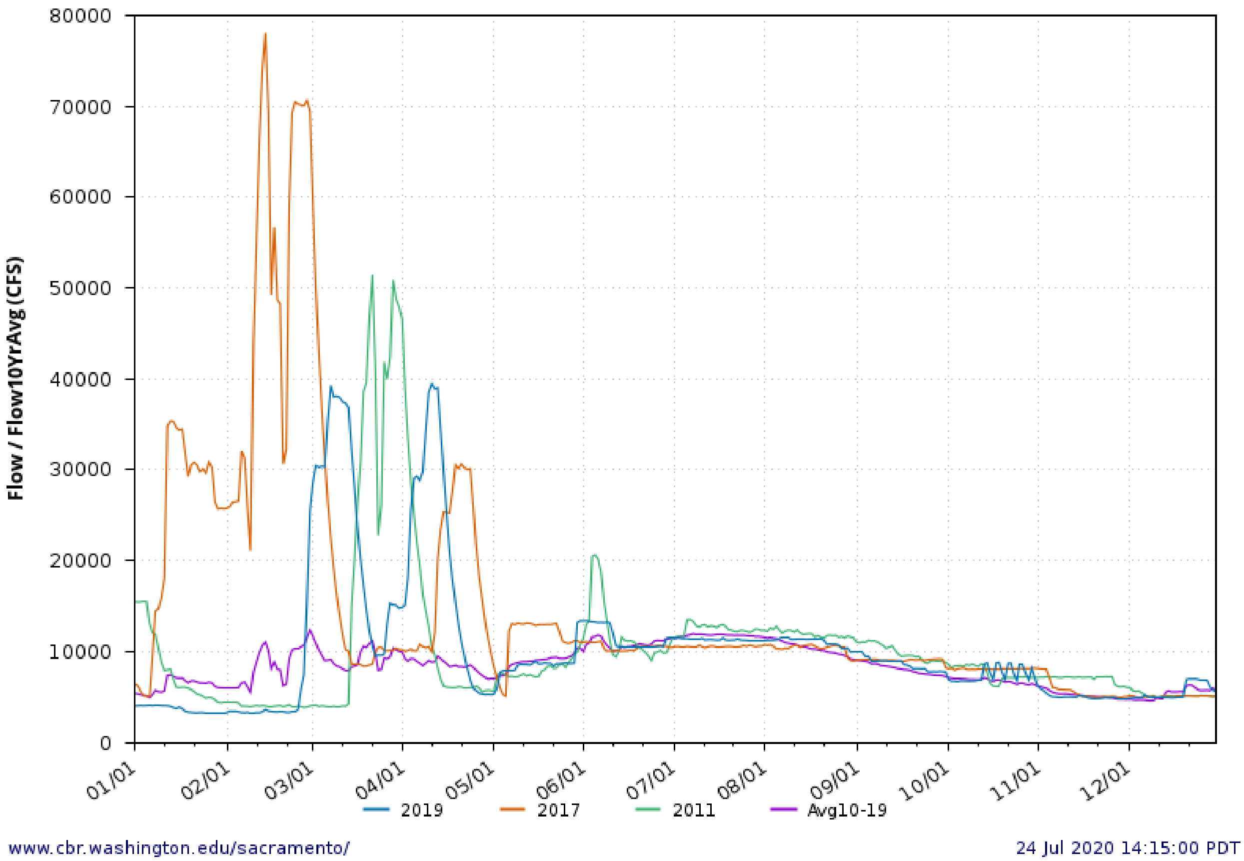
The following section summarizes the habitat attributes and environmental drivers that influenced returning adults in 2019.

4.2.1 River Flows and Keswick Dam Releases

WY 2019 was classified as a wet WY for the Sacramento River valley (CDWR 2020). Sacramento River flow at Bend Bridge (RM 257), just north of Red Bluff, had above-average flows from January through April 2019, with peak flows reaching more than 70 thousand cubic feet per second (kcfs) in early March 2019 and a second peak of approximately 55 kcfs occurring in mid-April 2019 (Figure 9). These higher-than-average flows occurred because of releases from Keswick Dam required by the U.S. Army Corps of Engineers for flood management. Flow then dropped to near the 10-year average by May 1, 2019. Flows below Keswick Dam during the spawning season (May through September 2019) were maintained at a level similar to the 10-year average except in late May and early June 2019, when there was an additional but smaller release for flood management, causing flows at

Bend Bridge to increase to approximately 15 kcfs, which is above the 10-year average. Flow for the remainder of the spawning season was comparable to the 10-year average.

Figure 9
Sacramento River Flow at Keswick Dam



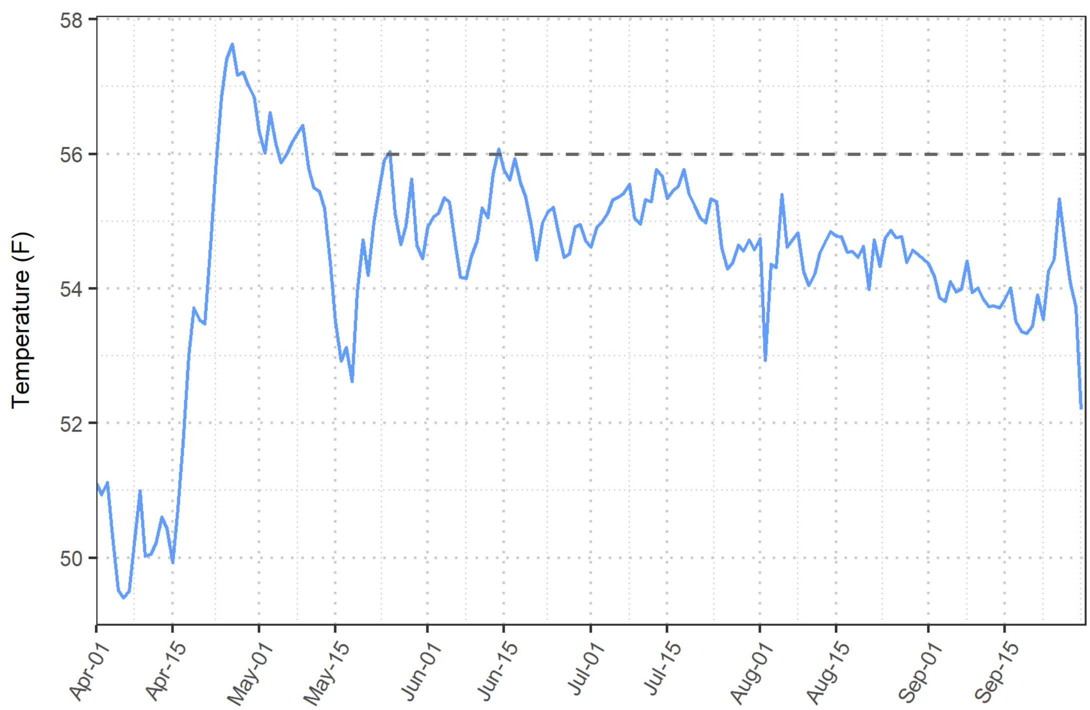
Sacramento River flow at Keswick Dam gage showing 2019, 10-year average flow, and similar wet WYs 2011 and 2017. Figure and data from SacPAS (2020).

4.2.2 Water Temperature

The State Water Resource Control Board Water Rights Order (WRO) 90-5 requires a daily average temperature of 56°F for the protection of WRCS in the Sacramento River during the temperature management season from May 15 through September 30. Since 2009, it has not been possible to meet the compliance temperature at RBDD (RM 242) as specified in WRO 90-5 (SRTTG 2019). Instead the water temperature compliance point (TCP) is set yearly by the Sacramento River Temperature Task Group (SRTTG) between Balls Ferry Bridge and Bend Creek (SRTTG 2019).

In 2019, the temperature criterion was set at 56°F at Balls Ferry Bridge for the entire season (i.e., from May 15 through September 30), which was met approximately 99% of the season (Figure 10). A pilot temperature criterion of 53.5°F at Clear Creek (RM 292) was also established for 2019, which was met 98% of the time (SRTTG 2019). The conditions in 2019 allowed for maximum cold-water storage in Shasta Reservoir and enabled managers to successfully meet the temperature criterion at both compliance locations almost all season.

Figure 10
Sacramento River Water Temperature at Ball's Ferry Bridge TCP in 2019



Sacramento River water temperature at Ball's Ferry Bridge gage (BSF) TCP in 2019. The temperature criterion of 56°F for the period between May 15 and September 30 is shown as a grey dashed line. Data from SacPAS (2020).

Because of the available cold water and distribution of redds in the Sacramento River downstream from the confluence with Clear Creek, an additional temperature management target of 53.5°F daily average temperature was established at the Airport Road Bridge (RM 284) on August 7, 2019 (SRTTG 2019). There is no temperature gage at the Airport Road Bridge, so water temperatures at this location had to be interpolated between Clear Creek and Balls Ferry Bridge. The TCP at the Airport Road Bridge was estimated to have been met 58.5% of the time. The estimated water temperature at the Airport Road Bridge and the effect of this criterion on occupied redds is discussed in more detail in Section 5.1.1.

In 2019, water temperatures at Balls Ferry Bridge in January through early February, when adults first started holding in the upper Sacramento River, were warmer than the 10-year average but then dropped below the 10-year average from early February to mid-April. This was likely related to large management flow releases from Shasta and Keswick reservoirs that occurred during this time frame (Figure 11, panel B). After briefly increasing above the 10-year average in late April, by May 15 temperatures remained comparable to or below the 10-year average at Balls Ferry Bridge through the end of spawning in late September. Water temperatures at Clear Creek were also similar to the 10-year average and below 54°F during spawning (Figure 11, panel A). This may explain the higher percentage of late-season spawning that occurred in 2019 compared to the 10-year average. Like WY 2019, WYs 2017 and 2011 were also classified as wet. Spawning season water temperatures in 2019 were similar to those that occurred in 2017 at both Clear Creek and Balls Ferry Bridge, whereas water temperature during summer 2011 were generally cooler (Figure 11, panels A and B).

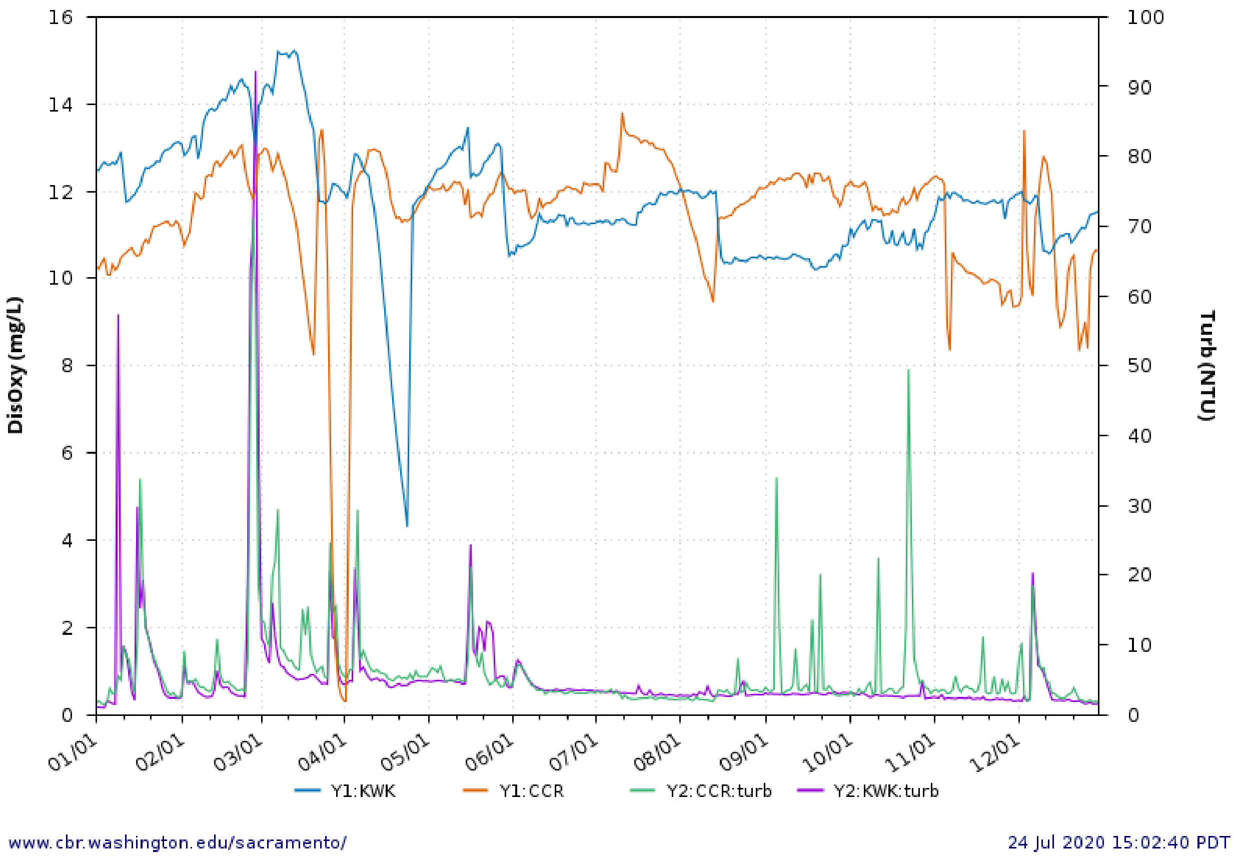
Figure 11
Sacramento River Water Temperature at Clear Creek and Balls Ferry Bridge

Water temperatures in 2019 at the Clear Creek confluence gage (upper panel; CCR, RM 292) and the TCP at Balls Ferry Bridge gage (lower panel; BSF, RM 275). Temperatures for 2017, 2011, and the 10-year average are also shown. There is no temperature monitor at the pilot TCP of Airport Road Bridge (RM 284) located between the two compliance locations. Figure and data from SacPAS (2020).

4.2.3 Turbidity and Dissolved Oxygen

Turbidity and DO experienced by adult spawners between Keswick Dam and the confluence with Clear Creek are shown in Figure 12. Turbidity during the period when adults were present between January and September 2019 was generally less than 10 nephelometric turbidity units (NTU), with occasional short durations of a few days of spikes between 20 and 90 NTU. Dissolved oxygen in this same reach was generally above 10 milligrams per liter (mg/L) during the period. However, there were two periods when pre-spawning adults experienced notable drops in DO. One drop in DO was recorded at the Clear Creek gage in late March. Although daily averaged data (Figure 12) appear to drop to nearly zero on March 28 (SacPAS 2020), further investigation of this low DO event at California Department of Water Resources (CDWR) Data Exchange Center (CDWR 2020) indicates that the lowest recorded DO was 5.2 mg/L, after which the monitor stopped recording or data were redacted. Monitored DO readings continued April 3, 2019. A second DO drop occurred just below Keswick Dam on April 23, and DO readings resumed on April 25. The lowest DO reported by CDWR was 5.0 mg/L. It is unclear if actual DO fell below 5.0 mg/L. Migrating adult Chinook salmon are documented to avoid water with DO concentrations less than 3.4 mg/L (Bergendorf 2002).

Figure 12
Dissolved Oxygen and Turbidity at Keswick Dam and Clear Creek in 2019

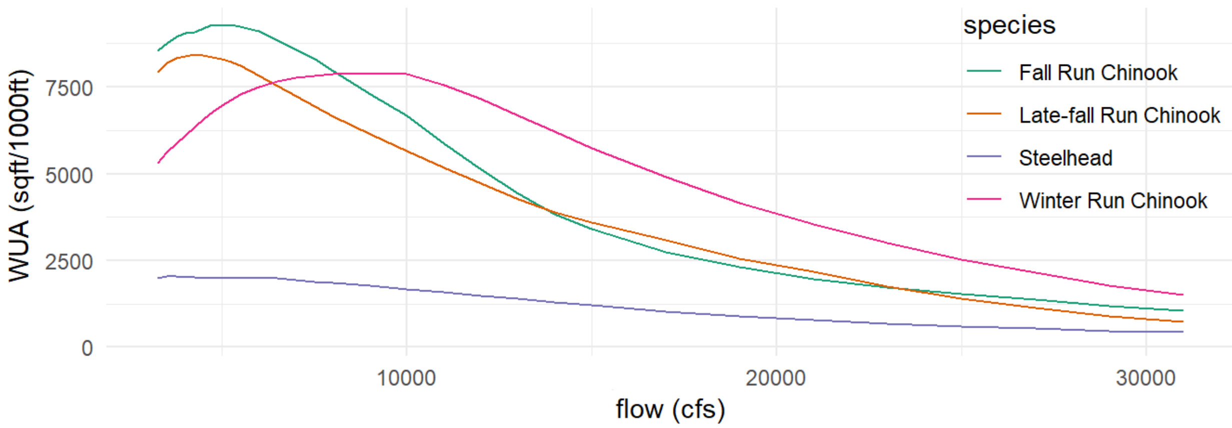


DO (Y1) and turbidity (Y2) in 2019 below Keswick Dam (KWK; RM 302) and just upstream from the confluence with Clear Creek (CCR; RM 292). Data and figure from SacPAS (2020).

4.2.4 Habitat Capacity

Habitat capacity was estimated by reviewing habitat modeling inputs to the CVPIA Science Integration Team (SIT) Salmon Population Model. Habitat modeling uses the concept of weighted usable area (WUA), an index of habitat suitability that varies by river discharge (Stalnaker et al. 1995). The amount of flow below Keswick Dam averaged just above 10,000 cubic feet per second (cfs) for the period May 1 to September 20. This resulted in a WUA of spawning habitat greater than 7,500 square feet per 1,000 feet (Figure 13). Based on CVPIA habitat modeling, this is close to the maximum possible amount of WRCS spawning habitat in the upper Sacramento River area (CVPIA 2020; USFWS 2003).

Figure 13
Upper Sacramento River Spawning Habitat Area



Upper Sacramento River spawning habitat area based on data from a USFWS 2003 study of spawning habitat in the Sacramento River between Keswick Dam and the confluence with Battle Creek (USFWS 2003). Figure was slightly modified from the one on the CVPIA website (Gill and Tompkins 2020).

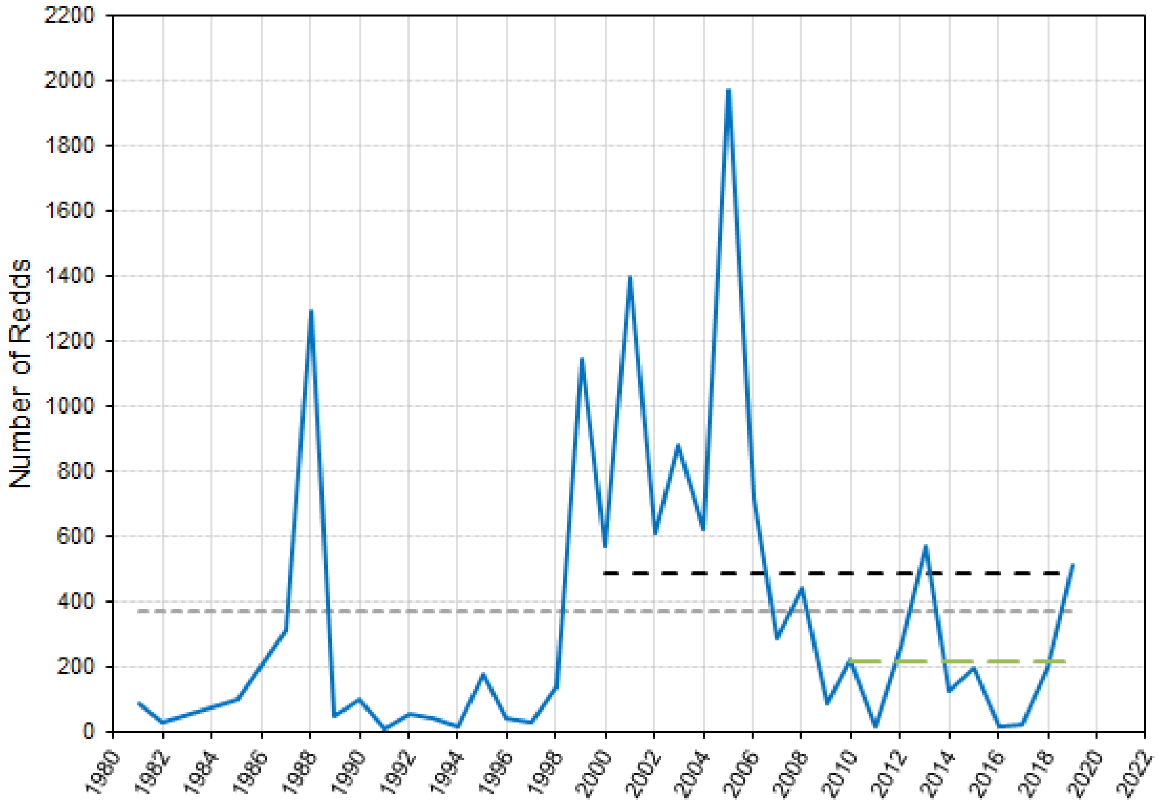
4.2.5 Distribution of Redds and Carcasses

A total of 515 WRCS redds were documented during aerial surveys in 2019. Since data collection began in 1981, there has been an average of 371 WRCS redds counted annually. The 20-year average is 486 redds counted, whereas since 2010 the yearly average has fallen to 215 redds (Figure 14).

Both carcass and redd surveys showed that in 2019 there was a greater distribution of spawners downstream of Highway 44 at Redding (RM 296), compared to the 10-year average (Figures 15 and 16). A total of 6.6% more carcasses and 35% more redds were reported in the two survey reaches downstream of Highway 44 to Balls Ferry Bridge (RM 296 to 288 and RM 288 to 276) compared to their respective 10-year averages. Conversely, although 3% more carcasses were found from just downstream of Keswick Dam to Anderson-Cottonwood Irrigation District (ACID) Dam (RM 302 to 298) in 2019 compared to the 10-year average, 30% fewer redds were documented in this same area compared to the 10-year average. From 2001 to 2004 total run size was similar to 2019, and the reach between Keswick Dam and ACID Dam (RM 298) supported an average of 365 redds during this period, compared to just nine redds counted in this reach in 2019.

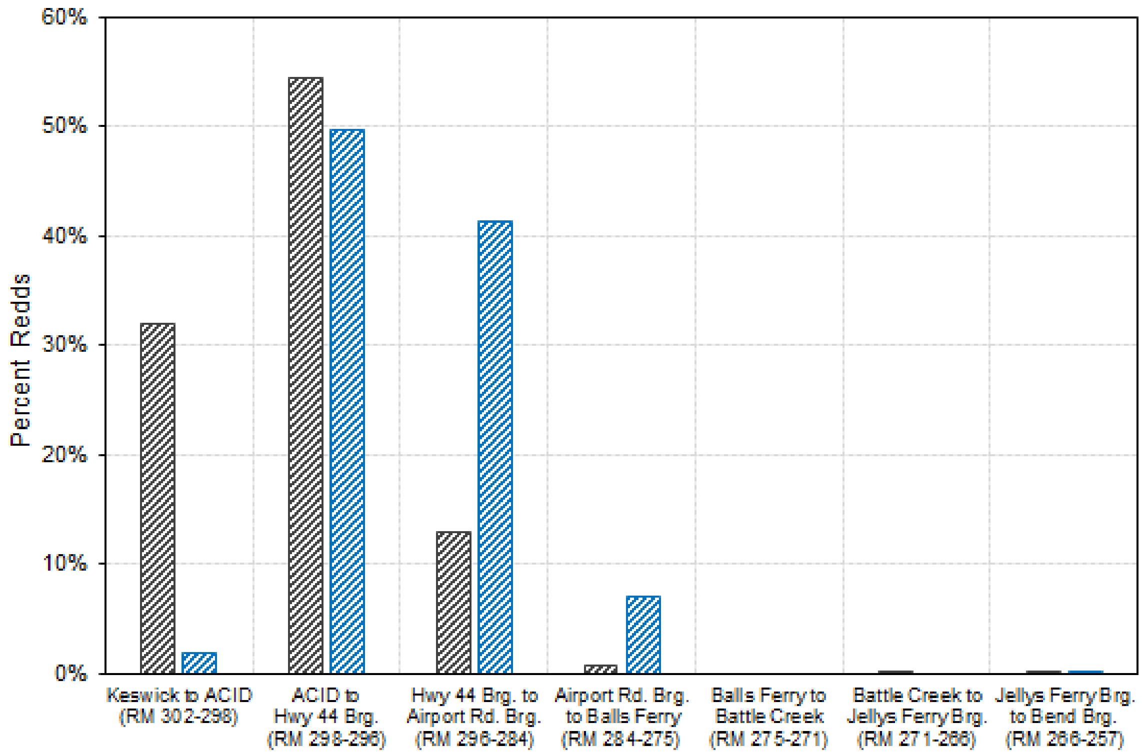
The total number of 515 redds counted in 2019 was less than the average of 876 redds counted in years of similar run size. The difference in redd counts may have been caused by difficult viewing conditions experienced in 2019 due to deep and turbid water conditions just downstream of Keswick Dam that were attributed to higher flows (Johnson 2020).

Figure 14
Number of Winter-Run Chinook Salmon Redds



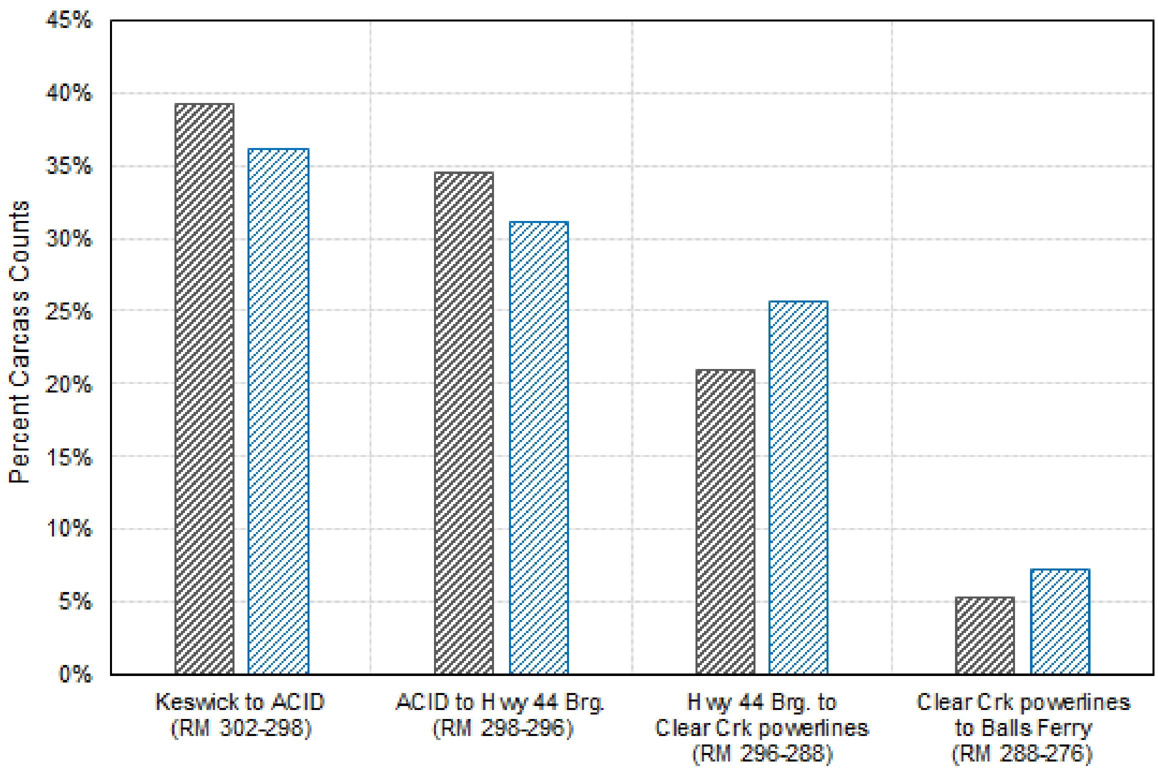
Number of WRCS redds counted annually, 1981 to 2019, shown with a blue line. The average since surveys began in 1981 is shown with a dotted grey line, the 20-year average is shown with a dashed black line, and the most recent 10-year average is shown as a long-dashed green line. Data from CalFish (2020).

Figure 15
Distribution of Winter-Run Chinook Salmon Redds for 2019



Distribution of WRCS redds by aerial survey reach for 2019 (blue) and for the 10-year average (grey). Data from CalFish (2020).

Figure 16
Distribution of Female Spawner Carcasses for 2019



Distribution of adult female spawner carcasses by survey reach for 2019 (blue) and the 10-year average (grey). ACID refers to ACID Dam. Data from CalFish (2020).

4.3 Key Management Questions and Findings

In the following section, information is synthesized regarding key management questions related to adult spawning.

4.3.1 Was Pre-Spawn Mortality Low in 2019 Given the Beneficial Flow and Temperature Conditions?

Yes, pre-spawn mortality in 2019 was slightly higher than the 10-year average (1.3% vs 1.1%) but was still low overall and less that the recent peak of 2% observed in 2015. Flow levels were optimal for creating the maximum spawning habitat based on estimated WUA (Figure 13), the temperature criterion (56°F) at Balls Ferry Bridge was met approximately 99% of the required time within the spawning season, and the pilot temperature criterion of 53.5°F at Clear Creek was met 98% of the time during spawning. However, there was concern about impacts to habitat conditions from runoff due to effects from the 2018 Carr Fire (SRTTG 2019).

4.3.2 Was the Estimated Hatchery Influence on the 2019 Spawning Population Higher Than Recommended?

Yes, although decreasing from the recent past, there is still a higher than desired influence of hatchery-origin fish in the BY 2019 spawning population. In 2019, hatchery-origin fish made up 36.6% of the spawning population. This proportion is higher than the 10-year average of 32.6% but lower than in 2017 and 2018 (82.4% and 82.3%, respectively). In 2019, 2% of the returning run was used for broodstock (180 of 8,033). The 10-year average is 8%, and the greatest percent taken was 18% in 2017 when the lowest run (977) for the 10-year period occurred. Both factors determine the PNI, which was 0.46 in 2019. This PNI value is below the recommended value of greater than or equal to 0.67. Hatchery production was greatly increased in 2014 and 2015, when hatchery juveniles made up 54% and 49% of total juveniles entering the Delta. These fish seem to have returned to spawn in 2017 and 2018, given the high proportion of hatchery-origin spawners. Despite the 2019 PNI being lower than recommended (LSNFH 2020), there is currently no evidence that hatchery-origin broodstock return more offspring than natural-origin broodstock. This indicates that strong adaptation in captivity is not occurring (Thompson 2019). In addition, Thompson found that there is little to no selection for early or late spawn timing, or run timing, as measured by capture date at Keswick Dam. This indicates that the LSNFH hatchery program is not altering diversity of winter-run phenology phenotypes in a significant way.

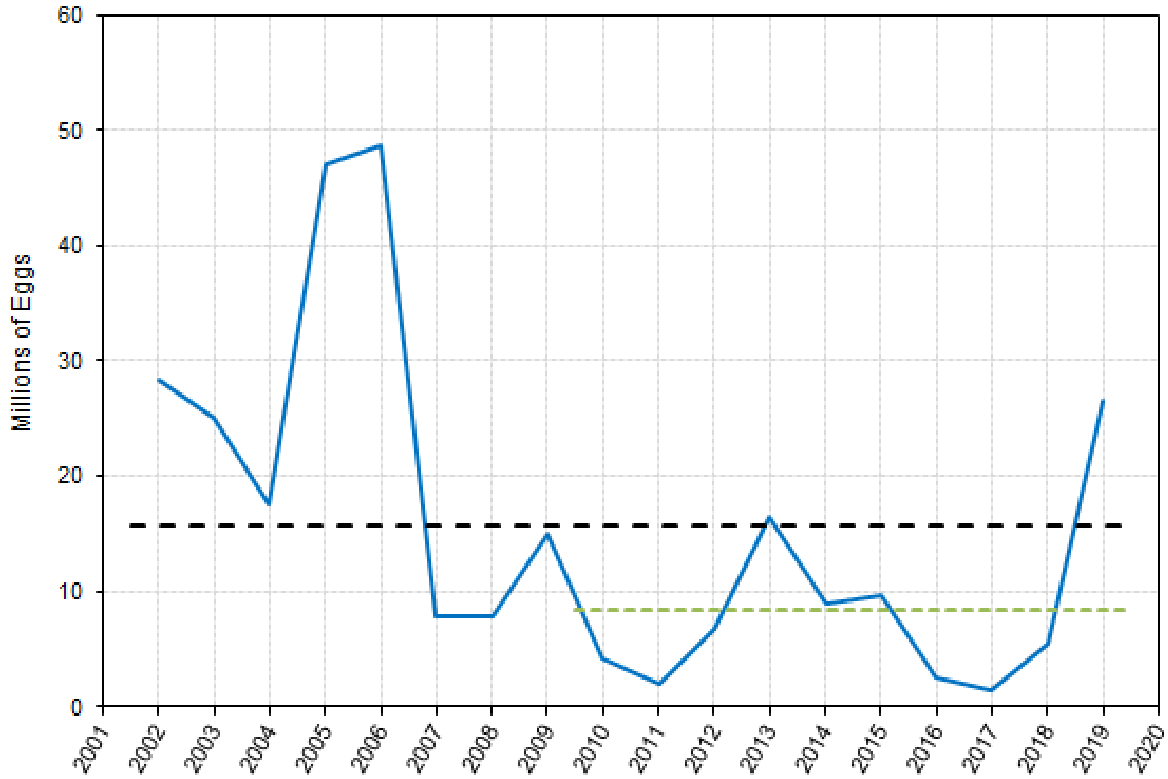
5 Egg-to-Fry Emergence and Survival in the Upper Sacramento River

This section describes the assessment findings for egg-to-fry emergence and survival in the upper Sacramento River. A summary of findings is provided in the following subsections, followed by the analysis each of fish response and habitat attributes and environmental drivers.

The number of eggs based in BY 2019 was estimated to be the highest observed since 2006 (Figure 17). The large number of potential eggs is attributed to the large number of spawners, higher than normal fecundity, and low pre-spawn mortality.

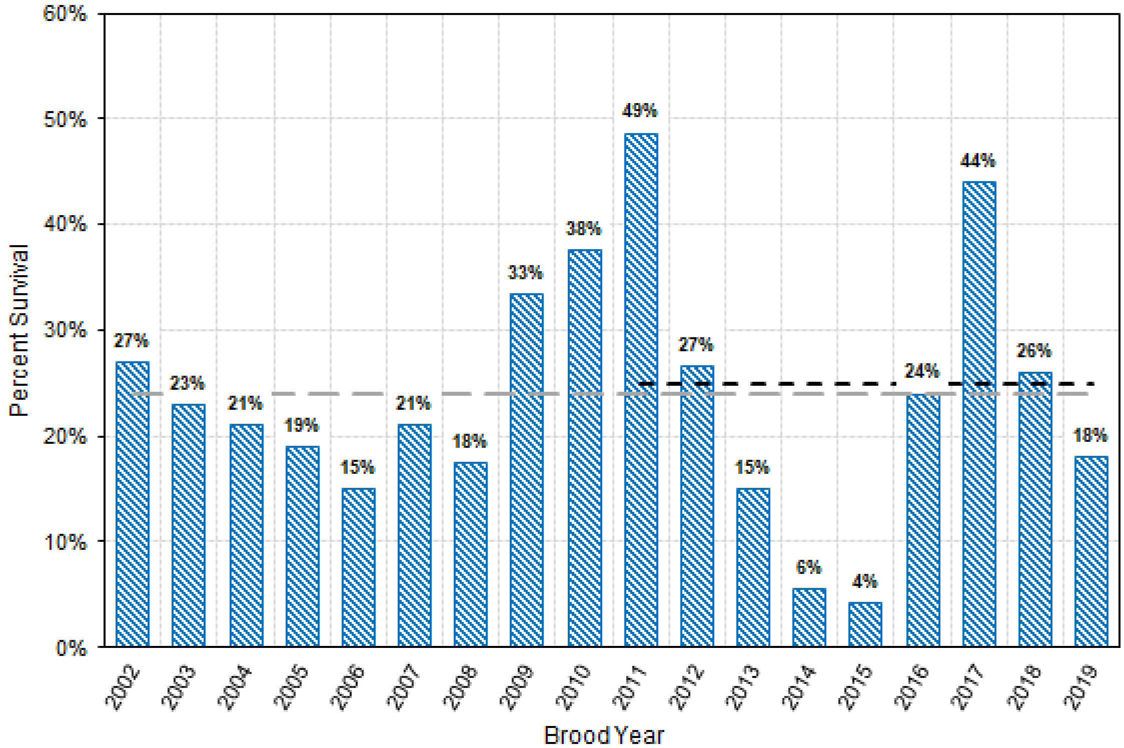
Egg-to-fry survival for BY 2019 was lower than the 10-year average, despite habitat conditions (e.g., flow, temperature, and DO) that were generally better than the 10-year average. The reason for the lower egg-to-fry survival could not be determined by the data that were synthesized and reviewed, but several explanations were considered. There was a potential density-dependent effect in 2019 given the large number of returning adults and based on egg-to-fry survival being generally lower in years with more spawners. This effect could account for part of the lower egg-to-fry survival for BY 2019. However, BY 2019 survival was lower than what was observed in past years with similar numbers of spawners (Figure 18). Another consideration is that in 2019, redds were distributed further downstream than usual and may have experienced higher temperature exposure during the critical hatching period. An additional temperature target at Airport Road Bridge (RM 284) was implemented on August 7 to address the downstream distribution of redds in 2019 but was only met 58.5% of the time. Little to no data were available to evaluate other factors that could influence survival, including fine sediment, pathogens or disease, or contaminants. Pathogens, disease, and contaminants affect the survival of eggs and the condition of emerging fry and can be exacerbated by increased water temperature and reductions in flow (Windell et al. 2017). Asymptomatic presence of a salmon parasite, *Ceratonova shasta*, was documented in WRCS fry in 2019 (Foott et al. 2019), but because this parasite is not transmitted vertically, there is low risk for eggs or alevin before emergence (Hallett and Bartholomew 2012). Additional mortality or reduced condition of eggs, alevin, or newly emerged fry could have resulted from environmental impacts of the 2018 Carr Fire and other fires in the region. Finally, the lower egg-to-fry survival could have been caused by conditions influencing fry between emergence and arrival at RBDD (RM 242), as discussed in Section 6.

Figure 17
Estimate of Upper Sacramento Winter-Run Chinook Salmon Potential Total Eggs



Estimate of upper Sacramento River WRCS total eggs by BY. Estimates are calculated based on estimated mainstem escapement, percent females, percent pre-spawn mortality, and fecundity. Data from Killam (unpublished).

Figure 18
Egg-to-Fry Survival



Egg-to-fry survival is back-calculated from the JPI and total estimated viable eggs. The long-term average since 2002, 24%, is shown as a dashed grey line. The 10-year average, 25%, is shown as a dashed black line. Data from Killam (unpublished) and NMFS (2020).

5.1 Fish Response

5.1.1 Egg-to-Fry Survival

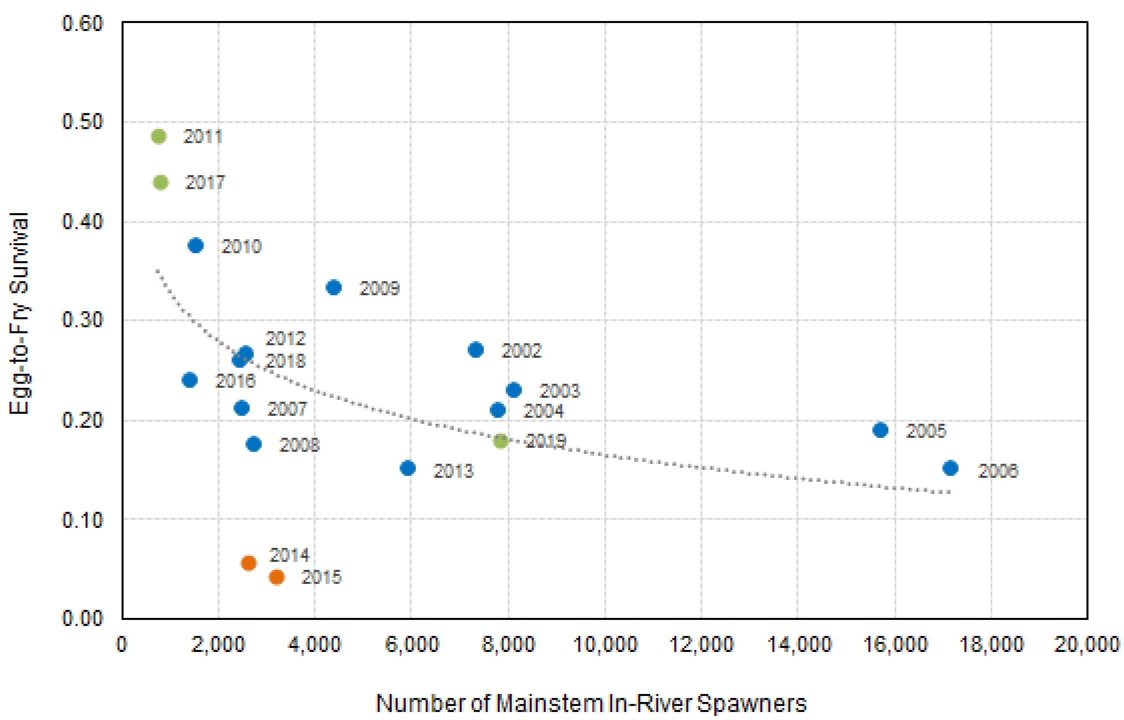
Egg-to-fry survival was back-calculated by dividing JPI by the estimate of total viable eggs as described in the JPE letter (NMFS 2020). The JPI is determined from rotary screw trap (RST) data for juveniles at RBDD. Since 2002, the number of potential total eggs has been calculated using the estimated percentage of female in-river spawners, carcass survey-based estimates of pre-spawn mortality, and fecundity reported from LSNFH (NMFS 2020).

For BY 2019, WRCS potential total eggs were estimated at approximately 26.5 million (Figure 17). This is the highest potential total egg estimate since 2006 and higher than the average of 15.6 million eggs produced annually since 2002.

The BY 2019 potential total eggs along with a JPI of 4,762,142 (discussed further in Section 6) resulted in an estimated egg-to-fry survival of 18% for BY 2019 (Figure 18) from egg deposition in the redds to fry passage at RBDD. This was higher than egg-to-fry survival for the drought years 2013 through 2015 but much lower than comparable wet WYs that influenced BYs 2011 and 2017. The average since 2002 is 24%, which is slightly lower than the most recent 10-year average of 25%.

A comparison of the number of mainstem spawners to egg-to-fry survival since 2002 shows that as the number of spawners increases, egg-to-fry survival is generally lower (Figure 19). This relationship indicates a potential density-dependent reduction in egg-to-fry survival based on the number of spawners or the number of fry produced by the spawners. Estimated egg-to-fry survival for BY 2019 was consistent with this relationship. Though BYs 2011 and 2017 experienced similar wet WYs, there were also far fewer spawners in those years (fewer than 1,000). In years with a similar number of spawners, 2002 through 2004, egg-to-fry survival was similar.

Figure 19
Relationship Between Adult In-River Spawners and Egg-to-Fry Survival

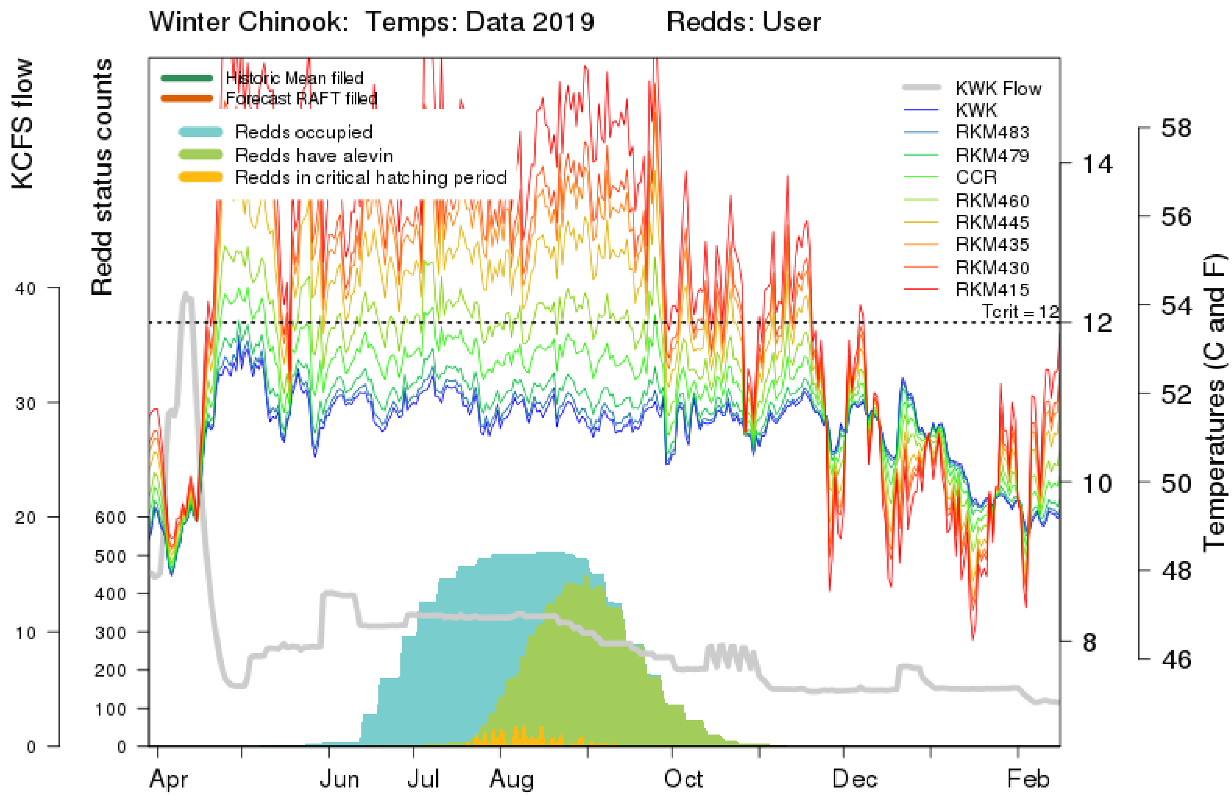


Relationship between the number of adult in-river spawners (male and female) and egg-to-fry survival from 2002 to 2019. Similar wet WYs 2011, 2017, and 2019 are shown in green. Severe drought years 2014 and 2015 are shown in orange. All other years are shown in blue. Data from Killam (unpublished).

An alternate predictive modeling method for estimating egg-to-fry survival is currently available and was used to compare to the JPI back-calculated survival rate (SacPAS 2020). This method uses 2019 data for the number of redds and their distribution, water temperature, flow, and the survival and emergence timing models described by Anderson (2018). The critical temperature was set to 12°C (~53.5°F), which is defined as the temperature above which oxygen uptake near the time of hatching would be limited. Other model parameters were set to closely fit existing Sacramento River WRCS data for 2002 to 2015, as described in Table 2, Model III in Anderson (2018). The redd dewatering component using Keswick Dam (RM 302) flow was also included. The model estimated egg-to-fry survival rate to be between 20.9% and 24.5% in 2019, indicating that the JPI back-calculated egg-to-fry survival of 18% was slightly lower than theoretically predicted survival.

Estimated survival in the SacPAS model was sensitive to placement of the redds in the reach from Highway 44 to Airport Road Bridge and the inclusion of the dewatering component. For example, if all redds were assumed to be located near the confluence with Clear Creek near RM 292 (river kilometer [RKM] 470), survival was higher. If redds were assumed to be closer to the temperature management point at Airport Road Bridge (RM 284; RKM 458), survival was lower, since there was a greater chance eggs would experience temperatures greater than 53.5°F during a critical period of development (Figure 20). The temperature-only component of mortality in the model ranged from 5.6% to 13.2% when redd dewatering was not included, and adding the dewatering component to the model increased mortality an additional 1% to 3.7%, depending on where in the model redds were placed (located) in the river reach. Further details of the SacPAS modeling analysis are provided in Appendix A.

Figure 20
SacPAS Egg-to-Fry Survival Model Results



SacPAS (2020) model results for BY 2019 redd occupation, hatching, and alevin presence (blue, yellow, and green areas, respectively). Keswick Dam flow is shown as a grey line. Keswick Dam (KWK) and Clear Creek (CCR) water temperatures are shown as blue and lime green, respectively. Water temperatures at other locations, including Airport Road Bridge (RKM 460; olive green) are interpolated. The critical water temperature of 12°C (~53.5°F) is shown as a black dotted line for reference. Redd timing data are from CalFish (2020).

Although egg-to-fry survival is generally well-explained by water temperature and density conditions during egg development and hatching to fry emergence (Anderson 2018), egg-to-fry survival also encompasses fry survival in the upper Sacramento River. This includes fry survival during rearing after leaving the redd area and migrating approximately 50 miles downstream to RBDD. This component of egg-to-fry survival is discussed in Section 6.

5.1.2 Redd Conditions

As discussed in Section 4.2.5, more redds were detected downstream of the confluence with Clear Creek (RM 292) in 2019 compared to recent years. Forecasting model runs performed by the NMFS-SWFSC during the 2019 season compared historical and 2019 redd distributions through July 24 (SRTTG 2019). NMFS-SWFSC modeling showed that temperature-dependent egg mortality was higher (mean ~10%) when using the 2019 redd distribution compared to the 2012 through 2017 distribution (mean ~4%), but there was little difference between meteorological scenarios for either redd distribution (e.g., warm and dry, warm and wet). This prompted managers to implement an additional temperature management target of 53.5°F at Airport Road Bridge starting on August 7. Reclamation was able to meet the target temperature Airport Road Bridge compliance point 58.5% of the time (SRTTG 2019).

WRCS redds are susceptible to dewatering as management flows from Keswick Dam are reduced from September through November. This is done to be protective of spring-run and fall-run Chinook salmon spawning that begins in late September through early October. Reducing flows to between 5,000 and 6,000 cfs during fall months prevents dewatering of spring-run and fall-run Chinook salmon redds when winter flows are reduced to 3,250 to 4,500 cfs to increase storage in Shasta Reservoir. Although this flow reduction prevents dewatering of spring-run and fall-run Chinook salmon redds, it puts WRCS redds at risk for dewatering (SRTTG 2019). Redd surveys in 2019 documented five dewatered redds between RM 293.5 and RM 300, upstream of the confluence with Clear Creek, between September 4 and October 3 (Table 2; CalFish 2020). These dewatered redds occurred as flow from Keswick Dam began to decline from a steady summer flow of approximately 11,000 cfs between early July through late August. CDFW staff observed that dewatering was less of an issue for BY 2019 than other BYs (Johnson 2020). Flows from Keswick Dam were similar to the 10-year average, which may have benefited WRCS by reducing spawning at the margins that would have become dewatered later (Johnson 2020).

Table 2
Location and Depth of Dewatered Redds in BY 2019

Date	River Half Mile	River Section	Water Depth	Flow at Keswick Dam (cfs)
9/4/2019	298	Keswick Dam to ACID	1.5	9439
9/17/2019	300	Keswick Dam to ACID	0.5	8541
10/3/2019	297	ACID Dam to Highway 44 Bridge	0	6735
10/3/2019	297.5	ACID Dam to Highway 44 Bridge	2	6735
10/3/2019	293.5	Highway 44 Bridge to Airport Road Bridge	0	6735

Note:
Each line represents a single observed redd.

5.1.3 Emergence Timing

The SacPAS fish model estimates emergence using a temperature-based egg-to-emergence timing model (Zueg et al. 2012, as described in Anderson 2018). For BY 2019, the model estimated a mean emergence day of year (DOY) of 264 (September 21, 2019) and last emergence on DOY 315

(November 11, 2019). This is consistent with the genetic findings from BY 2017 that are described in more detail in the following paragraph. Based on female carcass data, peak spawning in 2017 was two weeks later (week 29) than in 2019 (week 27); however, 2019 data showed a "double peak" in spawning (Figure 7), with the second peak occurring in week 29.

Timing of emergence is usually estimated by length-at-date (LAD) data collected at RBDD and used to assign run timing (Israel et al. 2015). However, the trend towards later peak spawning for WRCS has resulted in later emergence and migration in some years (Figures 7 and 8). A genetic analysis conducted on BY 2017 fish found that WRCS were incorrectly assigned as spring-run Chinook salmon using LAD criteria for a period of 34 days from mid-October through late November 2017. Based on this information, the timing of last emergence for BY 2017 WRCS fry was changed to early November, which is consistent with the modeled estimate of emergence timing for BY 2019.

5.2 Habitat Attributes and Environmental Drivers

The following section summarizes the habitat attributes and environmental drivers that influenced BY 2019 during the egg-to-fry emergence life stage.

5.2.1 River Flows and Keswick Dam Releases

Flows in the upper Sacramento River reach are discussed in Section 4.2.1. As shown in Figure 9, flows during egg-to-fry emergence between June and November 2019 were similar to the 10-year average, except in late May through mid-June, when there was a small storage management release that caused flows at Bend Bridge (RM 257) to increase to approximately 15 kcfs, which is above the 10-year average.

5.2.2 Water Temperature

See the discussion of upper Sacramento River water temperatures in Section 4.2.2. As shown in Figure 11, water temperatures during egg-to-fry emergence between June and November 2019 at both Clear Creek and Balls Ferry Bridge (RM 275) were generally below the 10-year average, except in mid-July when temperatures were higher than the 10-year average. Water temperatures at both Clear Creek and Balls Ferry Bridge for WY 2019 were higher than similar WYs in 2011 and 2017 between early June and early August and were generally consistent with the similar WYs 2011 to 2012 and 2017 to 2018 between August and November 2019.

5.2.3 Turbidity and Dissolved Oxygen

In June, July, and August 2019, turbidity averaged 3.4 NTU below Keswick Dam and 3.1 NTU above Clear Creek confluence. Starting in early September through mid-November, there were four events where turbidity above the Clear Creek confluence ranged as high as 50 NTU, which would have affected late-emerging fry. No similar high turbidity events were observed below Keswick Dam.

DO, which is critical to egg development, remained above 10 mg/L for most of the egg-to-fry emergence period between June and early November below Keswick Dam and at Clear Creek (Figure 12). DO dropped to 8.8 mg/L at Clear Creek confluence (at CCR gage) on August 14 before recovering to 11.5 mg/L on August 15.

5.2.4 Air Temperature

Weather data from Redding show that the upper Sacramento River region experienced the second-warmest August on record in 2019, with 29 days reaching a maximum air temperature at or above 90°F (SRTTG 2019; NWS 2020). This created challenging conditions for water managers despite a historically large pool of cold water stored in Shasta Reservoir in 2019 (SRTTG 2019).

5.3 Key Management Question and Finding

In the following section, information is synthesized regarding the key management question related to egg-to-fry emergence and survival.

5.3.1 Was Egg-to-Fry Survival Better Than the 10-Year Average Given the Beneficial Habitat Attributes and Environmental Drivers During Egg Incubation and Emergence?

No, BY 2019 egg-to-fry survival was 18%, which is lower than the 10-year average of 25% and the average survival since 2002 of 24%. Flow conditions allowed the maximum amount of spawning habitat to be available (Figure 13). From May 1 to September 30, DO was greater than 10 mg/L 98% of the time below Keswick Dam (except for 3 days in August where it fell to ~9 mg/L) and 100% of the time at Clear Creek (Figure 11). DO was greater than 11 mg/L at Clear Creek 95% of the time and 63% of the time below Keswick Dam. Turbidity was generally low, although a period of higher turbidity occurred from mid- to late May (Figure 12). Additional periods of high turbidity occurred above Clear Creek after September 1. Temperatures were below the 56°F TCP criterion at Ball's Ferry for 99% of the season (May 15 to September 30), and hovered close to the secondary compliance point criterion of 53.5°F at Airport Road Bridge (requested to be in place from August 7 to September 30, 2019). Water temperatures above Clear Creek were below 53°F and below 54°F at Balls Ferry Bridge after October 1. Water temperatures at both locations were below the 10-year average during late emergence. Additional mortality or reduced condition of eggs, alevin, or newly emerged fry could have resulted from environmental impacts of the 2018 Carr Fire and other fires in the region, but there were no data to evaluate this (Figure 21).

Only five redds were documented as dewatered in 2019. All five occurred between Keswick Dam and Airport Road Bridge (RM 302 to 293.5). Two of the dewaterings occurred on September 4 during the peak occupancy of redds (Table 2 and Figure 20). The other three occurred in early October when relatively fewer redds were still occupied. CDFW staff observed that dewatering was less of an issue for BY 2019 than other BYs (Johnson 2020). Flows from Keswick Dam were similar to the 10-year average, which may have benefited WRCS by reducing spawning at the margins that would have become dewatered later (Johnson 2020).

Since the habitat attributes and environmental drivers that were evaluated were similar to or better than the 10-year average condition during spawning, incubation, and emergence, the lower egg-to-fry survival for BY 2019 was due to density dependence or conditions influencing the egg stage or the fry stage (between emergence and arrival at RBDD) that were not evaluated.

Figure 21
Photograph of Keswick Dam after the Carr Fire

Sacramento River looking upstream toward Keswick Dam 1 year after the Carr Fire that burned during July and August 2018. Photograph by Ryan Revnak as used in SRTTG Annual Report (SRTTG 2019).

6 Rearing-to-Out-Migrating Juveniles in the Upper Sacramento River

This section describes the assessment findings for rearing-to-out-migrating juveniles in the upper Sacramento River. A summary of findings is provided in this section, followed by the analysis each of fish response and habitat attributes and environmental drivers.

Fry abundance in 2019 as estimated by the JPI was high despite egg-to-fry survival being lower than the 10-year average. The high fry abundance is attributed to the large number of spawners and their higher-than-normal fecundity in 2019. The lower-than-normal egg-to-fry survival could also have been influenced by conditions that impacted fry in the upper Sacramento River between emergence and arrival at RBDD (RM 242). Habitat attributes and environmental drivers evaluated (flows, temperature, DO) were generally better than the 10-year average or expected to benefit BY 2019, though there were two low DO events at Bend Bridge (RM 257) and Balls Ferry Bridge (RM 275). One of these events corresponded with the fall pulse flows. No corresponding increases in turbidity occurred. Another exception to the better-than-average habitat conditions was access to the floodplain. WUA modeling shows that most floodplain habitat only becomes available during wet WYs when flows are greater than 25,000 cfs. The maximum flow in WY 2020 was under 18,000 cfs. Though WUA modeling provides an estimate of the physical amount of habitat available for a given amount of flow, it does not provide detailed information about the quality of the habitat conditions, such as the availability of food and refugia, that may change year to year.

Similar to egg-to-fry emergence, little to no data were available to evaluate other factors that could have influenced fry survival in 2019, including fine sediment, pathogens or disease, or contaminants. The salmon parasite, *C. shasta*, is known to be present in WRCS fry, but it is mostly asymptomatic during below normal or wetter WYs and likely did not greatly increase fry mortality for BY 2019. In dryer years there may be greater risk of *C. shasta*-related mortality (Foott et al. 2019). There were no available data to evaluate fine sediment, other pathogens or disease, or contaminants.

Migration of BY 2019 juveniles past RBDD was earlier than the 10-year average and BYs 2011 and 2017, which experienced comparable WYs. There was a management decision to implement pulse fall flows during the last half of October to improve habitat conditions for Chinook salmon while maintaining water delivery commitments. The pulse flows appeared to influence migration timing for WRCS. Median passage of juveniles past RBDD had occurred 10 days earlier than normal by the end of September. This timing was before the start of fall pulse flows on October 14; however, there was a clear increase in downstream migration in response to the flow pulses. Cumulative downstream passage increased from 60% to 90% during pulse flows, and a peak in daily passage rates occurred. Fork length averages for the entire season were smaller for BY 2019 fish (47.5 to 71.2 mm) than the

10-year average (54.6 to 77.1 mm), indicating that fish were smaller as they moved into the middle Sacramento River reach.

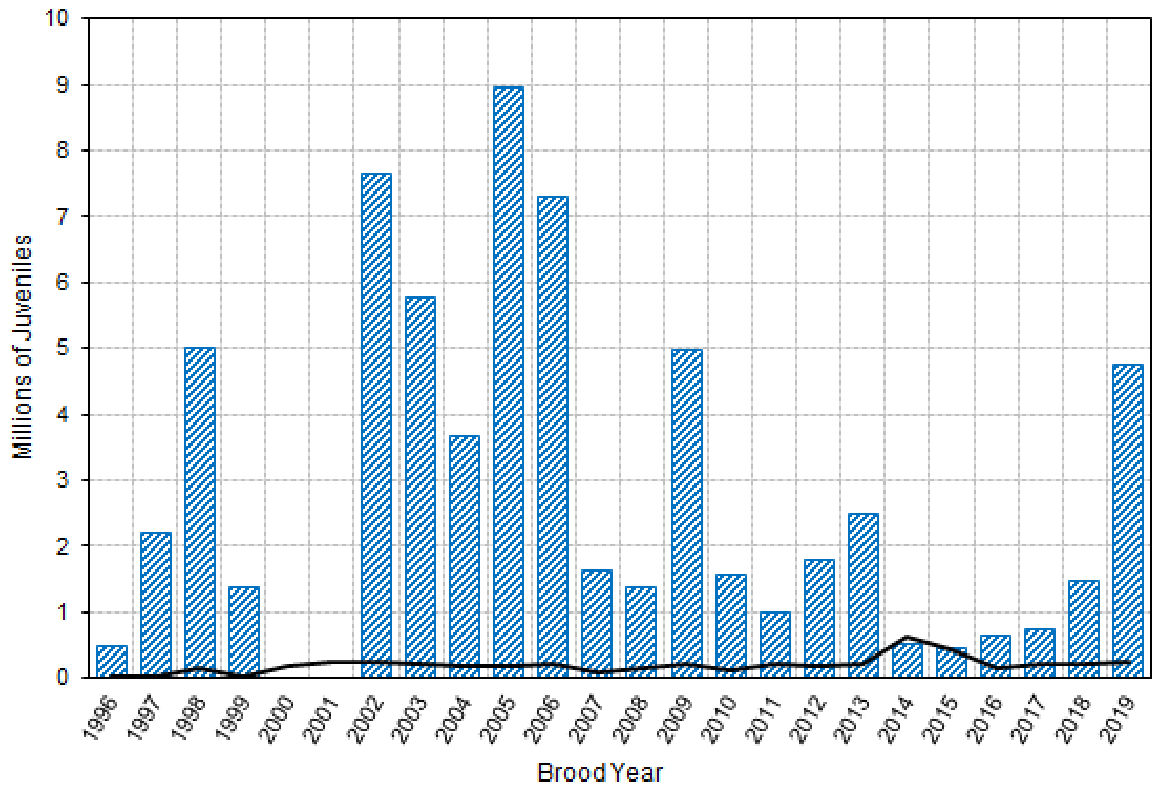
6.1 Fish Response

6.1.1 Fry Abundance—Juvenile Production Index

Fry abundance is estimated using the JPI. The JPI estimate for BY 2019 was 4,762,142 fish (Figure 22), which is the largest fry abundance estimate since 2009. JPI is calculated at RBDD by summing the following: 1) the estimated fry passage based on data from the RST; and 2) the estimated number of smolts and pre-smolts that pass RBDD, which are converted to fry-equivalents by applying the inverse of the fry-to-smolt survival rate (O'Farrell et al. 2018). Prior to BY 2019, a constant fry-to-smolt survival rate of 0.59 was used. An alternative method for calculating fry-to-smolt survival was developed by O'Farrell et al. (2018). The new method was used for BY 2019 that incorporates survival estimates for natural- and hatchery-origin WRCS that are updated annually. Using this new method resulted in an estimated fry-to-smolt survival rate of 0.47 for BY 2019, which is lower than the estimate based on the constant fry-to-smolt survival rate and suggests there may be some uncertainty when comparing the 2019 JPI to estimates from previous years. However, there was clearly an increase in the estimated JPI of WRCS fry passing RBDD for BY 2019 fish compared to recent BYs that were greatly impacted by drought conditions. JPI was also higher for BY 2019 compared to BYs 2011 or 2017, cohorts that experienced similar WY conditions as BY 2019.

As described in Section 5.1.1, egg-to-fry survival is calculated once JPI is determined at RBDD, and for BY 2019 it was less than the 10-year average. Although much of the variation in egg-to-fry survival each year can be explained by conditions that occur between the time of egg deposition and emergence, egg-to-fry survival also encompasses fry survival following emergence and the period of rearing and migrating in the upper Sacramento River prior to reaching RBDD. Environmental drivers and habitat attributes that affect the fry component of egg-to-fry survival are discussed more in Section 6.2.

Figure 22
Fry-Equivalent JPI



Fry-equivalent JPI (blue bars) from rotary screw trapping at RBDD and number of hatchery juveniles released in-river (black line). Data from Killam (unpublished). JPI values were not calculated in 2000 and 2001 because rotary trapping was not conducted (CDFW 2010).

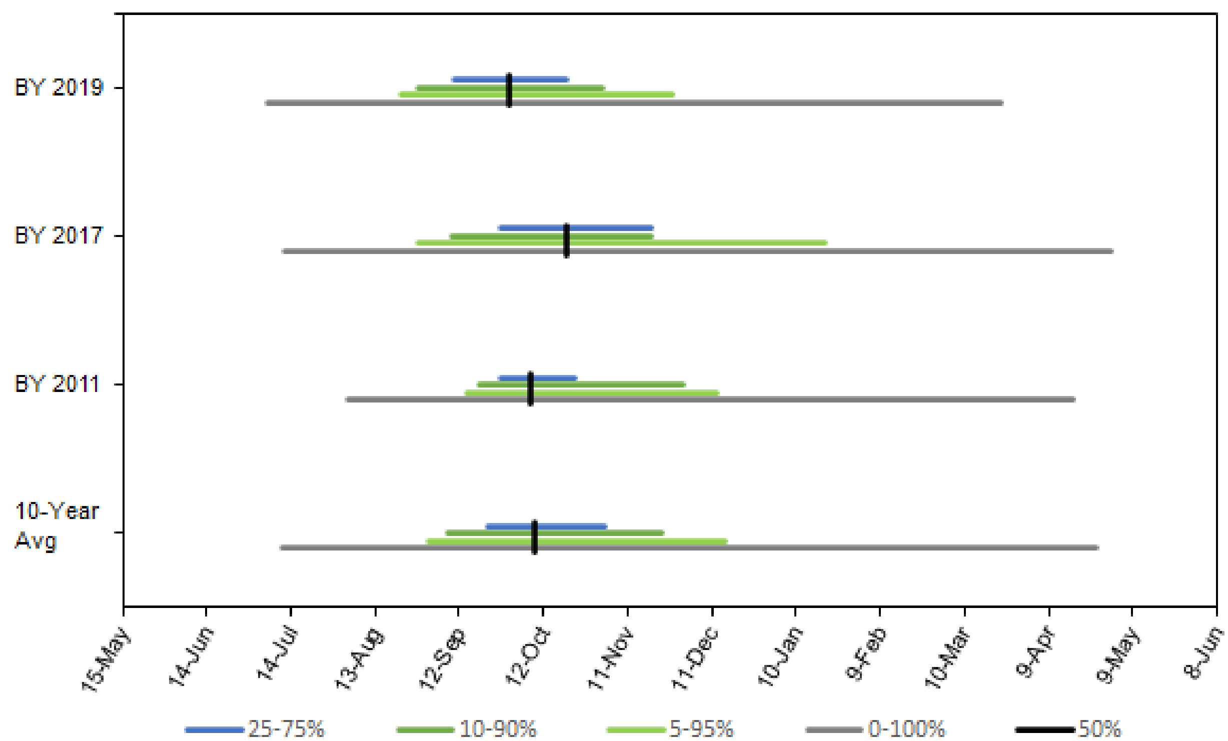
Since 2002, 13% of all juveniles produced in the upper Sacramento River are estimated to have been of hatchery origin. In response to low natural production during the drought, for BYs 2014 and 2015, the number of hatchery-origin juveniles released and natural-origin juvenile fry-equivalents produced were approximately equal (Figure 22). However, for BY 2019, natural production once again far exceeded hatchery releases (Figure 22). In 2019, releases of fish reared at LSNFH included 152,809 juveniles on March 10, 2020; 97,505 juveniles on March 23, 2020, into the Sacramento River at Caldwell Park in Redding; and 168,650 juveniles on March 23, 2020, into Battle Creek at Wildcat Road Bridge near the town of Manton.

6.1.2 Timing of Passage at RBDD

Fry emergence typically ends by early November, whereas mean emergence is estimated to occur in September, and juveniles begin arriving at RBDD in the first or second week of July (Figure 23). The 10-year average cumulative 50% (median) date of passage at RBDD is October 5 (DOY 280), whereas the 95% date of passage occurs on December 12 (DOY 347). Juveniles stop passing RBDD between late March and mid-May of the following year.

For BY 2019, passage timing at RBDD was earlier than the 10-year average (Figure 23). Median passage at RBDD occurred on September 29, 2019, which is approximately 10 days earlier than the 10-year average. The last passage of BY 2019 occurred on March 23, 2020, which is approximately 34 days earlier than the 10-year average. In fact, cumulative passage timing of BY 2019 WRCS at RBDD was earlier than the 10-year average for the first and last date of passage and every quantile in between, and the difference generally increased as the season progressed (Table 3). It is unclear how this early migration timing will ultimately impact BY 2019 fish.

Figure 23
Migration Timing at RBDD of Juvenile BY 2019 WRCS



Migration timing at RBDD of juvenile BY 2019 WRCS compared to BYs 2017 and 2011 and the 10-year average. Horizontal lines represent dates between which the middle 50%, 80%, 90%, and 100% of BY 2019 fish reached RBDD. The black vertical line represents the date at which 50% of all BY 2019 fish reached RBDD. Data from SacPAS (2020).

Table 3
Cumulative Passage Timing of Winter-Run Chinook Salmon at RBDD for BY 2019 Compared to the 10-Year Average

Cumulative Passage Percent	Passage Date				Difference in Days Between BY 2019 and the 10-Year Average
	BY 2019	10-Year Average	10-Year First	10-Year Last	
First	July 5, 2019	July 11	July 2	August 2	-6
5%	August 21, 2019	September 1	August 21	September 14	-11
10%	August 27, 2019	September 8	August 27	September 21	-12
25%	September 9, 2019	September 22	September 9	October 5	-13
50%	September 29, 2019	October 9	September 26	October 27	-10
75%	October 19, 2019	November 3	October 19	November 26	-15
90%	November 1, 2019	November 23	November 1	December 27	-22
95%	November 26, 2019	December 16	November 22	February 9	-20
Last	March 23, 2020	April 26	March 23	May 20	-34

6.1.3 Fish Condition

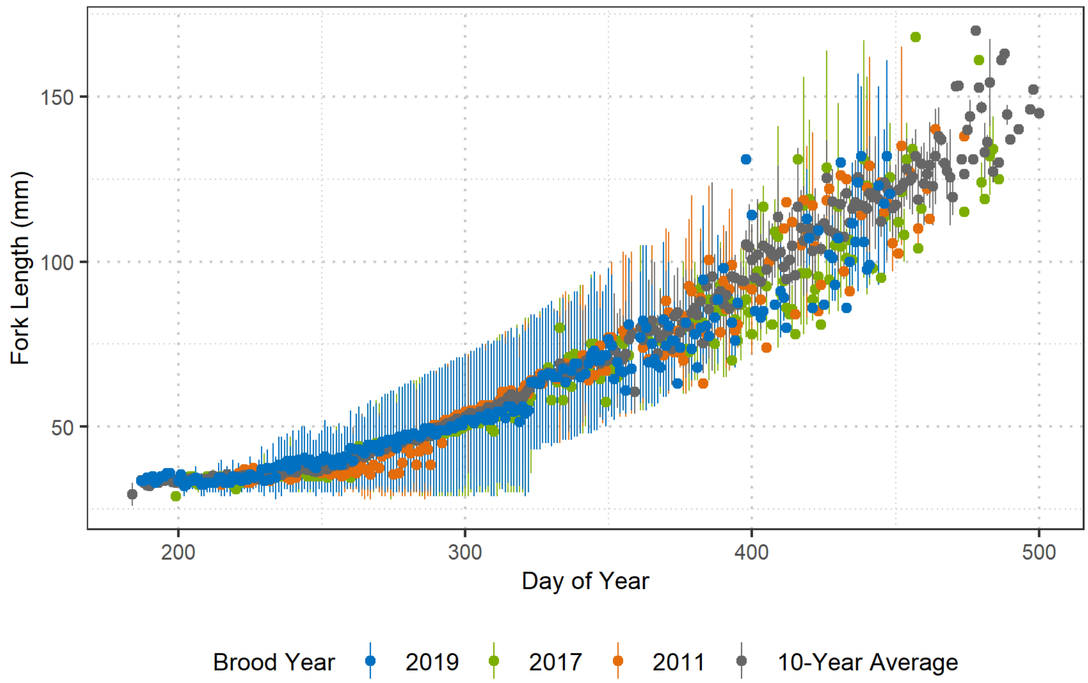
Limited data on fish condition are collected in the upper Sacramento River. Fish length data are collected at the RST at RBDD, and some sampling for pathogens and disease research is conducted by CNFHC on fish before being released from LSNFH and wild and caged WRCS fry at RBDD. These data are described in the following subsections.

6.1.3.1 Size at Passage

Fork length data for BY 2019 show that juveniles passing RBDD increased in length from an average daily range of 31 to 39 mm during July and August 2019 to an average daily range of 98 to 122 mm in March 2020. During the middle 50% (25% to 75%) of cumulative passage at RBDD between September 9 and October 19, 2019, fork lengths ranged from 29 to 68 mm. However, fork length averages for the entire season were smaller for BY 2019 fish (47.5 to 71.2 mm) than the 10-year average (54.6 to 77.1 mm).

BYs 2011 and 2017 experienced similar wet WYs as BY 2019, but without pulse flows. During the middle 50% of cumulative passage at RBDD for those years, fork lengths ranged between 28 and 81 mm for BY 2017 (larger range than BY 2019) and 28 and 69 mm for BY 2011 (similar range to BY 2019). Although the BY 2019 and BY 2017 fork length distributions were very similar (Figure 24), the maximum daily average fork length during BY 2017 was approximately 10 mm larger than was observed for BY 2019 fish. BY 2011 fork lengths during the middle 50% of migration were very similar to BY 2019. The larger maximum size observed for BY 2017 fish may have resulted from fish migrating later in 2017 and 2018 because cumulative median passage at RBDD for BY 2017 fish occurred approximately 20 days later than it did for BY 2019 fish. In contrast, the maximum size observed for BY 2011 fish was similar to BY 2019 fish, and cumulative median passage at RBDD in 2010 to 2011 for BY 2011 fish was only 9 days later than BY 2019 fish.

Figure 24
WRCS Fork Lengths at RBDD



Center value and ranges of daily fork length reported by USFWS at RBDD RST for juvenile BY 2019 WRCS compared to BYs of comparable WYs (BY 2011 and BY 2017) and to the 10-year average. Data from SacPAS (2020).

6.1.3.2 Pathogens/Disease

CNFHC noted that BY 2019 hatchery-origin fish tested positive for *Flavobacterim psychrophilium* and were assumed positive for infectious hematopoetic necrosis virus and *Aermonas salminicida* due to stocks being found positive for those pathogens in 2019 (USFWS 2020b). Hatchery juveniles were released after 95% of wild WRCS salmon juveniles passed RBDD in late November 2019.

Studies by CNFHC on wild and caged WRCS fry at RBDD in 2016 and 2018 found the presence of the parasite *C. shasta* in the Sacramento River (Foott et al. 2019). Though this parasite can cause significant mortality for juvenile Chinook salmon in the Klamath River, the presence of the parasite in the Sacramento River produced from 0 to 93% asymptomatic infections in caged salmon in those years. In WYs rated below normal or wetter, *C. shasta* appears to represent a low to moderate disease risk for juvenile WRCS during their out-migration in the Sacramento River. In drier years there may be a higher risk of symptomatic infection and mortality (Foott et al. 2019). WY 2019 was rated as a wet WY. WY 2020 has not yet been rated but will likely be rated below normal, given current WY conditions for Northern California (Simeral 2020).

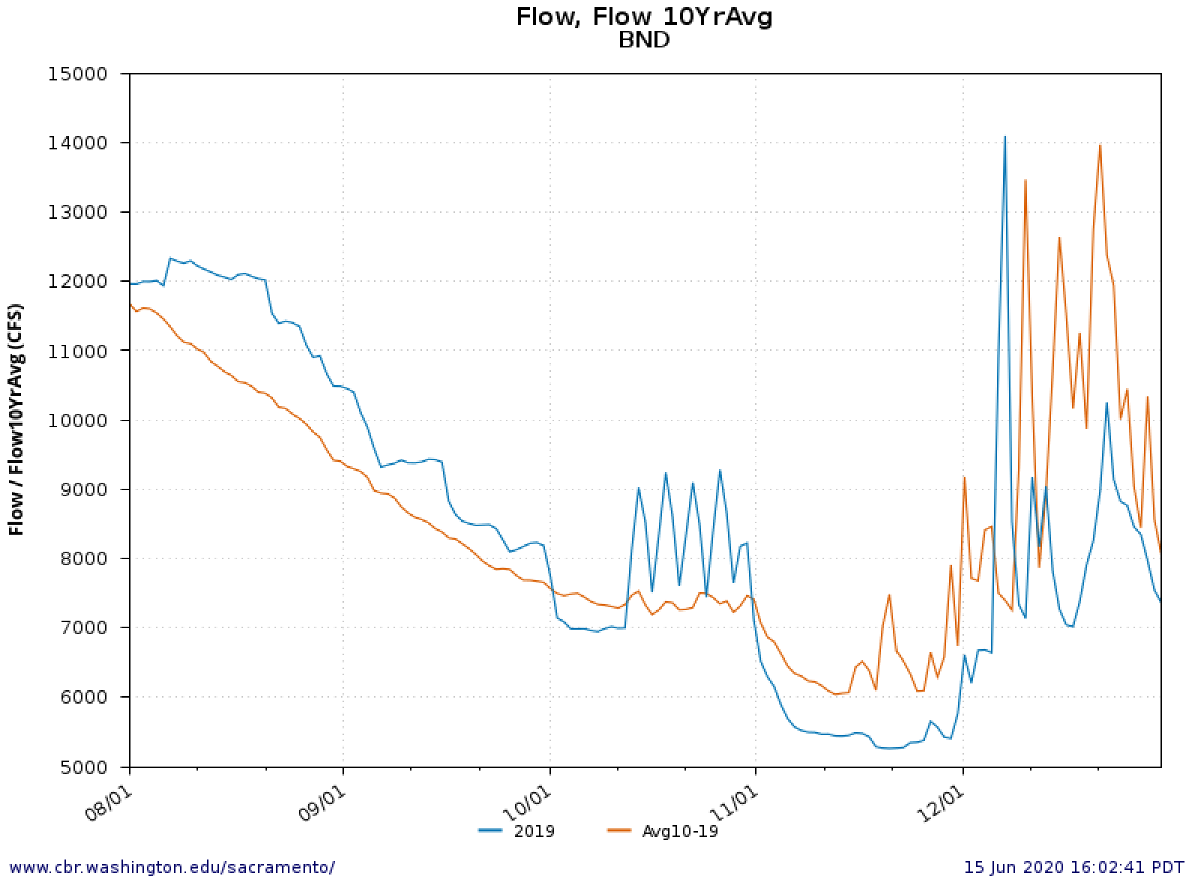
6.2 Habitat Attributes and Environmental Drivers

6.2.1 River Flows and Keswick Dam Releases

River flows during fall 2019 that the BY 2019 fish experienced were unique because of the greater-than-average cold-water storage in Shasta Reservoir. The increased storage allowed managers to release a series of pulse flows from mid- to late October (Figure 25). The 2019 fall flow pulses were implemented by USBR through coordinating the diversions of the Sacramento River Settlement Contractors and based on interagency discussions with NMFS, CDFW, and USFWS. Both the percentage cumulative passage and daily juvenile passage percentage at RBDD indicate that juvenile WRCS responded to the fall pulse flows and moved downstream (Figure 26, panels A and B).

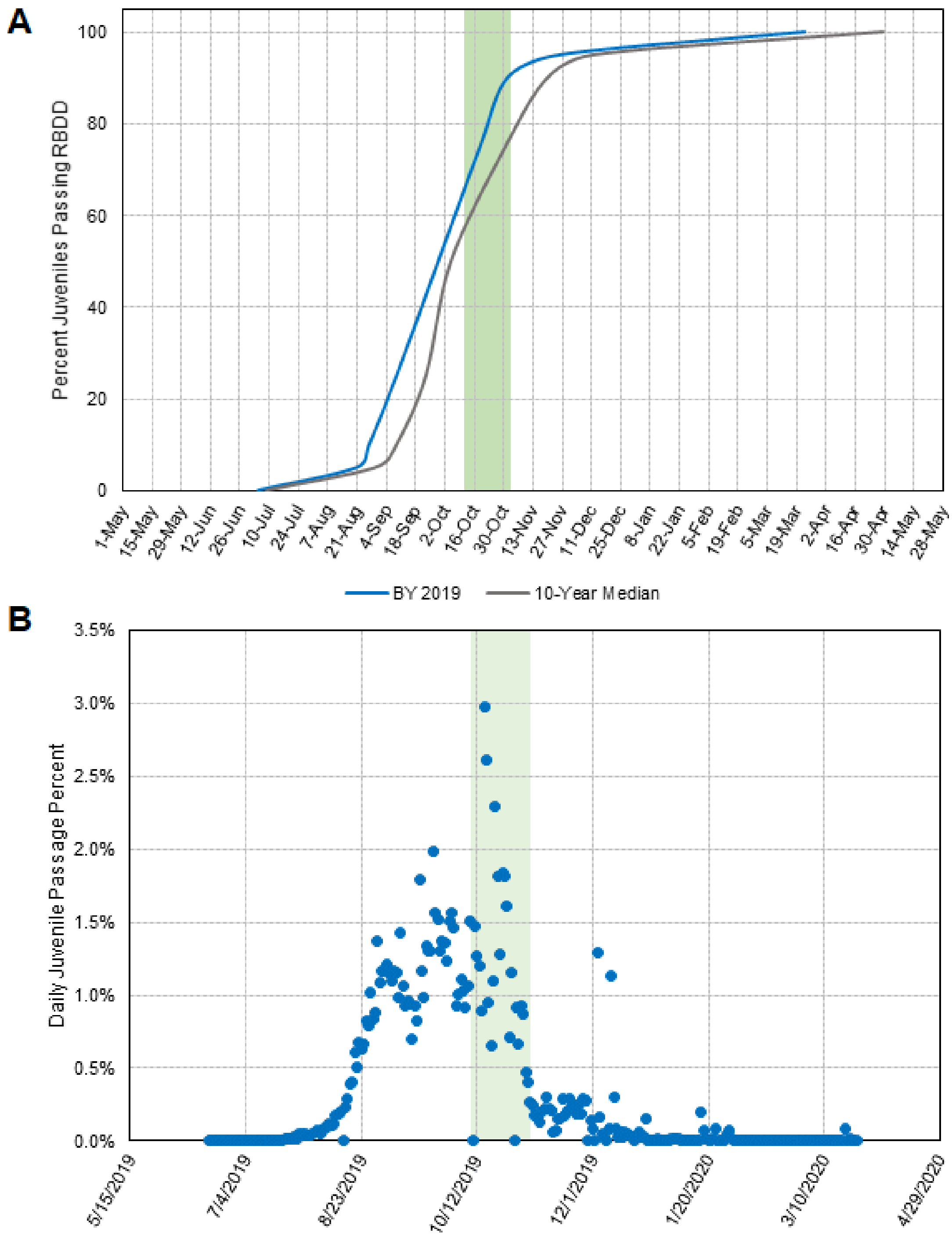
Water managers typically begin reducing flows from peak summer flows near 10,000 cfs during August and September. Over the last 10 years, base fall flow has reached an average low of approximately 6,000 cfs (Figure 25). In some years under drier conditions or reduced storage in Shasta Reservoir, base flow is reduced further to the minimum of 3,250 cfs (SRTTG 2019). However, maintaining releases above 5,000 cfs provides increased rearing habitat for juvenile WRCS, and it decreases juvenile stranding (SRTTG 2019). In 2019, a series of pulse flow releases from Keswick Dam (RM 302) occurred from mid- to late October. Four pulses with peaks of approximately 9,000 cfs occurred between October 14 and October 23, and a fifth, lower pulse of 8,200 cfs occurred on October 30 and 31.

Figure 25
Fall Sacramento River Flows at Bend Bridge



Note: Reduction in flow at Bend Bridge on the Sacramento River during fall, showing 2019 flow pulses and the most recent 10-year average (data and figure from SacPAS 2020)

Figure 26
Downstream Migration Response of BY 2019 WRCS to Fall Flow Pulse

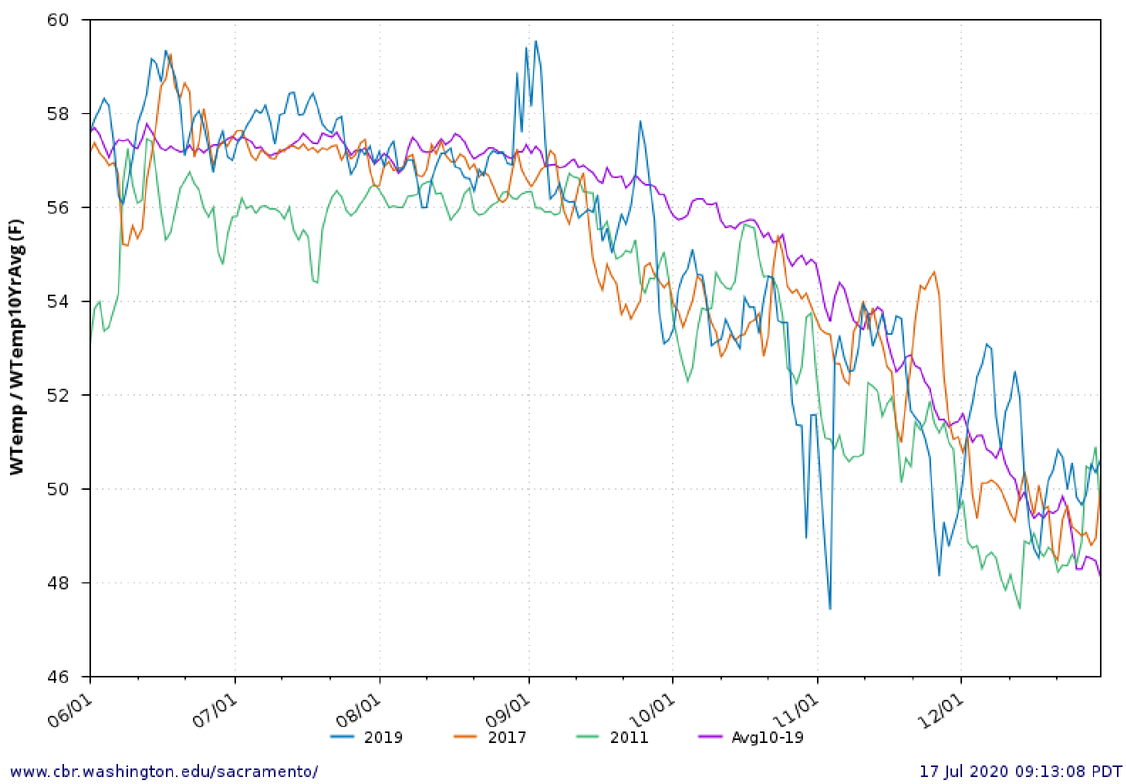


Note: Cumulative passage percentage (A) and daily juvenile passage percent (B) of BY 2019 at RBDD in response to the Keswick Dam flow pulses (shown as shaded green box; data are from SacPAS 2020).

6.2.2 *Water Temperatures*

Water temperatures from mid-August to early December 2019 when a majority of BY 2019 juveniles were rearing in the upper Sacramento River were generally similar to or below the 10-year average at Bend Bridge (Figure 27). Water temperatures during this time period were below 57°F. Exceptions occurred at the end of August through early September 2019 when temperature rose to 59°F and again in late September 2019 when water temperatures rose to 58°F. Both spikes in water temperature corresponded to multiple-day periods in which air temperatures at Redding were warmer than the 30-year average (average departure +5.8°F from August 21 to September 6 and +13.3°F from September 23 to 26). Water temperatures were again warmer than the 10-year average in early to mid-December 2019, but by this time 90% of BY 2019 WRCS juveniles had passed RBDD. Water temperatures during summer and fall 2019 were also generally similar to those in observed in 2011 and 2017.

Figure 27
Fall Sacramento River Water Temperature at Bend Bridge



Water temperatures at Bend Bridge (BND, RM 257) from June through December in 2019 (WY 2020) compared to 2017 and 2011 and the 10-year average. Data from SacPAS (2020).

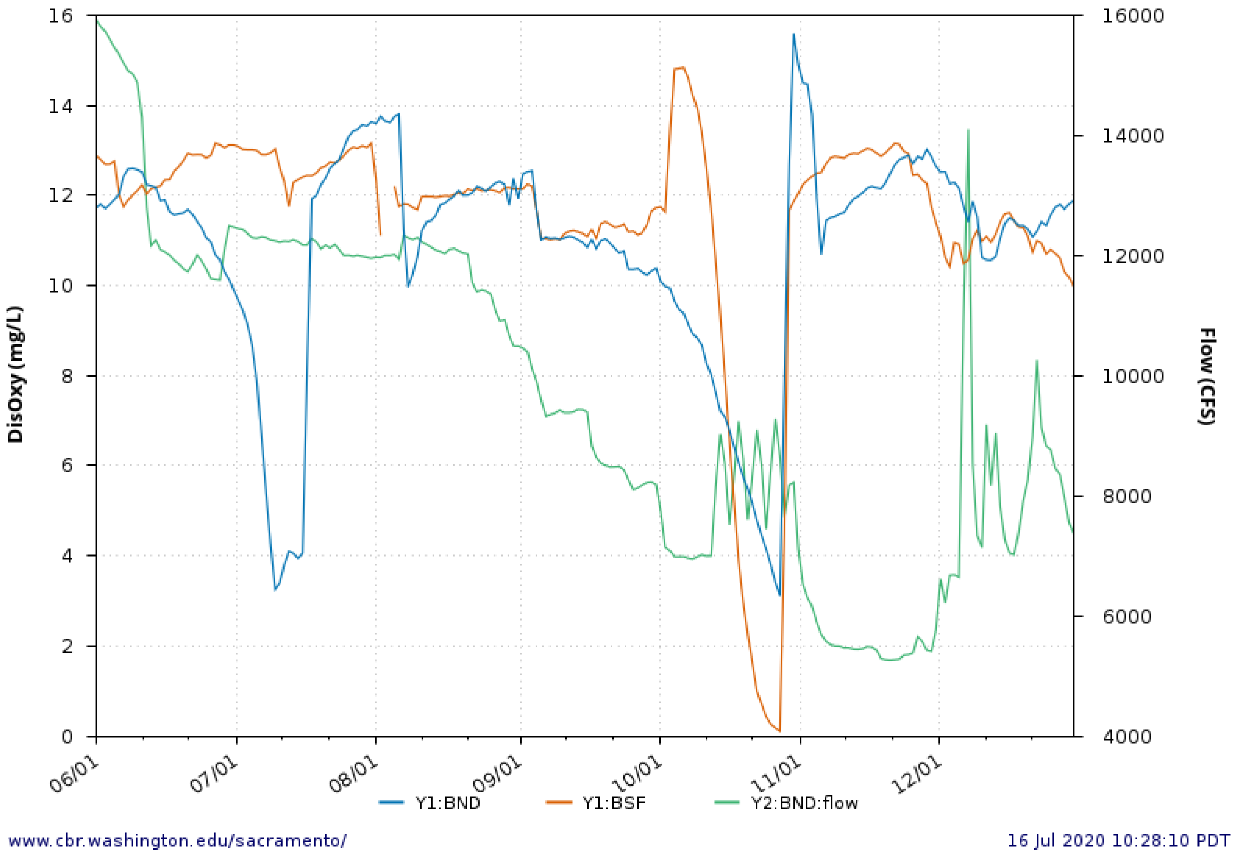
6.2.3 *Dissolved Oxygen*

DO was generally greater than 10 mg/L when most of the juveniles were rearing in the upper Sacramento River between mid-August and early December 2019. There was an exception where DO fell below 6 mg/L at Bend Bridge on October 19, 2019 (Figure 28). DO below 6 mg/L could potentially reduce the fitness of migrating fish, as discussed in the next paragraph. The October low DO event was also recorded at the Balls Ferry Bridge gage, and an additional low DO event was recorded at RBDD starting on August 26, 2019. The total time of low DO could have been as high as 15 days in August and 16 days in October. However, the total time of low DO is unknown because hourly DO data show that the gages stopped recording data, were taken offline, or had data retracted for quality reasons when DO reached 5.0 mg/L (CDWR 2020). Extended periods of low DO are potentially harmful for fish if they cannot be avoided. The Jellys Ferry Bridge DO gage (RM 266) was not active for the majority of 2019.

Laboratory studies of juvenile Chinook salmon have shown that swimming speed can be reduced by 14% to 20% at temperatures ranging from 11°C to 15°C and when DO levels drop to 4 to 6 mg/L (Carter 2005). Daily average water temperatures during the low DO events observed in 2019 were approximately 58°F (14°C) in July and August and 53.5°F (12°C) in October. Juvenile Chinook salmon are documented to show marked avoidance of DO below 4.5 mg/L, although no avoidance to DO levels near 6 mg/L was documented (Carter 2005). Because upstream and downstream areas of higher DO were available during all the low DO events, WRCS may have been able to avoid these areas. During the July low DO event at Bend Bridge, DO at RBDD and at Balls Ferry Bridge remained above 10 mg/L; during the August low DO event at RBDD, DO at Bend Bridge remained above 10 mg/L, and during the October event, DO remained above 10 mg/L above Clear Creek (RM 292) and at RBDD.

Unavoidable areas where DO levels dropped below 3 mg/L would have to persist for longer than 3 days to cause significant juvenile Chinook salmon mortality, and this likely did not happen (Carter 2005). However, it is possible that taken together, the periods of low DO did cause some reduction in fitness for some rearing juvenile WRCS in 2019.

Figure 28
DO and Flow at Balls Ferry Bridge and Bend Bridge in Summer and Fall 2019

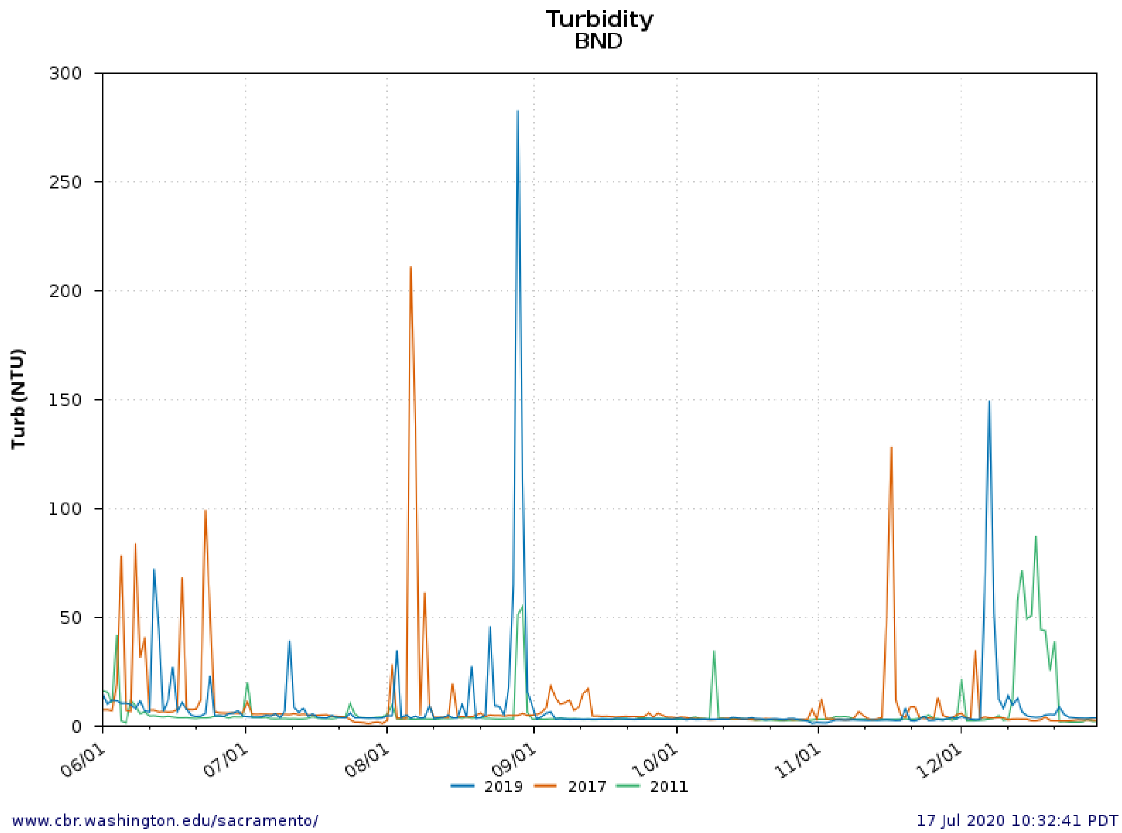


DO levels at Balls Ferry Bridge (BSF, RM 275) and DO and flow at Bend Bridge (BND, RM 257) in 2019. Data and figure from SacPAS (2020).

6.2.4 Turbidity

Turbidity in summer and fall 2019 was generally similar to conditions in similar WYs in 2011 and 2017 (Figure 29) and included three events where turbidity at Bend Bridge was greater than 50 NTU between June and December. The highest turbidity recorded at Bend Bridge was approximately 280 NTU in late August. It was not associated with increased flow or low DO events at Bend Bridge or Balls Ferry Bridge but did occur during the same time period as the low DO event at RBDD. This high-turbidity event may have encouraged downstream migration of WRCS based on median passage occurring 12 to 13 days earlier in 2019 than the 10-year average during late August and early September (Table 3). Another high-turbidity event of approximately 150 NTU occurred in mid-December. This event was associated with a high-flow event that occurred at the same time (Figure 28), but most juvenile WRCS (95%) had migrated past RBDD by this time.

Figure 29
Turbidity at Bend Bridge in Summer and Fall 2019



Turbidity at Bend Bridge (BND; RM 257) during BY 2019 rearing and out-migrating. Data from SacPAS (2020).

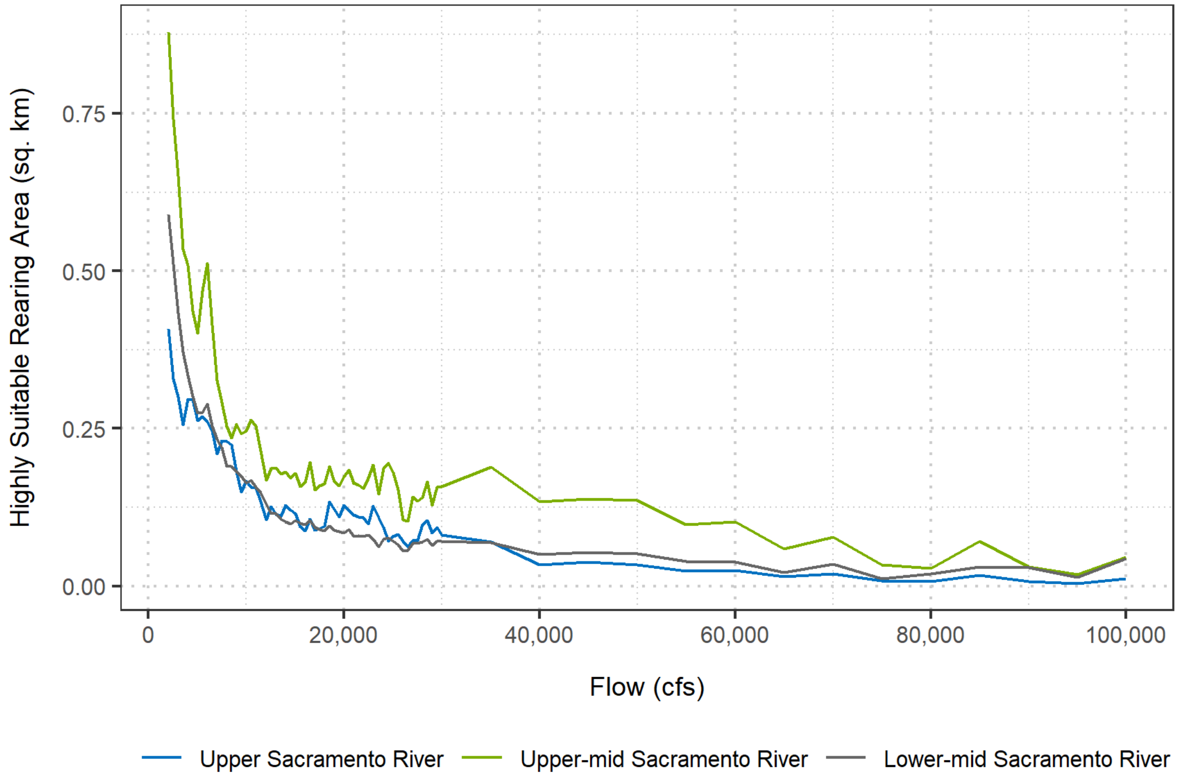
6.2.5 Rearing Habitat Capacity

During the period from August 27 to November 1, 2019, 80% of BY 2019 WRCS moved downstream of RBDD. Flows decreased from approximately 10,500 cfs in late August to 7,000 cfs in early October as part of management actions to prepare for spring and fall-run Chinook salmon spawning and prevent redd dewatering. Implementation of pulse flows of approximately 9,000 cfs began on October 14 and continued through October 31, 2019. Habitat modeling showed that, between 7,000 and 10,500 cfs, approximately 0.21 to 0.16 square kilometers (km^2) of in-stream rearing habitat was available in the upper Sacramento River (CVPIA 2020; Figure 30). As discussed in Section 6.2.1, except for the pulse flows, the fall reduction to winter flows was similar to other years. This indicates that the amount of in-stream rearing habitat available for rearing was likely similar to other years.

Habitat modeling has shown that a negligible amount of floodplain rearing habitat is available for salmonids at flows below 25,000 cfs (CVPIA 2020; Figure 31). Although summer and fall flows in 2019 were similar to other years, maximum WY 2020 winter flows between December 2019 and March 2020 peaked at 18,000 cfs. This is similar to the 10-year average but much lower than the maximum winter flow in wet WYs that occurred in WYs 2019, 2017, and 2011, when periods of flows between 25,000 and 93,000 cfs allowed for 1.31 to 6.0 km^2 of floodplain habitat to be available (Figure 31). However, winter flows in WY 2020 that were experienced by BY 2019 peaked at 18,000 cfs, indicating that a negligible amount of floodplain habitat was available for these juvenile fish.

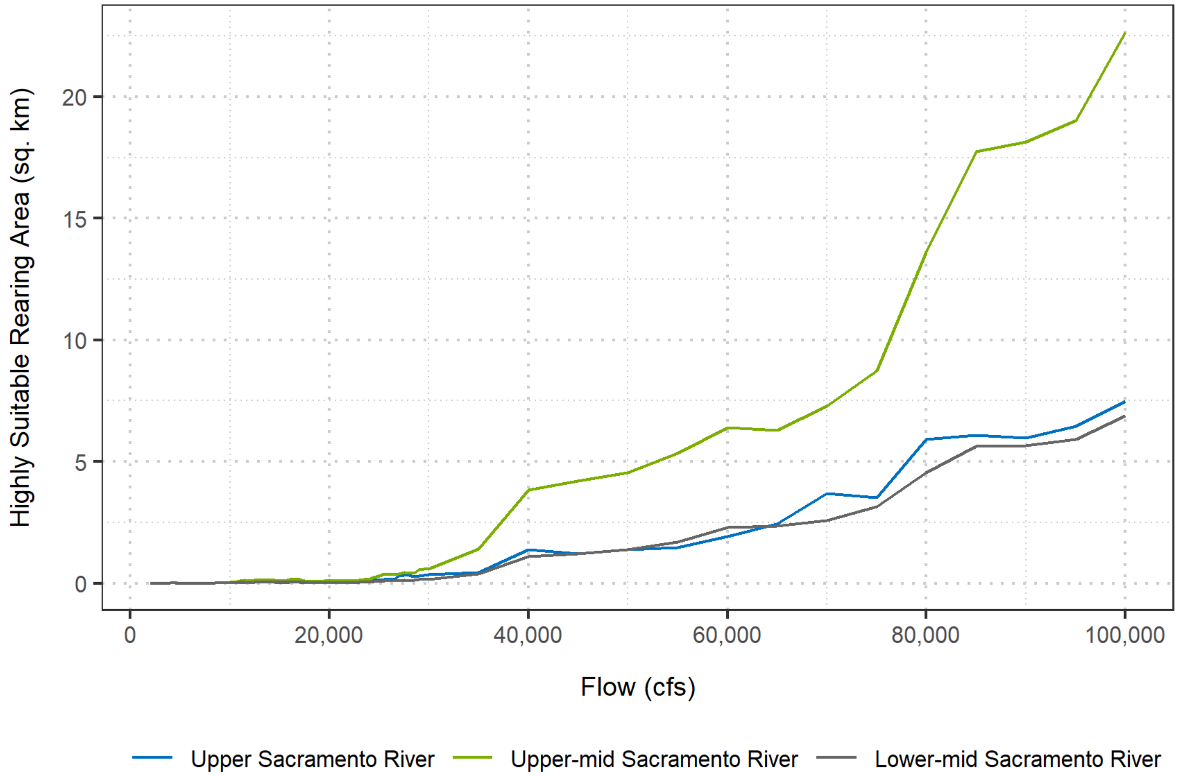
Because of water management changes in flow conditions, fish agencies conducted juvenile stranding surveys for WRCS in the fall and early winter of 2019 and 2020. Between November 11, 2019, and January 27, 2020, a total of 1,611 WRCS fry were rescued from stranding sites in the upper Sacramento River region (Keswick Dam to RBDD; Table 4). This is far fewer than the 7,766 juvenile WRCS that were rescued from stranding sites in 2018 (Israel and Johnson 2020), especially considering the much greater number of BY 2019 fry. This may indicate that late-migrating fry that might have otherwise been stranded were instead pushed downstream by pulse flows.

Figure 30
In-Stream Rearing Habitat



In-stream rearing habitat area based on habitat modeling conducted for the NMFS WRCS life cycle model The entire mapped rearing extent of the Sacramento River was modeled using the Central Valley Floodplain Evaluation and Delineation (CVFED) HEC-RAS hydraulic model that was refined for use in their WRCS life cycle model (Gill and Tompkins 2020). Data were retrieved from the CVPIA SIT Salmon Population Model data website (CVPIA 2020).

Figure 31
Floodplain Rearing Habitat



Floodplain rearing habitat area based on habitat modeling conducted by NMFS for their WRCS life cycle model. The entire mapped rearing extent of the Sacramento River was modeled using the CVFED HEC-RAS hydraulic model that was refined for use in their WRCS life cycle model (CVPIA 2020).

Table 4
Juvenile WRCS Rescued During Stranding Surveys Conducted in 2019 on the Upper and Middle Sacramento River

Date	Number of Juveniles	Sacramento River Region	River Section	River Mile	River Flow (cfs)	River Flow Gage
11/7/2019	26	Upper	Highway 44 Bridge to Airport Road Bridge	296–284	4993	KWK
11/12/2019	491	Upper	ACID Dam to Highway 44 Bridge	298–296	4987	KWK
11/13/2019	138	Upper	ACID Dam to Highway 44 Bridge	298–296	4971	KWK
11/14/2019	292	Upper	Keswick Dam to ACID Dam	302–298	4961	KWK
11/15/2019	385	Upper	Keswick Dam to ACID Dam	302–298	5031	KWK
11/18/2019	10	Upper	Airport Road Bridge to Balls Ferry Bridge	284–275	4872	KWK

Date	Number of Juveniles	Sacramento River Region	River Section	River Mile	River Flow (cfs)	River Flow Gage
11/20/2019	17	Upper	Airport Road Bridge to Balls Ferry Bridge	284–275	4792	KWK
11/21/2019	2	Upper	Airport Road Bridge to Balls Ferry Bridge	284–275	4800	KWK
11/22/2019	130	Upper	Airport Road Bridge to Balls Ferry Bridge	284–275	4806	KWK
12/5/2019	75	Upper	ACID Dam to Highway 44 Bridge	298–296	4904	KWK
12/9/2019	27	Upper	Bend Bridge to RBDD	257–242	8530	BND
1/7/2020	5	Middle	RBDD to Tehama Bridge	242–229	6834	BND
1/13/2020	10	Middle	RBDD to Tehama Bridge	242–229	6862	BND
1/27/2020	3	Middle	RBDD to Tehama Bridge	242–229	12134	BND
Total:	**1611**					

Note:
River flow gages are Keswick Dam (KWK) and Bend Bridge (BND).

6.3 Key Management Questions and Findings

In the following section, information is synthesized regarding key management questions related to rearing and out-migrating juveniles in the upper Sacramento River.

6.3.1 Did Fry Production Increase for BY 2019?

Yes, the number of fry and fry-equivalents (JPI) at RBDD (4,762,142 fish) was the highest since 2006, despite a lower egg-to-fry survival. Fry-to-smolt survival was revised downward for BY 2019, which could inflate the estimate of fry-equivalents compared to previous years. The larger JPI was related to the larger number of in-river spawning females and a higher-than-average fecundity estimate in 2019 but could also have been influenced by the lower fry-to-smolt survival.

Habitat attributes and environmental drivers that were evaluated in the upper Sacramento River during fry rearing and out-migration were all similar to or better than the 10-year average or expected to benefit BY 2019. The only exception to this trend was that floodplain habitat was not accessible. There were also two spikes in water temperature above the 10-year average in late August and late September when air temperatures in Redding were higher than the 30-year average. DO dropped to low levels on three different occasions during out-migration, but these events were not expected to cause mortality. On the upper Sacramento River, 1,593 WRCS juveniles, or less than<1% of the JPI, were documented as being stranded. This indicates that flows during late summer and fall 2019 were managed in a way that reduced stranding risk and benefited juvenile survival.

6.3.2 Did Pulse Flows Change Migration Patterns and Stimulate Earlier Movement Downstream?

Yes, it appears that the pulse flows stimulated migration, which resulted in earlier cumulative migration and caused fish to be smaller in size at RBDD (although many factors influence fish size such as habitat quality, food availability, and temperature). For BY 2019, median cumulative passage occurred approximately 10 days earlier compared to the 10-year average, which was before the pulse flows were implemented. After the pulse flows were implemented on October 14, WRCS 95% cumulative passage occurred approximately 20 days earlier than the 10-year average, and 100% cumulative passage occurred 34 days earlier than the 10-year average. Based on this information, it appears that the fall pulse flows caused fry to emigrate earlier than normal. BYs 2011 and 2017 experienced similar WY conditions but without the pulse flows. The date of median cumulative passage was approximately 20 days later in 2017 and 9 days later in 2011. Fork length averages at RBDD for the entire season were smaller for BY 2019 fish (47.5 to 71.2 mm) than the 10-year average (54.6 to 77.1 mm). The BY 2019 and BY 2017 fork length distributions at RBDD were very similar, but maximum fork length and maximum average daily fork length for BY 2017 were approximately 10 mm larger, and median passage at RBDD for BY 2017 was 20 days later than for BY 2019. The maximum size observed for BY 2011 fish was similar to BY 2019 fish, and cumulative median passage at RBDD in 2010 to 2011 for BY 2011 fish was only 9 days later than for BY 2019 fish. It is noted that none of the monitoring sites on the upper Sacramento River report water velocity, and increased velocity associated with higher flows could be the environmental cue fish are responding to as flows increase.

6.3.3 Was Rearing Habitat (In-River and Floodplain) Higher Than Normal for BY 2019?

No, the amount rearing habitat (in-stream and floodplain) was similar to or lower than other years. Suitable habitat is based on flow, and except for the pulse flows, the fall reduction to winter flows was similar to other years. This indicates that the amount of in-stream rearing habitat available for rearing was likely similar to other years. Winter flows in WY 2020 that were experienced by BY 2019 peaked at 18,000 cfs, indicating that a negligible amount of floodplain habitat was available for these juvenile fish. This is similar to the 10-year average but is much lower than the maximum winter flow in wet WYs allows for connection of floodplain habitat.

6.3.4 Were Environmental Conditions Necessary for Good Productivity and Survival Met?

Yes, environmental conditions were generally similar or better than the 10-year average for BY 2019 rearing and out-migrating juveniles. Environmental conditions that were better than the 10-year average were water temperature, DO, flows, system hydrology, and migration cues. Turbidity and air temperatures were similar to the 10-year average. There were fewer juvenile strandings in 2019, and in-stream habitat capacity was similar to the 10-year average. The exception to conditions that were beneficial for BY 2019 was the lack of connection to floodplain rearing habitat, as discussed in the previous question. The environmental conditions experienced by BY 2019 resulted in the highest JPI since 2006, despite a slightly lower fry-to-smolt survival.

6.3.5 Did the Rearing and Migration Periods Overlap for Natural-Origin WRCS and Hatchery Releases?

No, 95% of BY 2019 natural-origin juveniles passed RBDD by November 26, 2019, and 95% of BY 2019 natural-origin juveniles passed Sacramento Trawls at Sherwood Harbor (RM 55) by February 6. In contrast, hatchery-origin juveniles were reared at LSNFH until being released at Redding (RM 299) on March 10 and 23 and at North Fork Battle Creek (~16 miles above the confluence with the Sacramento River at RM 271) on March 23. Because of this difference in timing of natural-origin WRCS migrations and hatchery-origin WRCS release dates, there was likely minimal co-occupancy of habitats and interactions between the two sources of BY 2019 fish in the upper or middle Sacramento River.

We compared migration timing and release dates because hatchery reared juveniles released at the same time could interact with natural-origin migrants. Interactions that negatively affect natural-origin WRCS migrants, such as competition for resources or transmission of disease, could reduce survival and abundance of wild-origin fish.

7 Rearing-to-Out-Migrating Juveniles in the Middle Sacramento River

This section describes the assessment findings for rearing-to-out-migrating juveniles in the middle Sacramento River. A summary of findings is provided, followed by the analysis each of fish response and habitat attributes and environmental drivers.

The number of juveniles surviving the middle Sacramento River and entering the Delta (i.e., the JPE) for BY 2019 fish was the highest since 2013, despite estimated natural-origin smolt survival being the lowest value since BY 2013. The large numbers of juveniles entering the Delta were due to a higher number of fry (JPI) because new methods used for estimating both fry-to-smolt survival and smolt survival resulted in lower values than would have been estimated using the previous methods. Habitat attributes and environmental drivers in the middle Sacramento River during rearing were similar to the 10-year average or were expected to benefit BY 2019, except for flows and floodplain connectivity. WY 2020 will likely be ranked as a below normal WY, and little to no floodplain connectivity occurred during WRCS out-migrations due to the low flows. No data are available to assess fish growth rate on the middle Sacramento River (Johnson et al. 2017). However, it is likely that the lack of floodplain habitat access in WY 2020 reduced the growth potential for BY 2019 fish given the benefits associated with floodplain productivity (Cordoleani et. al. 2020). The amount of in-stream rearing habitat available during BY 2019 rearing and out-migration through the middle Sacramento River was greater than the 10-year average.

The pattern observed in the upper Sacramento River where downstream migration timing was advanced carried into the middle Sacramento River reach. Median passage at Knights Landing (RM 90) was 5 to 10 days earlier than the 10-year average, and median passage of WRCS past Sherwood Harbor (RM 55) near Sacramento occurred nearly 2 months earlier than the 10-year passage. The reason for this early migration timing is unclear but could be due to an increase in flow and high turbidity that occurred near the town of Verona (RM 78). The impact of this earlier migration to the Delta on survival through the Delta, San Francisco Bay, and upon ocean entry is unknown.

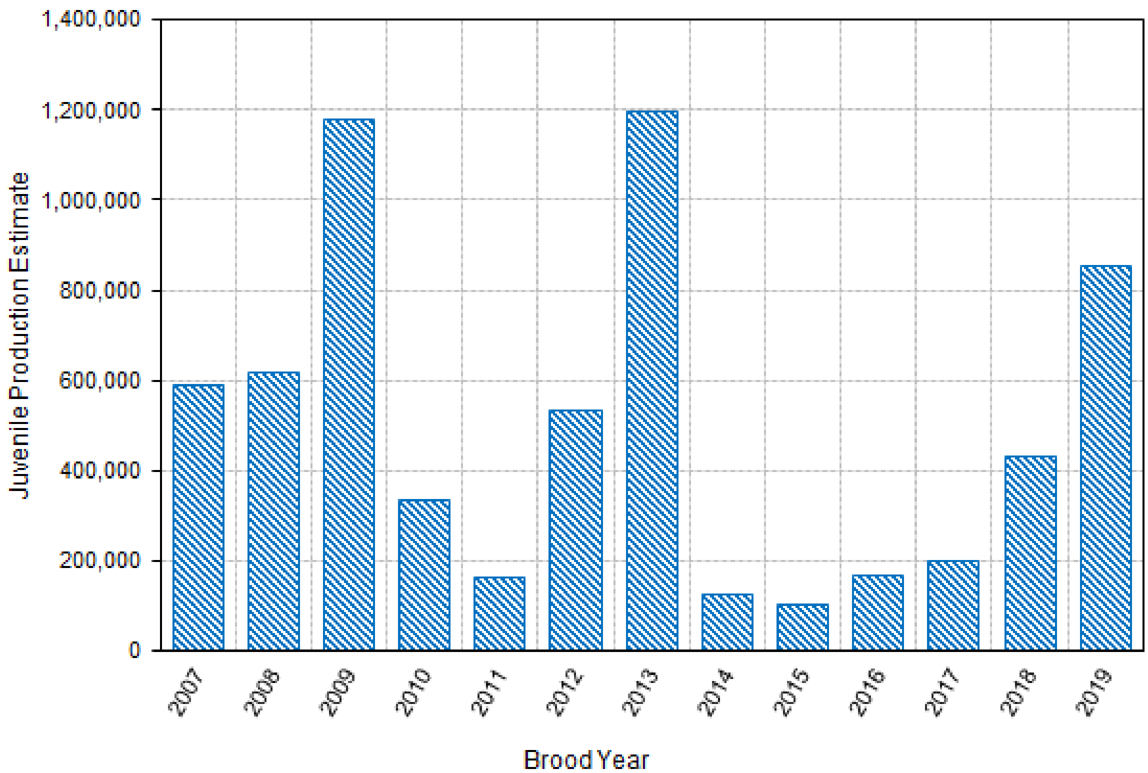
7.1 Fish Response

7.1.1 Juvenile Production (Abundance)

The natural-origin JPE for BY 2019 WRCS entering the Delta was 854,941 fish. This was the highest value since BY 2013 and continues a trend of increasing JPE since BY 2015 (Figure 32). Natural-origin JPE is calculated using the fry-equivalent JPI at RBDD (RM 242), fry-to-smolt survival at RBDD, and smolt survival from RBDD to Tower Bridge at RM 59 in Sacramento (NMFS 2020).

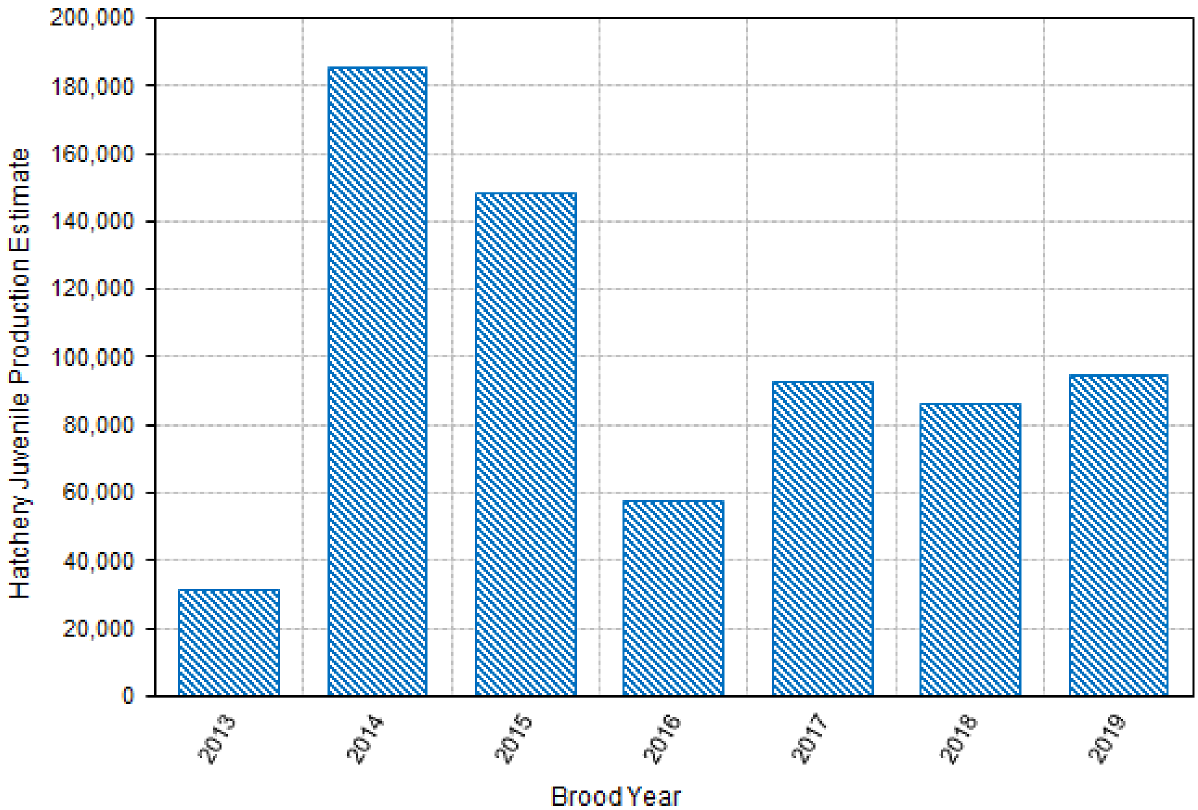
The hatchery-origin JPE for BY 2019 was estimated as 94,528 fish (Figure 33). Hatchery-origin JPE is calculated using the number of hatchery smolts released above RBDD and smolt survival from the release site above RBDD to Tower Bridge (NMFS 2020). JPE for BY 2019 hatchery-origin fish was similar to the past 2 BYs and reflects reduced hatchery supplementation as WRCS have recovered from severe drought in 2014 and 2015. Fry-to-smolt survival, JPI, and hatchery releases are discussed more in Section 6.1.1. Natural- and hatchery-origin smolt survival are discussed in Section 7.1.2.

Figure 32
Natural-Origin Juvenile Production Estimates for Sacramento River Winter-Run Chinook Salmon



Natural-origin JPE for Sacramento River WRCS entering the Delta. Data from NMFS (2011,2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020).

Figure 33
Hatchery-Origin Juvenile Production Estimates for Sacramento River Winter-Run Chinook Salmon



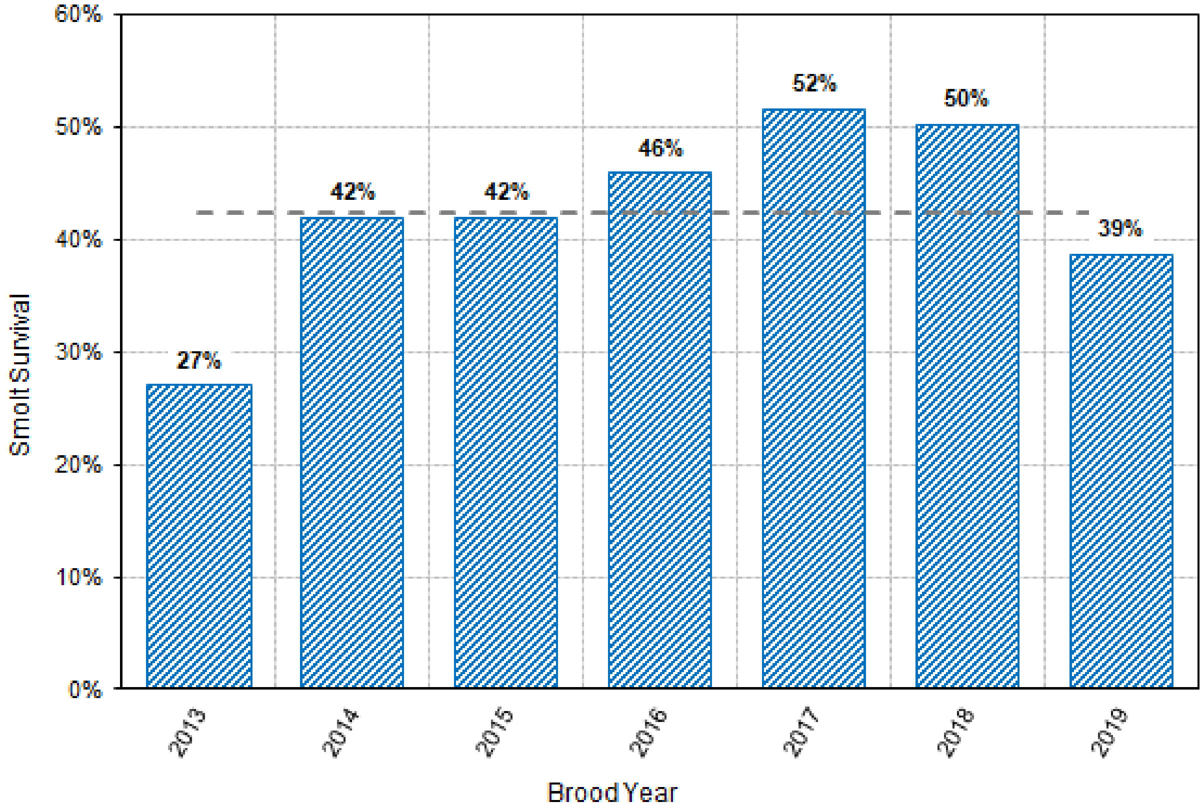
Hatchery-origin JPE for Sacramento River WRCS entering the Delta. Data from NMFS (2014, 2015, 2016, 2017, 2018, 2019, 2020).

7.1.2 Smolt Survival

Smolt survival to the Delta is calculated based on a weighted average survival of acoustically tagged hatchery WRCS released at RBDD and is measured to Tower Bridge (NMFS 2020). Natural-origin smolt survival for BY 2019 was estimated to be 38.6% (Figure 34). The lower smolt survival for BY 2019 was due to a revised calculation method (O'Farrell et al. 2018). BY 2019 smolt survival calculated using the previous method (used for BYs 2013 to 2018) produced a value of 47.6%, which is similar to the prior three BYs and greater than the average survival of 42% since 2013 (NMFS 2020).

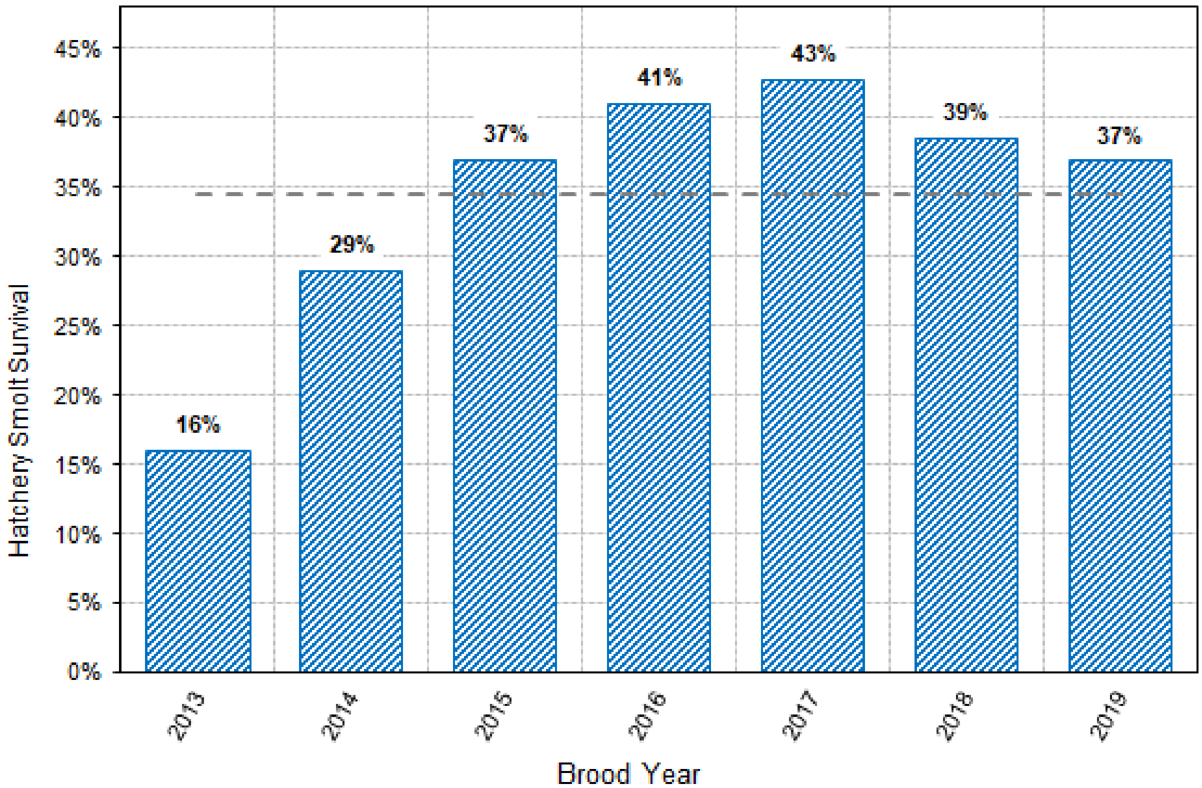
Hatchery-origin smolt survival is based on acoustically tagged hatchery WRCS released approximately 60 miles upstream from RBDD and is also measured from RBDD to Tower Bridge (NMFS 2020). Hatchery-origin smolt survival for BY 2019 was estimated to be 36.9%, which was similar to the average survival of 34% since BY 2013 (Figure 35). Hatchery-origin smolt survival was also calculated using the previous method, which resulted in a slightly higher value of 38.6%.

Figure 34
Natural-Origin Smolt Survival from RBDD to Tower Bridge



Natural-origin smolt survival from RBDD to Tower Bridge in Sacramento, based on acoustically tagged fish. The average survival rate since 2013 (42%) is shown as a dashed grey line. Prior to 2013 a constant value of 0.54 was used in the JPE calculation each year. Data from NMFS (2014, 2015, 2016, 2017, 2018, 2019, 2020).

Figure 35
Hatchery-Origin Smolt Survival from RBDD to Tower Bridge

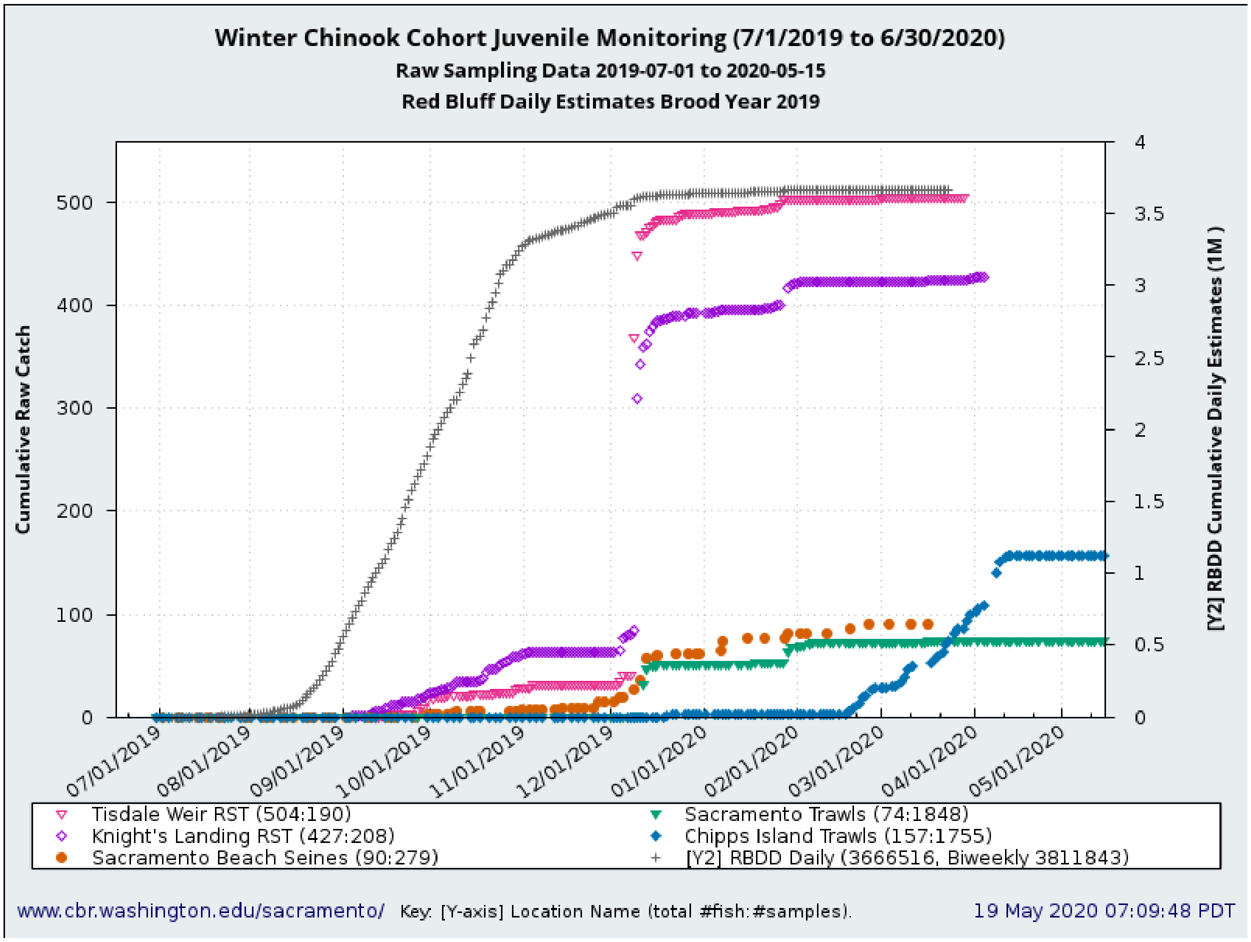


Hatchery-origin smolt survival from RBDD to Tower Bridge in Sacramento, based on acoustically tagged fish. The average survival rate since 2013 (34%) is shown as a dashed grey line. Prior to 2013 a constant value of 0.54 was used in the JPE calculation each year. Data from NMFS (2014, 2015, 2016, 2017, 2018, 2019, 2020).

7.1.3 Migration Timing

As juveniles make their way downstream from RBDD to the Delta, they pass RST and trawl sampling locations that help determine passage timing. Sampling with RSTs occurs at three locations: the Glenn-Colusa Irrigation District (GCID) (RM 205), the Tisdale Weir (RM 119), and Knights Landing, just north of the Sacramento International Airport (Figure 1). A total of 5,353 juvenile BY 2019 WRCS were sampled at GCID, 504 at Tisdale Weir, and 427 at Knights Landing RSTs (Figure 36). Trawl sampling in the Sacramento River occurs at Sherwood Harbor, just downstream from Sacramento, and is considered the entry point to the Delta. Trawling in winter 2020 reported a raw catch of 74 winter-run juveniles, which was used to calculate an index catch of 72.9 fish. Further details of migration timing and count data at each location are provided in Appendix B. Overall, a majority of the WRCS juveniles were present in the middle Sacramento River from the beginning of September (when 5% passage at RBDD had occurred) until early February 2020 (when 95% passage at Sherwood Harbor had occurred).

Figure 36
Cumulative Raw Catch of BY 2019 WRCS at Middle Sacramento River Sampling Locations Compared to Cumulative Daily Passage at RBDD



Middle Sacramento River cumulative raw catch is shown on the left Y axis. Cumulative daily passage in millions at RBDD is shown on the right Y axis. Figure and data from SacPAS (2020).

Passage timing of BY 2019 fish through the middle Sacramento River was earlier than other BYs over the last 10 years (Table 8-1). As discussed in Section 6.1.2, cumulative median passage at RBDD occurred on September 29, 2019, which was approximately 10 days earlier than the 10-year average. The reach of the middle Sacramento River between RBDD and GCID is approximately 37 RM long. At GCID, 32% of the cumulative passage had occurred by the end of September, and 75% had occurred by the end of October. Daily passage data based on RST sampling were not available to calculate the exact date of 50% (median) passage at GCID.

Median cumulative passage of BY 2019 WRCS at Tisdale RST occurred on December 9, 2019. This means that BY 2019 juveniles spent approximately 71 days in the 123-mile reach between RBDD at

RM 242 and the Tisdale Weir RST at RM 119, which was the same as the 10-year average. The migration rate in this part of the middle Sacramento was approximately 1.73 miles per day using the median passage dates and distance traveled.

The Tisdale RST at RM 119 and Knights Landing RST at RM 90 are relatively close together, and juveniles reach these two sampling stations at approximately the same date in most years (Figure 35, Table B-1 and Table B-2 in Appendix B). This includes 2019, where median passage at the Tisdale Weir RST was on December 9, 2019, and at the Knights Landing RST was on December 10, 2019. The earlier migration timing at RBDD carried through to the lower river because median passage at Knights Landing RST occurred approximately 5 days earlier than the 10-year average (Table 5).

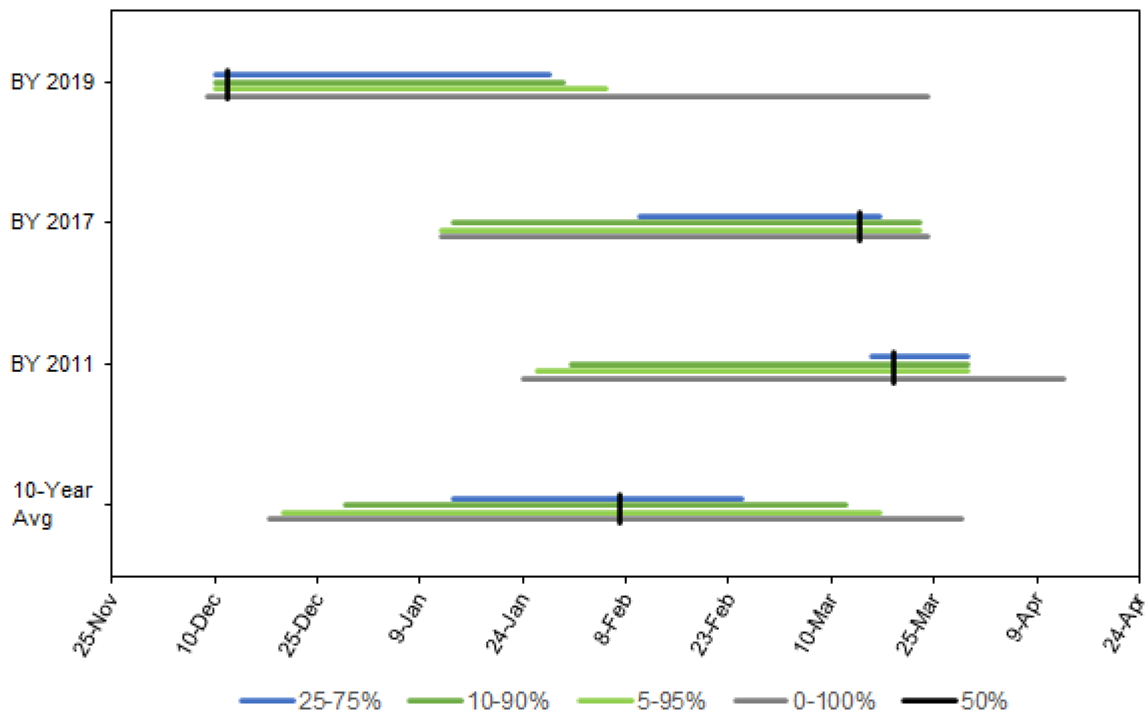
From Knights Landing, BY 2019 juveniles continued actively moving downstream through the middle Sacramento River to Sherwood Harbor, just south of Sacramento. Trawling data show that median passage at Sherwood Harbor occurred on December 12, which is just 2 days after median passage occurred at the Knights Landing RST and 57 days earlier than the 10-year average (Figure 37). In contrast, the average amount of time spent between the Tisdale Weir RST and Sherwood Harbor is 54 days over the past 10 years. During this period, average median passage occurred on February 7 each year. However, by early February 2020, cumulative passage of BY 2019 fish had already reached 95%, which is approximately 30 to 40 days earlier than the 10-year average. For BY 2019 fish, 100% cumulative passage occurred by the end of March 2020, which is similar to the 10-year average (Figure 37). It is unclear how the earlier migration timing impacted BY 2019 fish as they continued their out-migration through the Delta.

Table 5
Dates of 50% Cumulative Passage of BY 2019 Fish at Various Sampling Locations from RBDD to Sherwood Harbor Compared to the 10-Year Averages for Each Location

Location	River Mile	50% Cumulative Passage Date				Difference in Days Between BY 2019 and the 10-Year Average
		BY 2019	10-Year Average	10-Year First[1]	10-Year Last[1]	
RBDD RST	242	September 29, 2019	October 9	September 26	October 27	-10
GCID RST*	205	October	November	October	November	-
Tisdale Weir RST	119	December 9, 2019	December 9	October 29	February 27	-10
Knights Landing RST	90	December 10, 2019	December 15	October 31	March 2	-5
Sacramento Trawl at Sherwood Harbor	55	December 12, 2019	February 7	November 26	March 29	-57

Notes:
* only monthly catch data were reported by GCID.
-:no data were available
1. First and last juvenile WRCS recorded for the season.

Figure 37
Winter-Run Chinook Salmon Juvenile Passage Timing at the Sacramento Trawls (Sherwood Harbor; RM 55) for BY 2019 Compared to BYs 2011 and 2017 and the 10-Year Average



Data from SacPAS (2020).

7.2 Habitat Attributes and Environmental Drivers

Habitat attributes and environmental drivers are discussed in this section for the middle Sacramento River. The data in this section were obtained from the Vina Bridge (RM 218), Hamilton City (RM 199), and Verona gages. The Vina Bridge and Hamilton City gages are located between the RBDD and the Tisdale Weir, where RSTs are used to document fish migration timing. The Verona gage is located between Knights Landing and Sherwood Harbor, where an RST and trawls are used to document fish migration timing. For this analysis, fish were assumed to be present during the following times near each gage, based on the fish migration timing data:

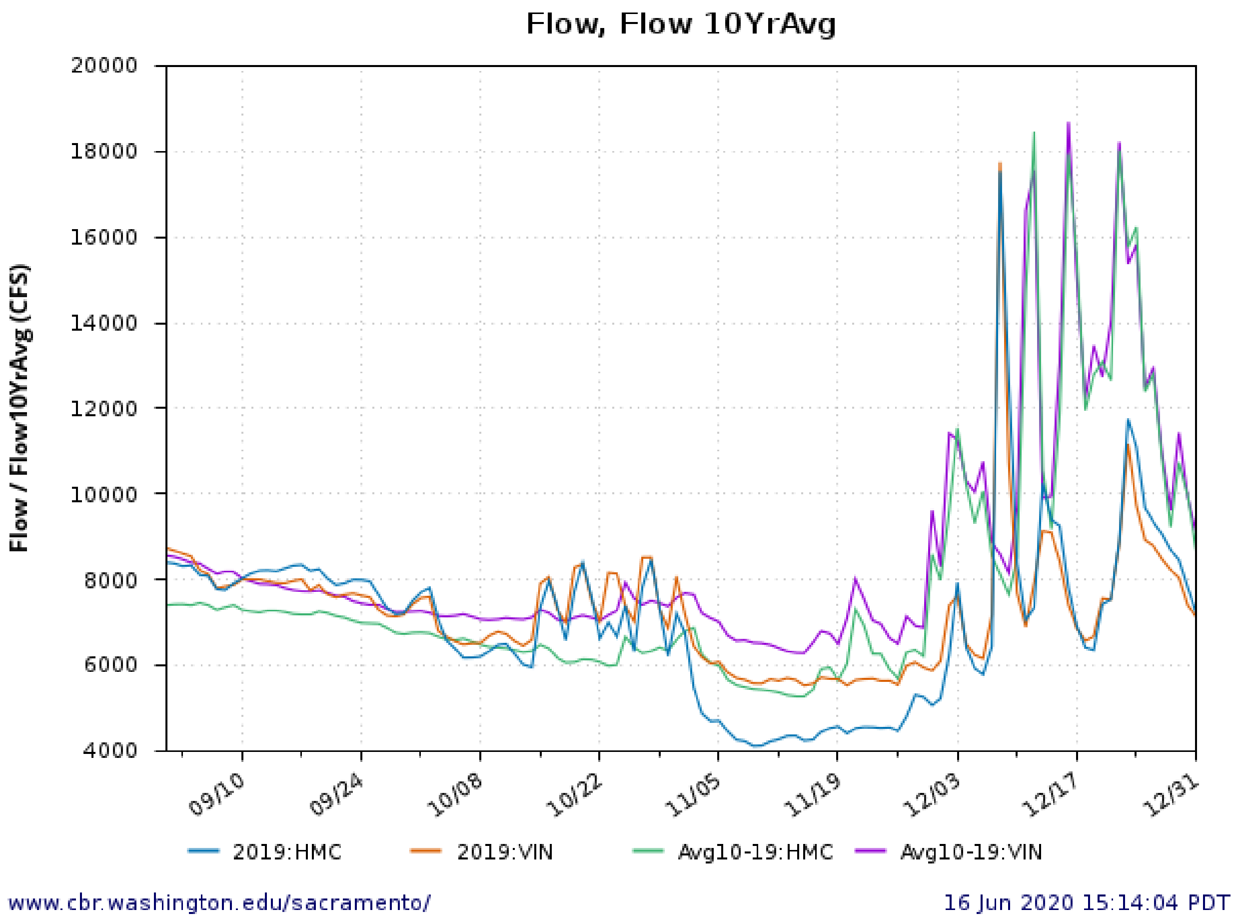
- **Vina Bridge and Hamilton City:** Fish were assumed to be present in this section of the river between the beginning of September and mid-December 2019 based on the timing of 5% cumulative passage at RBDD (beginning of September) and 95% cumulative passage at the Tisdale Weir (mid-December).
- **Verona:** Fish were assumed to be present in this section of the river between the end of September 2019 and the beginning of February 2020 based on the timing of 5% cumulative

passage at Knights Landing (end of September) and 95% cumulative passage at Sherwood Harbor (beginning of February).

7.2.1 River Flows

Flows in the middle Sacramento River at Vina Bridge and Hamilton City during juvenile rearing and out-migration between the beginning of September and mid-December 2019 were above and below the 10-year average. Between the beginning of September and early October, flows were above the 10-year average, and between early October and mid-December, flows were generally below the 10 year average (Figure 38), The only exception to this was during the pulse fall flows that occurred from mid- to late October, when flows were higher than the 10-year average. Flow at Vina Bridge represents middle Sacramento River flow above the GCID diversion, whereas Hamilton City represents flow below GCID. In November 2019, flows at Hamilton City dropped to just above 4,000 cfs, which was lower than the 10-year average for this time of year and lower than flows in similar below normal WYs (2012 and 2018). Flows at Vina Bridge in November dropped after the fall pulse flows as well but did not drop as much as flows at Hamilton City, indicating the GCID diversion caused the flows at Hamilton City to drop more than at Vina Bridge. Flows increased in December due to storm events but were lower than the 10-year average at both Vina Bridge and Hamilton City.

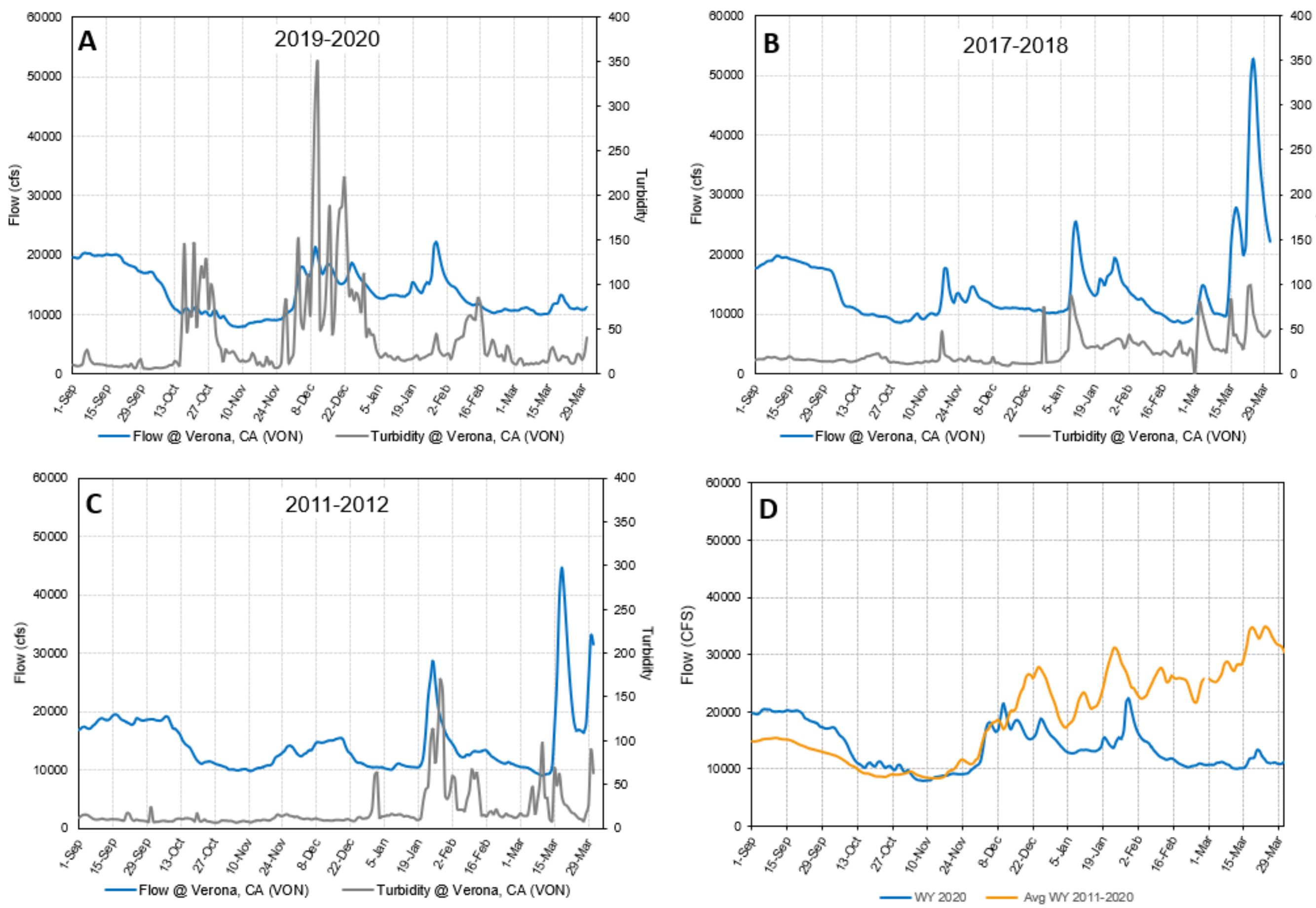
Figure 38
Middle Sacramento River Flow at Vina Bridge and Hamilton City



Sacramento River flow at Vina Bridge (VIN, RM 218) and at Hamilton City (HMC, RM 199) approximately 5 miles downstream of GCID. Fall 2019 flows and the 10-year average are shown for both locations. Data and figure from SacPAS (2020).

Flows in the middle Sacramento River near Verona during juvenile rearing and out-migration between the end of September 2019 and early February 2020 were above and below the 10-year average. Flows between the end of September and mid-December were above or similar to the 10 year average and flows between mid-December to early February were lower than the 10-year average (Figure 39). As a result, no overtopping of the Freemont Weir (into Yolo Bypass), Tisdale Weir (into Sutter Bypass), Colusa Weir, or Mouton Weir (into Butte Basin) occurred in WY 2020.

Figure 39
Turbidity and Flow Conditions in the Middle Sacramento River for WYs 2020, 2018, and 2012

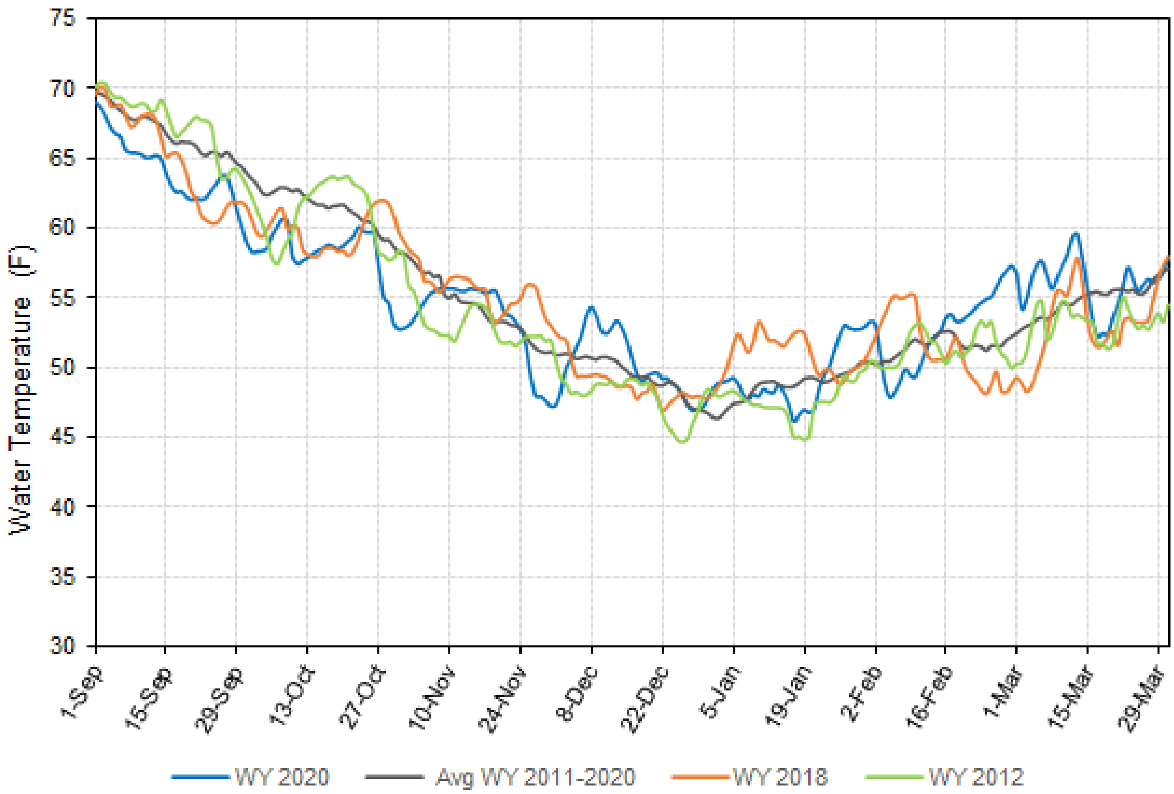


Sacramento River turbidity at Verona (VON, RM 78) just below the confluence with the Feather River and approximately 18 miles upstream of Sacramento. WY 2020 is shown with similar WY 2018 and 2012 for comparison (panels A to C). Flow at Verona for WY 2020 compared to the 10-year average is also shown (panel D). Data from SacPAS (2020).

7.2.2 Water Temperatures

Water temperatures at Verona in 2019 and 2020 were generally below the 10-year average from the end of September 2019 to early February 2020, when juveniles were rearing in this portion of the middle Sacramento River (Figure 40). Exceptions to this trend occurred between early and mid-December 2019, the first week of January 2020, and the last 2 weeks of January 2020 when water temperatures were higher than the 10-year average.

Figure 40
Middle Sacramento River Temperature at Verona



Sacramento River flow at Verona (VON, RM 78) just below the confluence with the Feather River and approximately 18 miles upstream of Sacramento. Data from SacPAS (2020).

7.2.3 Dissolved Oxygen

No DO data are available on the Sacramento River below RBDD until Rio Vista Bridge in the Delta.

7.2.4 Turbidity

Between the end of September and early February there were two periods of high turbidity that occurred in the middle Sacramento River near Verona while juveniles were rearing and out-migrating.

Turbidity up to 150 NTU occurred in mid-October to early November. This event may have been associated with the fall pulse flow releases from Keswick Dam (RM 302), though the pulses themselves were only detected at low amplitude so far downstream (Figure 39, panels A and D). Another event occurred starting in early December 2019, with maximum turbidity reaching 350 NTU. This event may have been associated with the increase in flow that occurred during the same period. However, similar increases in flow in WYs 2012 and 2018 did not result in such turbidity (Figure 39, panels A and B). The December 2019 increase in flow and turbidity corresponded with the rapid movement of WRCS juveniles between Knights Landing RST (RM 90) and Sacramento Trawls at Sherwood Harbor. No other turbidity gages are available on the middle Sacramento River between RBDD and the Delta.

7.2.5 Rearing Habitat Capacity

The largest amount of potential in-stream and floodplain rearing habitat is available to WRCS is in the reach between RBDD and Tisdale Weir. This reach corresponds with the Upper-Mid Sacramento CVPIA Sacramento Rearing Segment used for defining in-stream and floodplain rearing habitat area for the CVPIA SIT Salmon Population Model (CVPIA 2020; Hendrix et al. 2017). Between RBDD and RM 180 near Jacinto, California, the Sacramento River is relatively unconstrained by levees, and floodplain habitats can be accessed if flows are high enough. Between RM 180 and the city of Colusa (RM 145), the river is constrained by levees, but some floodplain habitat is available and accessible at certain flows. Below RM 145, levees tightly constrain the river, and little floodplain habitat is available. The estimated total amount of in-stream and floodplain rearing habitat available at different flows in the habitat component of the NMFS life cycle model is shown in Figures 30 and 31.

7.2.5.1 Upper Portion of the Middle Sacramento River

Average flow in the Sacramento River at Vina Bridge gage, just above the GCID diversion, for the period when the WRCS juveniles were moving through this section of the river (beginning of September to mid-December) was approximately 7,200 cfs. The average flow at Hamilton City was approximately 6,800 cfs for the same period. At these flows, the model (CVPIA 2020) estimates that approximately 313,000 to 363,000 square meters (m^2) of in-stream rearing habitat was available (Figure 30) and that very little floodplain rearing habitat was available (Figure 31). The 10-year average flows at Vina Bridge and Hamilton City during this period are 7,850 and 7,100 cfs, respectively. Because of the inverse relationship between in-stream habitat and flow, the amount of in-stream rearing habitat available in 2019 was greater than the 10-year average of 265,000 m^2 at Vina Bridge and 320,000 m^2 at Hamilton City.

7.2.5.2 Lower Portion of the Middle Sacramento River

The reach between Tisdale Weir RST and Knights Landing RST corresponds to the first 20 RM of the CVPIA Lower-Mid Sacramento Rearing Segment. The reach between Knights Landing RST and the Sacramento Trawling location at Sherwood Harbor roughly corresponds to the lower 40 miles of the

CVPIA Lower-Mid Sacramento Rearing Segment but extends approximately 5 miles below the confluence with the American River, which is the end of the CVPIA segment. During mid-October to mid-December 2019, flows at Verona near the Fremont Weir were similar to the 10-year average, so available in-stream habitat was also similar to the average. However, as discussed in Sections 7.1.3 and 7.2.4, passage data suggest that BY 2019 juveniles moved through this reach quickly (i.e., 50% passage at Sherwood Harbor occurred on December 10), possibly because of increased turbidity, rather than utilizing the available habitat. From mid-December 2019 through March 2020 when 50% to 100% of the fish passed Sherwood Harbor, flows at Verona were lower than the 10-year average and ranged between 20,000 and 10,000 cfs (Figure 39). These flows corresponded to approximately 84,500 to 163,500 m^2 of in-stream rearing habitat and approximately 33,500 to 9,000 m^2 of floodplain rearing habitat. In this same time period, the 10-year average flows ranged between 30,000 and 20,000 cfs, which corresponds to approximately 71,700 to 84,500 m^2 of in-stream rearing habitat and 161,600 to 33,500 m^2 of floodplain rearing habitat. Therefore, the amount of in-stream rearing habitat available to BY 2019 juveniles from mid-December 2019 through March 2020 in this section of the middle Sacramento River was higher than the 10-year average, whereas the amount of floodplain rearing habitat available was less than the 10-year average.

7.3 Key Management Questions and Findings

In the following section, information is synthesized regarding key management questions related to rearing and out-migrating juveniles in the middle Sacramento River.

7.3.1 Did the Earlier Migration Observed in the Upper Sacramento River Continue Through the Middle Sacramento River?

Yes, passage timing was earlier at Knights Landing and substantially earlier than the 10-year average at Sherwood Harbor. Median passage at Knights Landing occurred on December 10, 2019, which is 10 days earlier than the 10-year average. Median passage at Sherwood Harbor occurred just 2 days later on December 12, 2019, which was 57 days earlier than the 10-year average. In addition, the date when 95% cumulative passage occurred at Sherwood Harbor was February 5, 2020, which was 40 days earlier than the 10-year average. The date when 100% cumulative passage occurred was the end of March 2020, which was 5 days earlier than the 10-year average. The migration rate was similar to the 10-year average between RBDD and Knights Landing but was much faster between Knights Landing and Sherwood Harbor, using the median passage dates and distance traveled.

Clearly, the pattern of earlier migration seen in the upper Sacramento River extended into the middle Sacramento River reach. The exact cause of the higher migration rate through the lower portion of the middle Sacramento River could not be determined. However, there was a large increase in turbidity around December 9 (Figure 39) at Verona that was also associated with an increase in flow that likely stimulated fish to move quickly between Knights Landing and Sherwood Harbor. Following that event, freshet flows at Verona were lower than the 10-year average from mid-December through March.

7.3.2 Did Water Management Actions Taken in 2019 Result in Increased BY 2019 Smolt Survival Through the Middle Sacramento River?

No, but the BY 2019 smolt survival rate was calculated using a new method (O'Farrell et al. 2018), which accounts for the decrease. The natural-origin smolt survival rate (38.6%) based on the new method was lower than the average since 2013 (42%). However, natural-origin smolt survival calculated with the old method (used for BYs 2013 to 2018) was also available, and the rate for BY 2019 was 47.6%, which is comparable to recent years and higher than the average since 2013 (42%). This indicates that there likely were no major increases in mortality due to predation or other sources compared to other BYs and that the change in method is responsible for the lower natural-origin smolt survival rate rather than management actions.

The hatchery-origin smolt survival rate was estimated to be 36.9%, which is similar to the average since 2013 (34%).

7.3.3 Was There Better Floodplain Access for BY 2019? If So, Were Growth Rates Higher in the Middle Sacramento River?

No, weir overtopping did not occur in WY 2020, and flows were near or lower than the 10-year average during BY 2019 migration (Figures 36 and 37). Modeled habitat-to-flow relationships show that very little floodplain rearing habitat would be connected and available at the flows that occurred in WY 2020. No data were available to determine the amount of food available to WRCS juveniles while rearing and migrating through the middle Sacramento River or whether WRCS growth rates were higher through the reach since length data are only collected at RBDD.

8 Discussion

The SAIL CMs provided an effective framework to assess the relative success of the BY 2019 cohort by providing life-stage-specific hypotheses on how fish responses are influenced by environmental and habitat conditions that are controlled in part by water management operations. Data were readily available from sources such as SacPAS, NMFS JPE reports, and CDFW reports to evaluate approximately one-third to one-half of the environmental and habitat condition variables from the CMs. Based on this, it was possible to assess how the key biological response variables for BY 2019 responded to these conditions.

Table 6 provides a snapshot overview of the assessment results. BY 2019 had a relatively large number of spawners that had high fecundity and low pre-spawn mortality. The influence of hatchery fish on the spawners was lower than in the recent past but still higher than average. BY 2019 egg-to-fry survival was lower than average; however, the mechanism(s) that caused this lower survival were not apparent in the variables assessed beyond there being a potential density dependence effect. This suggests that egg-to-fry survival may be affected by a variable that was not monitored at the egg stage or the fry stage (between emergence and passage at RBDD [RM 242]). Although egg-to-fry survival was lower than average, BY 2019 had the most fry and fry-equivalents pass the RBDD since 2009 and the most natural-origin juveniles entering the Delta since 2013. However, juveniles passing RBDD were smaller (as measured by fork length) than the 10-year average for the whole migration period. Fry-to-smolt survival and natural-origin smolt survival were lower than normal, but this is attributed to a change in the methods used to calculate those rates. Fry-to-smolt survival and natural-origin smolt survival were lower only due to a change in the methods used to calculate those metrics.

Based on the variables that could be assessed, BY 2019 fish experienced environmental conditions that were better than or similar to the 10-year average or were expected to benefit BY 2019 fish (green and yellow cells in Table 6). This was the case in both the upper and middle Sacramento River reaches during spawning, egg incubation and fry emergence, fry and juvenile rearing, and migration to the Delta. The exceptions to this overall pattern were as follows: 1) air temperature was higher than average in the upper Sacramento River during egg incubation and fry emergence; 2) floodplain access was limited in the upper and middle Sacramento River reaches; and 3) flows in the middle Sacramento River reach were lower than normal during the second half of the BY 2019 out-migration due to 2020 being a below normal WY. In 2019, there was also a concern about impacts to habitat conditions in the upper Sacramento River from runoff due to effects from the 2018 Carr Fire.

Table 6
Summary of BY 2019 Responses to Environmental Drivers and Habitat Attributes in the Upper Sacramento River and Middle Sacramento River During Various Life Stages

Geographic Region	Upper Sacramento			Middle Sacramento
CM Variables[1]	**Adult Spawning**	**Egg-to-Fry Emergence**	**Rearing-to-Out-Migrating Juveniles**	**Rearing-to-Out-Migrating Juveniles**
Fish Response				
Adult Survival (Abundance)		-	-	-
Adults to Hatchery		-	-	-
Adult Fecundity		-		
Pre-Spawn Mortality		-	-	-
Egg-to-Fry Survival	-		-	-
Growth (FL)	-	-		ND
JPI (fry-equivalent)	-	-		-
Fry-to-Smolt Survival[2]	-	-		
Migration Timing	-	-		
Natural Smolt Survival[2]	-	-	-	
Natural JPE	-	-	-	
Hatchery Smolt Survival	-	-	-	
Hatchery JPE	-	-	-	
Habitat Attributes				
Redd Dewatering			-	-
Juvenile Stranding	-	-		-
Water Temperature				
DO				ND
In-Stream Habitat Capacity[3,4]				See Note 4
Habitat Refuge	ND	ND	ND	ND
Food Quality/Availability	ND	ND	ND	ND
Pathogens/Disease	ND	ND		
Hatchery Pathogens/Disease				
Toxicity/Contaminants	ND	ND	ND	ND
Substrate Size/Sedimentation*	ND	ND	-	-
Predation/Competition	-	ND	ND	ND
Fishery/Recreation Disturbance*	ND	ND	-	-

Geographic Region	Upper Sacramento			Middle Sacramento
CM Variables[1]	Adult Spawning	Egg-to-Fry Emergence	Rearing-to-Out-Migrating Juveniles	Rearing-to-Out-Migrating Juveniles
Migration Cues		-		
Entrainment Risk	-	-	ND/NE	ND/NE
Environmental Drivers				
Air Temperature				
Keswick Dam Releases*/Flows				See note 5
Fish Assemblage*	NE	NE	NE	NE
Hatchery Influence		-	-	-
Depth/Shallow Water[3]				
Food Production	ND	ND	ND	ND
Turbidity				
Mobilized Substrate	ND	ND	ND	ND
Contaminant Loading*	ND	ND	ND	ND
Irrigation Diversions*	NE	NE	NE	NE
Floodplain Connectivity[6]	-	-		
Shasta and Trinity Storage*/Hydrology				

Notes:
Green indicates conditions better than 10-year average or expected to have beneficial effects on BY 2019.
Yellow indicates conditions similar to 10-year average or expected to have neutral effects on BY 2019.
Red indicates conditions lower than the 10-year average or expected to have less beneficial effects on BY 2019.

1. Windell et al. 2017
2. Fry-to-smolt and natural smolt survival rate were calculated by a new method (O'Farrell et al. 2018) in 2019 that resulted in lower rates than in previous years, as discussed in Sections 6 and 7.
3. Evaluated based on spawning and in-stream rearing habitat WUA inputs to the CVPIA SIT Salmon Population Model for WRCS.
4. Habitat capacity in the middle Sacramento River was generally better than the 10-year average, except between mid-October and mid-December 2019 near Verona when habitat capacity was similar to the 10-year average.
5. Flows in the middle Sacramento River were both above and below the 10-year average during juvenile rearing and out-migration depending on the location and month.
6. Evaluated based on floodplain rearing habitat WUA inputs to the CVPIA SIT Salmon Population Model for WRCS.

* Management action
-: Not applicable to life stage
ND: No data were available
NE: No data were evaluated

8.1 Fish Responses Relative to Water Management Operations

Water management operations led to optimal flow levels that created the maximum spawning habitat, met the temperature criterion (56°F) at Balls Ferry Bridge (RM 275) approximately 99% of the required time within the spawning season, and also met the pilot temperature criterion of 53.5°F at

Clear Creek (RM 292) 98% of the time during spawning. Pulse flows were implemented over the last 2 weeks of October as an additional management action in 2019.

To assess the BY 2019 biological responses within the context of management actions, we posed several key management-related questions for each life stage and developed answers based on our review of the fish response, environmental conditions, and habitat attributes data. We found that biological responses to the 2019 to 2020 water management operations were generally positive or improving over recent conditions experienced during the drought years (Table 7).

Table 7
Summary of Key Management Questions and Findings by Life Stage and Geographic Region

Geographic Region	Life Stage	Key Management Question	Finding
Upper Sacramento River	Adult Spawning	Was pre-spawn mortality low in 2019 given the beneficial flow and temperature conditions?	Yes (1.3%); although slightly higher than the 10-year average, it was lower than the most recent high in 2015 (2%).
		Was the estimated hatchery influence on the 2019 spawning population higher than recommended?	Yes, although decreasing from the recent past, there is still a higher than desired influence of hatchery-origin fish in the BY 2019 spawning population.
	Egg-to-fry Emergence and Survival	Was egg-to-fry survival better than the 10-year average given the beneficial habitat attributes and environmental drivers during egg incubation and emergence?	No, BY 2019 egg-to-fry survival was 18%, which is lower than the 10-year average of 25% and the average survival since 2002 of 24%.
	Juvenile Rearing and Out-Migration	Did fry production increase for BY 2019?	Yes, the number of fry and fry-equivalents (JPI) at RBDD (4,762,142 fish) was the highest since 2006.
		Did pulse flows change migration patterns and stimulate earlier movement downstream?	Yes, it appears that the pulse flows stimulated migration and resulted in earlier cumulative migration at various quantiles and fish being smaller in size at RBDD.
		Was rearing habitat (in-river and floodplain) higher than normal for BY 2019?	No, the amount of in-stream rearing habitat was similar to the average, except for during the pulse flows, and flows were not high enough to connect floodplain habitat.
		Were environmental conditions necessary for good productivity and survival met?	Yes, environmental conditions, including water temperature, DO, flows, system hydrology, and migration cues were generally better than the 10-year average for BY 2019 rearing and out-migrating juveniles. Turbidity and air temperature were similar to the 10-year average.
		Did the rearing and migration periods overlap for natural-origin WRCS and hatchery releases?	No, because of a difference in timing of natural-origin WRCS migrations and hatchery-origin WRCS release dates, there was likely minimal co-occupancy of habitats and interactions between the two sources of fish.

Geographic Region	Life Stage	Key Management Question	Finding
Middle Sacramento River	Juvenile Rearing and Out-Migration	Did the earlier migration observed in the upper Sacramento River continue through the middle Sacramento River?	Yes, passage timing was earlier than the 10-year average at Knights Landing and substantially earlier at Sherwood Harbor.
		Did water management actions taken in 2019 result in increased BY 2019 smolt survival through the middle Sacramento River?	No, but the BY 2019 smolt survival rate was calculated using a new method, which accounts for the decrease.
		Was there floodplain access for BY 2019? If so, were growth rates higher in the middle Sacramento River?	No, the flows were not high enough to access the floodplains due to the below normal 2020 WY, which is not a result of a management action. Fish size was not measured at sampling points, so no data were available to assess growth.

The fall pulse flows were implemented for the first time in 2019 as a water management action. The earlier juvenile out-migration in the upper Sacramento River is attributed to the fall pulse flows that appeared to cause BY 2019 cumulative passage to occur earlier than average at RBDD. Before the pulse flows occurred, median passage at RBDD occurred 10 days earlier than average. After the fall pulse flows occurred, migration was accelerated because 95% cumulative passage occurred 20 days earlier than average and 100% passage occurred 34 days earlier than average. The early migration continued through the middle section of the river, where median cumulative passage between RBDD and Knights Landing occurred between 5 and 10 days earlier. Median cumulative passage at Sherwood Harbor, the entry to the Delta, occurred 57 days earlier than average. There was a turbidity spike recorded at the Verona gage associated with high flows in early December that is likely responsible for the extremely fast migration between Knights Landing and Sherwood Harbor. The effects of the early arrival of BY 2019 to the Delta are currently unknown. The early arrival could influence the length of time the fish spend in the Delta, timing of ocean entry, and survival. It will be important to follow this cohort through to escapement in 2022 to determine if the apparent benefits provided to BY 2019 during spawning, rearing, and migration extended to adulthood.

Flows in the upper and middle Sacramento River during juvenile rearing and migration were not high enough to access the floodplain habitat. These low flows were due to the below normal 2020 WY and not water management actions. The lack of floodplain access could be part of the reason BY 2019 juveniles continued their early migration throughout the upper and middle sections of the river to the Delta. Being able to access the floodplains at lower water levels in the future would likely provide additional growth opportunities for juvenile fish.

8.2 Fish Responses in Viable Salmonid Population Context

As discussed in the previous subsection, the fish responses to 2019 to 2020 water management actions were generally positive. In the context of a viable salmonid population, the WRCS population appears to be recovering from the drought years and showing signs of improved viability. The number of adult spawners for BY 2019 (7,852 in-river spawners) was the highest observed since 2006, and their fecundity was high, resulting in approximately 26.5 million eggs being produced, which is the highest since 2006 and higher than the 10-year average (8.4 million).

The large return of in-river spawners in 2019 translated to a CRR of 5.2 for BY 2016 fish that returned to spawn in 2019, indicating that each adult spawner from 2016 produced approximately five spawners in 2019. The CRR estimate assumes that all spawners are produced 3 years earlier. This is the first time since 2015 that CRR has been greater than 1, indicating a growing population. The rate has been below 1 in 5 of the last 10 years, indicating the population is not replacing itself and is decreasing in size. A population that is consistently failing to replace itself is an indicator of increased extinction risk. It is expected that most of BY 2019 adults will return to the Sacramento River in 2022 to spawn, and it remains to be seen if the high overall abundance of BY 2019 will translate into a CRR greater than 1 in 2022.

The hatchery influence on BY 2019 spawners was lower than during the drought years but still higher than normal. However, genetic studies conducted to evaluate the impact of increased hatchery supplementation during the drought have so far found no evidence to suggest differences in adult reproductive success by origin. The genetic studies also found that run timing diversity is being preserved. There was no evidence that selection for early or late spawn timing, or run timing, is occurring. Therefore, it appears that the diversity of phenology phenotypes in the WRCS population are not being altered in a significant way by the hatchery program at this time.

The number of naturally produced fry and fry-equivalents (JPI; 4,762,142) at the RBDD was the highest since 2009. Similarly, the number of natural-origin juveniles entering the Delta (JPE; 854,941) was the highest since 2013. Juveniles arrived at the RBDD early and were smaller than average. The fish continued moving quickly through the system and arrived at the Delta entry point 57 days earlier than the 10-year average. It is unknown if these positive fish responses will carry through the life cycle, result in a strong escapement and CRR in 2022, and continue to strengthen population viability through time.

8.3 Additional Data Needs

Anchor QEA identified the following data needs in the upper and middle Sacramento River reaches to facilitate future cohort assessments:

- Develop methods to better identify redds in the reach below Keswick Dam (RM 302), where the water is deep and visibility is impacted by turbidity from water released from the dam.

This is needed to improve the accuracy of redd counts. For example, in BY 2019, redd surveys only identified nine redds in this reach, and visibility was noted as fair, but anecdotally the visibility was poor. Historically there are typically hundreds of redds in this reach for similar-sized spawning runs. The number and location of redds are input parameters for the SacPAS survival model and are also important for managing water temperatures during egg incubation and emergence.

- Implement regular monitoring of floodplain access. A BY 2018 analysis conducted by Cordoleani et al. (2020) indicated juveniles that accessed floodplain areas had higher growth than fish that remained in the mainstem Sacramento River. This 1 year of study should be repeated to better inform water management actions that could support floodplain access and fish growth and track how this growth affects migration through the Delta.
- Consistent with a recommendation by Johnson et. al. (2017), collect weight, body condition, and length data at the GCID, Tisdale Weir, and Knights Landing RSTs to evaluate juvenile fish health and condition as they migrate and pass various locations and assess how management actions influence fish health and condition.
- Collect data on other factors that could influence egg-to-fry survival, fry-to-smolt survival, and smolt survival, including predators, pathogens or disease, contaminants, and suspended sediments. These data are needed to better understand what is driving fish responses so that water can be used efficiently.

8.4 Next Steps

Overall, the approach developed to assess BY 2019 was informed by a well-thought-out CM framework and a large amount of readily available data for the primary variables of interest. This allowed the assessment to be conducted efficiently. A robust analytical framework for assessing BY responses to water management actions each year has now been established so that the analyses can be easily replicated annually to accomplish the following: 1) potentially inform adjustments in water management operations to benefit WRCS; and 2) build a time series for trend analysis. This report constitutes the beginning of a time series of analytical results to assess population status and responses to water management operations and progress toward population viability through time.

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Appendix A
SacPAS Fish Modeling Details

Appendix A: SacPAS Fish Modeling Details

Fish Model Input Report

Table A-1
Modeling Input Report Values as Provided by SacPAS (2020).

What = Value
Tempsource = DB Temps from KWK:DailyAvg to CCR:DailyAvg in 2019
Redds = from user. See below.
Temperature Mortality = Stage-dependent (near hatching)
Hatch mechanism = Count ATUs
Hatch ATUs = 487
Tcrit (C) = 12
Critical days = 2
b (rate) = 1.19
Density base rate = 0.47
Carry capacity = 39
Dewatering = Off
Egg timing model = Zeug
ATUs to emergence = 958
Eggs per redd = 5424

Essential outputs
    Survival to RBDD = 0.243

NOTE: display setting (e.g., plot ranges) are not recorded here.

Upload / input redds:
Day,RKM483,RKM479,RKM465,RKM445,RKM440,RKM430,RKM415
128,0,1,3,0,0,0,0
144,0,0,2,0,0,0,0
150,0,4,2,0,0,0,0
164,0,28,32,11,0,0,0
170,2,43,42,9,0,0,0
178,1,49,52,7,0,0,1
184,2,53,29,6,0,0,0
191,1,33,22,3,0,0,0
198,2,24,9,0,0,0,0
205,0,8,12,0,0,0,0
210,1,8,7,0,0,0,0
226,0,5,1,0,0,0,0

Note:
Stage dependent model parameter inputs are those suggested by Anderson (2018). Redd distribution inputs are from 2019 WRCS redd survey data (CalFish 2020).

Sensitivity Analysis Results

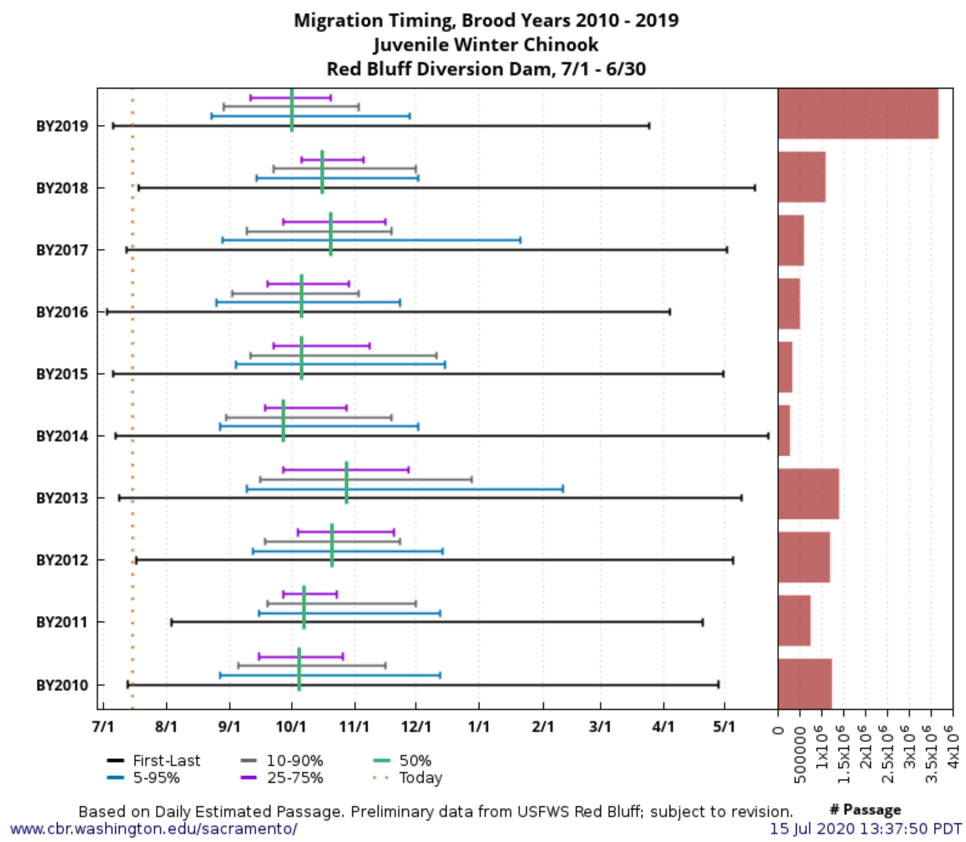
Table A-2
WRCS Egg-to-Fry Survival Modeled Using SacPAS Fish Model.

Placements of Redds in Clear Creek to Airport Road Bridge Reach (RKM)	460		465		468	
Dewatering Component	Yes	No	Yes	No	Yes	No
Temperature Effect Only	83.4%	86.8%	90.2%	93.8%	90.7%	94.4%
Full Stage-Dependent Model	20.90%	21.70%	23.4%	24.3%	23.6%	24.5%

Appendix B
Migration Timing on the Middle Sacramento River

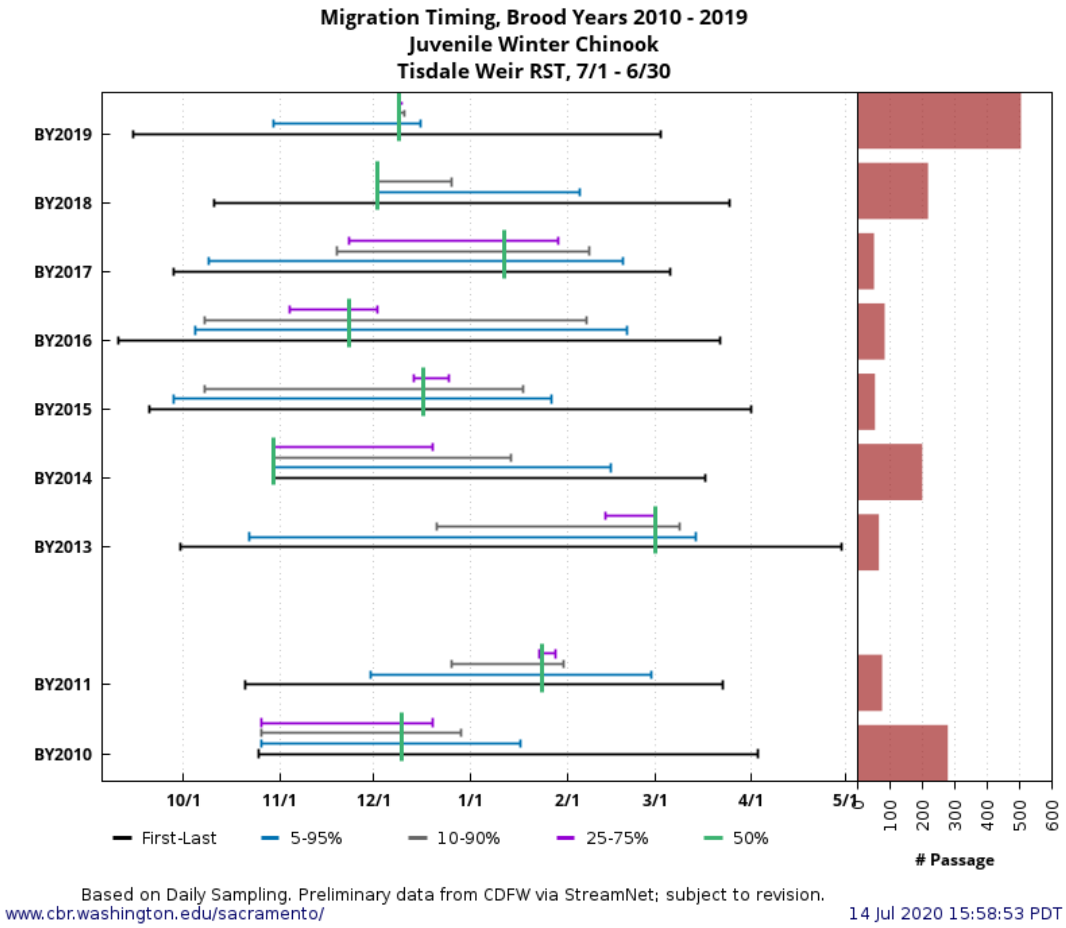
Appendix B: Migration Timing on the Middle Sacramento River

Figure B-1
Migration Timing at RBDD



Juvenile winter-run Chinook salmon passage timing range and counts at RBDD RST (RM 119) comparing BY 2019 through BY 2010.

Figure B-2
Migration Timing at Tisdale Weir RST

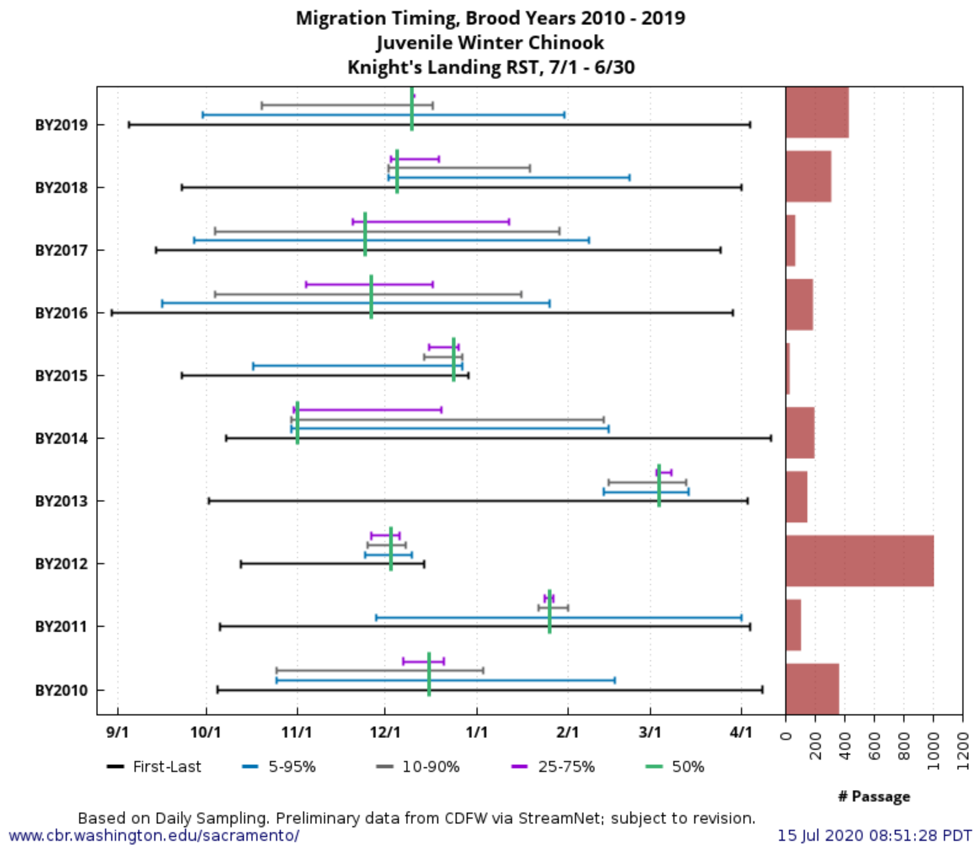


Juvenile winter-run Chinook salmon passage timing range and counts at Tisdale RST (RM 119) comparing BY 2019 through BY 2010.

Table B-1
Juvenile Winter-Run Chinook Salmon Cumulative Passage at Tisdale RST (RM 119) Compared to the 10-Year Average (2010 to 2019)

Cumulative Passage Percent	Passage Date				BY 2019 to 10-Year Average
	BY 2019	10-Year Average	10-Year First	10-Year Last	
First	September 13, 2019	October 3	September 9	October 29	-20
5%	October 23, 2019	October 25	September 27	December 1	-2
10%	December 5, 2019	November 14	October 7	December 25	21
25%	December 8, 2019	December 14	October 25	February 11	4
50%	December 9, 2019	December 19	October 29	February 27	-10
75%	December 9, 2019	December 30	December 1	February 27	-21
90%	December 10, 2019	January 18	December 9	March 7	-38
95%	December 15, 2019	February 5	December 14	March 12	-51
Last	March 29, 2020	March 25	March 4	April 28	4

Figure B-3
Migration Timing at Knights Landing RST

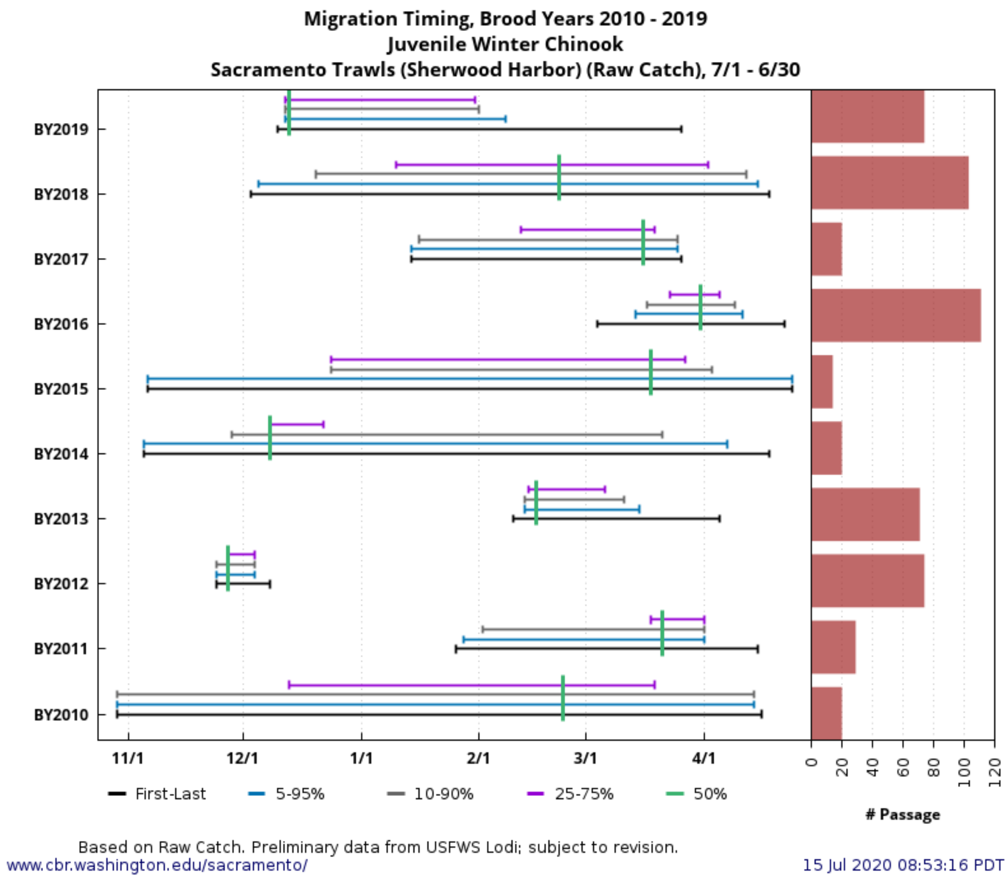


Juvenile winter-run Chinook salmon passage timing range and counts at Knights Landing RST (RM 90) comparing BY 2019 through BY 2010.

Table B-2
Juvenile Winter-Run Chinook Salmon Cumulative Passage at Knights Landing (RM 90) Compared to the 10-Year Average (2010 to 2019)

Cumulative Passage Percent	Passage Date				BY 2019 to 10-Year Average
	BY 2019	10-Year Average	10-Year First	10-Year Last	
First	September 6, 2019	September 23	August 29	October 12	-18
5%	September 30, 2019	November 4	September 15	February 11	-35
10%	October 20, 2019	November 20	October 3	February 13	-31
25%	December 9, 2019	December 10	October 30	March 1	-1
50%	December 10, 2019	December 15	October 31	March 2	-5
75%	December 10, 2019	December 30	December 5	March 6	-20
90%	December 16, 2019	January 15	December 7	March 11	-29
95%	January 28, 2020	February 5	December 9	March 30	-8
Last	April 5, 2020	March 11	December 13	April 9	25

Figure B-4
Migration Timing at Sacramento Trawls



Juvenile winter-run Chinook salmon passage timing range and counts at Sacramento Trawls at Sherwood Harbour (RM 90) comparing BY 2019 through BY 2010.

Table B-3
Juvenile Winter-Run Chinook Salmon Cumulative Passage at Sacramento Trawls (RM 55) Compared to the 10-Year Average (2010 to 2019)

Cumulative Passage Percent	Passage Date				BY 2019 to 10-Year Average
	BY 2019	10-Year Average	10-Year First	10-Year Last	
First	December 9, 2019	December 18	October 28	March 2	-9
5%	December 10, 2019	December 20	October 28	March 12	-10
10%	December 10, 2019	December 29	October 28	March 15	-19
25%	December 10, 2019	January 14	November 26	March 21	-35
50%	December 12, 2019	February 7	November 26	March 29	-57
75%	January 28, 2020	February 25	December 3	April 3	-28
90%	January 30, 2020	March 12	December 3	April 12	-41
95%	February 5, 2020	March 17	December 3	April 22	-40
Last	March 24, 2020	Marcy 29	December 7	April 22	-5