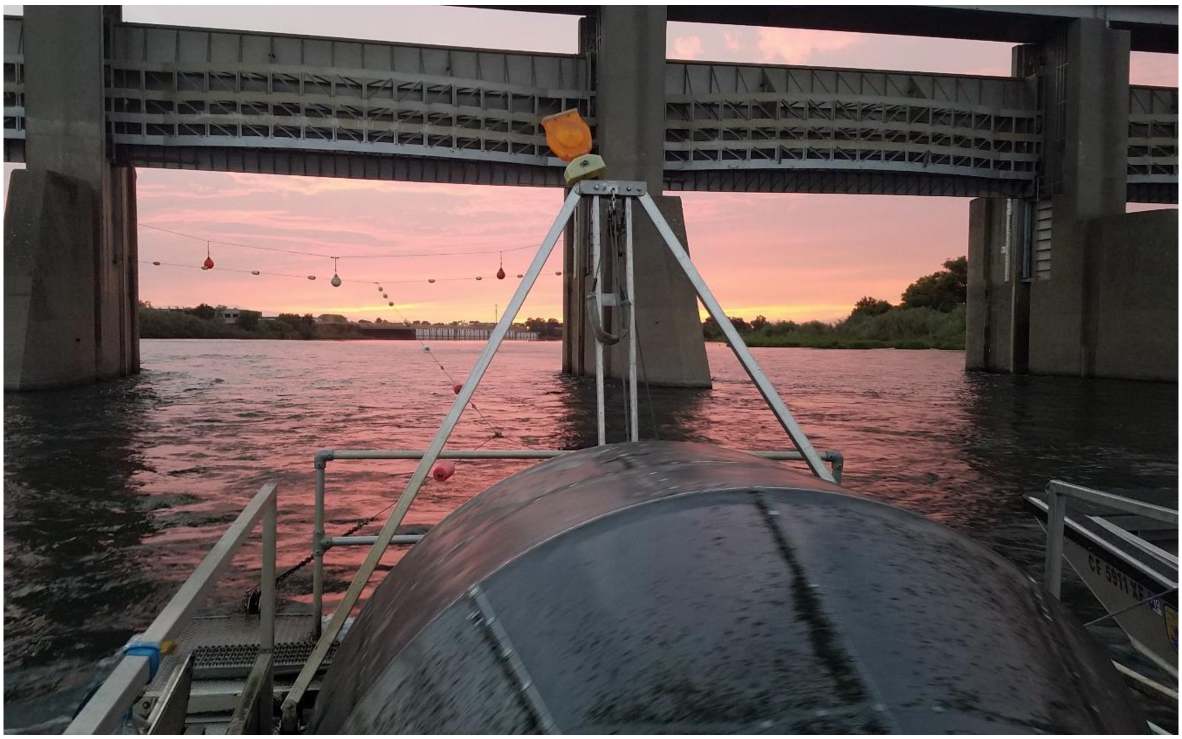
2019 RED BLUFF DIVERSION DAM ROTARY TRAP JUVENILE ANADROMOUS FISH ABUNDANCE ESTIMATES

Prepared for:
U.S. Bureau of Reclamation
2019 USFWS Annual RBDD Juvenile Fish Monitoring Report



Prepared by:
Scott D. Voss and William R. Poytress

U.S. Fish and Wildlife Service
Red Bluff Fish and Wildlife Office
10950 Tyler Road
Red Bluff, CA 96080

January 2022

Disclaimer

The mention of trade names or commercial products in this report does not constitute endorsement or recommendation for use by the federal government.

The correct citation for this report is:

Voss, S. D. and W. R. Poytress. 2022. 2019 Red Bluff Diversion Dam Rotary Trap Juvenile Anadromous Fish Abundance Estimates. Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation, Sacramento, CA.

2019 Red Bluff Diversion Dam Rotary Trap
Juvenile Anadromous Fish Abundance Estimates

Scott D. Voss and William R. Poytress

U.S. Fish and Wildlife Service
Red Bluff Fish and Wildlife Office

Abstract.— Brood year (BY) 2019 juvenile winter Chinook salmon (*Oncorhynchus tshawytscha*) estimated passage at Red Bluff Diversion Dam (RBDD) was 3,813,589 for fry and pre-smolt/smolts combined. The fry-equivalent rotary trap juvenile production index (JPI) was estimated at 4,691,7645 with the lower and upper 90% confidence intervals (CI) extending from 2,630,095 to 6,753,433 juveniles, respectively. The estimated egg-to-fry (ETF) survival rate, based on the BY2019 winter Chinook fry-equivalent JPI was 17.5%, below the 21-year average ETF survival rate of 24.0%. The range of ETF survival rates based on the 90% CI was 9.8% to 25.2%.

Following a cycle of wet weather in early 2019, Shasta Reservoir reached top of conservation pool by the end of April, providing adequate cold-water pool availability for temperature compliance for BY2019 winter Chinook. The Sacramento River Temperature Management Plan proposed a 56˚F daily average temperature (DAT) compliance point at Balls Ferry (RKM 444.5) while also targeting a 53.5˚F DAT at the Clear Creek gaging station (RKM 466). With adequate water temperatures, lower than average ETF survival estimates for BY2019 winter Chinook may have been attributed to thiamine deficiency complex.

From analyses of mark-recapture trials conducted in the fall of 2019 with naturally produced winter Chinook fry, it was determined that sampling four traps across the RBDD transect consistently produced efficiency values higher than our regression model predicted. Passage estimates for the months of September and October of 2019 were revised using data from three traps rather than four to better align modeled trap efficiency values with observed values. Further, winter Chinook passage estimates were revised following genetic analyses of fin clips taken from juvenile length-at-date spring Chinook in the fall of 2019.

A pause in sampling activities occurred from 3/25/2020 through 6/30/2020 in order to protect employee health and safety during the Coronavirus global pandemic (COVID-19)until local authorities provided additional guidance to continue safe operations. During that time, no sampling was conducted and traps were removed from the river. The non-sampled period impacted BY2019 spring and fall Chinook passage estimates and abundance indices for (WY2020) lamprey species.

BY2019 juvenile spring Chinook salmon estimated passage was 161,444 fry and pre-smolt/smolts combined. The fry-equivalent JPI for 2019 spring Chinook was 250,801 with

the lower and upper 90% CI extending from 52,518 to 449,084 juveniles, respectively. BY2019 fall Chinook juvenile estimated passage at RBDD was 7,326,883 fry and pre-smolt/smolts combined. The fry-equivalent JPI for 2019 fall Chinook was 7,575,182 with the lower and upper 90% CI extending from 2,718,701 to 12,431,662 juveniles, respectively. BY2019 juvenile late-fall Chinook estimated passage at RBDD was 152,086 fry and pre-smolt/smolts combined. The fry-equivalent JPI for BY2019 late-fall was 193,758 with the lower and upper 90% CI extending from 37,292 to 350,225 juveniles, respectively.

Sturgeon captured during calendar year 2019 ranged in length from 17 to 116 mm. In addition to the 4,299 larval sturgeon captured in the traps during calendar year 2019, four juvenile sturgeon exhibited fully developed morphometric features (lateral scutes) and were able to be positively identified in the field as Green Sturgeon (*Acipenser medirostris*). Yearly sturgeon catch per unit volume (CPUV) for 2019 was 22.2 fish/ac-ft; this value was well above the 18-year mean of 6.7 fish/ac-ft and was the third highest value since the program began operating rotary traps at the RBDD.

Lamprey species sampled during WY2020 included Pacific Lamprey (*Entosphenus tridentata*), Kern Brook Lamprey (*Lampetra hubbsi*) and River Lamprey (*Lampetra ayresi*). Unidentified lamprey ammocoetes and Pacific Lamprey composed 99.9% of all captures, 21.5% and 78.5% respectively. Lamprey CPUV for WY2020 was 22.4 fish/ac-ft and 92.7 fish/ac-ft for unidentified lamprey ammocoetes and Pacific lamprey, respectively. Despite the break in sampling, both of these abundance values fall above the 17-year averages of 14.6 ± 18.6 fish/ac-ft and 54.4 ± 65.9 fish/ac-ft for unidentified lamprey ammocoetes and Pacific lamprey, respectively.

Table of Contents

Table of Contents Continued

List of Tables

List of Tables continued

Table **Page**

List of Tables continued

Table..... .... Page

List of Figures

List of Figures continued

List of Figures continued

Introduction

The United States Fish and Wildlife Service (USFWS) has conducted direct monitoring of juvenile Chinook salmon, *Oncorhynchus tshawytscha* passage at Red Bluff Diversion Dam (RBDD) river kilometer (RK) 391 on the Sacramento River, California since 1994 (Johnson and Martin 1997). Martin et al. (2001) developed quantitative methodologies for indexing juvenile Chinook passage using rotary-screw traps (RST) to assess the impacts of the United States Bureau of Reclamation's (USBR) RBDD Research Pumping Plant. Absolute abundance (production and passage) estimates were needed to determine the level of impact from the entrainment of salmonids and other fish community populations through RBDD's experimental 'fish friendly' Archimedes and internal helical pumps (Borthwick and Corwin 2001). The original project objectives were met by 2000 and funding of the project was discontinued.

From 2001 to 2008, funding was secured through a CALFED Bay-Delta Program grant for annual monitoring operations to determine the effects of restoration activities in the upper Sacramento River aimed primarily at winter Chinook salmon[1]. The USBR, the primary proponent of the Central Valley Project (CVP), has funded this project since 2010 due to regulatory requirements contained within the National Marine Fisheries Service's (NMFS) Biological Opinion for the Long-term Operations of the CVP and State Water Project (NMFS 2009 and 2019).

Protection, restoration, and enhancement of anadromous fish populations in the Sacramento River and its tributaries are important elements of the Central Valley Project Improvement Act (CVPIA), Section 3402. The CVPIA has a specific goal to double populations of anadromous fishes in the Central Valley of California. Juvenile salmonid production monitoring is an important component authorized under Section 3406 (b) (16) of CVPIA (USFWS 1997) and has funded many anadromous fish restoration actions which were outlined in the CVPIA Anadromous Fisheries Restoration Program (AFRP) Working Paper (USFWS 1995), and Final Restoration Plan (USFWS 2001).

Martin et al. (2001) stated that RBDD was an ideal location to monitor juvenile winter Chinook production because (1) the spawning grounds occur almost exclusively above RBDD (Vogel and Marine 1991; Snider et al. 1997, USFWS 2011), (2) multiple traps could be attached to the dam and sampled simultaneously across a transect, and (3) operation of the dam could control channel morphology and hydrological characteristics of the sampling area providing for consistent sampling conditions for measuring juvenile fish passage.

Since 2002, the USFWS RST winter Chinook juvenile production indices (JPI's) have been used in support of production estimates generated from carcass survey derived adult

[1] The National Marine Fisheries Service first listed Winter-run Chinook salmon as threatened under the emergency listing procedures for the ESA (16 U.S.C.R. 1531-1543) on August 4, 1989 (54 FR 32085). A proposed rule to add winter Chinook salmon to the list of threatened species beyond expiration of the emergency rule was published by the NMFS on March 20, 1990 (55 FR 10260). Winter Chinook salmon were formally added to the list of federally threatened species by final rule on November 5, 1990 (55 FR 46515), and they were listed as a federally endangered species on January 4, 1994 (59 FR 440).

escapement data using NMFS' Juvenile Production Estimate (JPE) Model. Since 2014, the RBDD winter Chinook fry-equivalent JPI has been used as the basis of the NMFS' JPE Model. Moreover, RBDD JPI's are compared to adult escapement to evaluate adult spawning success in relationship to annual Sacramento River water temperature and flow management plans.

Fall, late-fall, spring, and winter Chinook salmon and steelhead/Rainbow Trout, *Oncorhynchus mykiss* spawn in the Sacramento River and tributaries upstream of RBDD throughout the year, resulting in year-round juvenile salmonid passage (Moyle 2002). Sampling of juvenile anadromous fish at RBDD allows for year-round quantitative production and passage estimates of all runs of Chinook salmon and steelhead/Rainbow Trout. Timing and abundance data have been provided in real-time for fishery and water operations management purposes of the CVP since 2004[2]. Since 2009, 90% confidence intervals, indicating uncertainty in weekly passage estimates, have been included in real-time bi-weekly reports to allow better management of available water resources and to reduce impact of CVP operations on both federal Endangered Species Act (ESA) listed and non-listed salmonid stocks. Currently, Sacramento River winter Chinook salmon are ESA-listed as endangered and Central Valley spring Chinook salmon and Central Valley steelhead (hereafter *O. mykiss)* are listed as threatened.

Incidental capture of Green Sturgeon (*Acipenser medirostris*) and various Lamprey species (*Entosphenus sp.* and *Lampetra sp.)* has occurred throughout juvenile Chinook Salmon monitoring activities at RBDD since 1995 (Gaines and Martin 2002). Although rotary traps were designed to capture out-migrating salmonid smolts, yet data from the incidental capture of sturgeon and lamprey species has become increasingly relied upon for basic life-history information and as a measure of relative abundance and species trend data. The Southern Distinct Population Segment of the North American Green Sturgeon was listed as threatened under the Federal ESA on June 6, 2006. Pacific Lamprey (*Entosphenus tridentatus*) are thought to be extirpated from at least 55% of their historical habitat and have been recognized by the USFWS as a species needing a comprehensive plan to conserve and restore these fish (Goodman and Reid 2012 & 2018).

The objectives of this annual progress report are to: (1) summarize the estimated abundance of all four runs of Chinook salmon and *O. mykiss* passing RBDD for brood year (BY) 2019, (2) define temporal patterns of abundance for all anadromous salmonids passing RBDD, (3) correlate juvenile salmon production with adult salmon escapement estimates (where appropriate), (4) describe various life-history attributes of anadromous juvenile salmonids produced in the upper Sacramento River as determined through long-term monitoring efforts at RBDD, and (5) estimate annual relative abundance of Green Sturgeon and Lamprey species.

This annual progress report addresses, in detail, our juvenile anadromous fish monitoring activities at RBDD for the period January 1, 2019 through November 30, 2020. This report includes JPI's for the 2019 brood year emigration period for the four runs of Chinook salmon, passage estimates of *O. mykiss* and relative abundance indices for Green Sturgeon and Lamprey

[2] Real-time biweekly reports for download located at: http://www.fws.gov/redbluff/rbdd_biweekly_final.html

spp. in the Sacramento River and is submitted to the US Bureau of Reclamation to comply with contractual reporting requirements for funds received through the Fish and Wildlife Coordination Act of 1934 under Interagency Agreement No. R15PG00067.

Study Area

The Sacramento River originates in northern California near Mt. Shasta from the springs of Mt. Eddy (Hallock et al. 1961). It flows south through 600 kilometers (km) of the state draining numerous slopes of the Coast, Klamath, Cascade, and Sierra Nevada ranges and eventually reaches the Pacific Ocean via San Francisco Bay (Figure 1). Shasta Dam and its associated downstream flow regulating structure, Keswick Dam, have formed a complete barrier to upstream anadromous fish passage since 1943 (Moffett 1949). The 95 River Kilometer (RKM) reach between Keswick Dam (RK 486) and RBDD (RK 391) supports areas of intact riparian vegetation and largely remains unobstructed. Within this reach, several major tributaries to the Sacramento River upstream of RBDD support various Chinook salmon spawning populations. These include Clear Creek and Cottonwood Creek (including Beegum Creek) on the west side of the Sacramento River and Cow Creek, Bear Creek, Battle Creek and Payne's Creek on the east side (Figure 1). Below RBDD, the river encounters greater anthropogenic impacts as it flows south to the Sacramento-San Joaquin Delta. Impacts include, but are not limited to, channelization, water diversion, agricultural and municipal run-off, and loss of associated riparian vegetation.

RBDD is located approximately 3-km southeast of the city of Red Bluff, California (Figure 1). The RBDD is 226 meters (m) wide and composed of eleven, 18-m wide fixed-wheel gates. Between gates are concrete piers 2.4-m in width. The USBR's dam operators were able to raise the RBDD gates allowing for run-of-the-river conditions or lower them to impound and divert river flows into the Tehama-Colusa and Corning canals. USBR operators generally raised the RBDD gates from September 16 through May 14 and lowered them May 15 through September 15 during the years 2002-2008. As of spring 2009, the RBDD gates were no longer lowered prior to June 15 and were raised by the end of August or earlier in an effort to reduce the impact to spring Chinook salmon and Green Sturgeon (NMFS 2009). Since fall 2011, the RBDD gates have remained in the raised position due to the construction of a riverside pumping facility and fish screen (NMFS 2009). Adult and juvenile anadromous fish currently have unrestricted upstream and downstream passage through this reach of the Sacramento River. The RBDD conveyance facilities were relinquished to the Tehama Colusa Canal Authority (TCCA) by USBR as of spring 2012. The RBDD gates were permanently raised and infrastructure decommissioned in 2015 leaving the transect location vulnerable to periodic changes in channel morphology under run-of-the-river conditions.

Methods

Sampling Gear.—Sampling was conducted along a transect using three to four 2.4 m diameter RSTs (E.G. Solutions® Corvallis, Oregon) attached via aircraft cables directly to RBDD. The horizontal placement of rotary traps across the transect varied throughout the study period but generally sampled in the river-margins (east and west) and mid-channel habitats simultaneously (Figure 2). RSTs were positioned within these spatial zones unless sampling equipment failed, river depths were insufficient (< 1.2m), or river hydrology restricted our ability to sample with all traps (water velocity < 0.6 m/s).

Changes in river channel morphology following the decommissioning of the RBDD gates in 2011 currently influence river depths across the RST transect. Substrate aggradation created insufficient river depths across many gates during periods of low flows (e.g., < 5kcfs). Insufficient depths lead to equipment damage and/or failure when RST cones interact heavily with river substrates. Oftentimes, RSTs created their own depression in the river bottom allowing continued sampling but in some instances resulted in conditions unfit to sample. Beginning on July 1, 2020, four 1.5-m diameter RSTs were used in concert with one 2.4-m RST, lending flexibility to sample a total of either four or five traps across the transect.[3]

Sampling Regimes.—In general, RSTs sampled continuously throughout 24-hour periods and samples were processed once daily[4]. During periods of high fish abundance, elevated river flows, or heavy debris loads, traps were sampled multiple times per day, continuously, or at randomly generated periods to reduce incidental mortality. When abundance of Chinook salmon was very high, sub-sampling protocols were implemented to reduce take and incidental mortality of listed species in accordance with NMFS' ESA Section 10(a)(1)(A) research permit terms and conditions. The specific sub-sampling protocol implemented was contingent upon the number of Chinook captured or the probability of successfully sampling various river conditions. Initially, RST cones were structurally modified to sample one-half of the normal volume of water entering the cones (Gaines and Poytress 2004). If further reductions in capture were necessary, the number of traps sampled was reduced from four to three or after June 30, 2020 from five to four. During storm events and associated elevated river discharge levels, each 24-hour sampling period was divided into four or six non-overlapping strata and one or two strata were randomly selected for sampling (Martin et al 2001). Estimates were extrapolated to un-sampled strata by dividing catch by the strata-selection probability (i.e., P = 0.25 or 0.17). If further reductions in effort were needed or river conditions were intolerable, sampling was discontinued or not conducted. When days or weeks were not sampled, mean daily passage estimates were imputed for missed days based on weekly or monthly interpolated mean daily estimates, respectively.

Data Collection.— All fish captured were anesthetized, identified to species, and enumerated with fork lengths (FL) measured to the nearest millimeter (mm). When capture of Chinook juveniles exceeded approximately 200 fish/trap, a random sub-sample of the catch was measured to include approximately 100 individuals, with all additional fish being enumerated and recorded. Chinook salmon race was field assigned using length-at-date (LAD) criteria developed by Greene (1992)[5]. Fin clips of juvenile salmonids >34 mm FL were sampled at a

---

[3] Sampling of (4) 1.5-m and (1) 2.4-m RST is equivalent to sampling 87.5% volume of (4) 2.4-m RST's.

[4] 24-hr sample periods were defined as beginning at 07:00 on day 1 and ending at 06:59 on day 2.

[5] Generated by Sheila Greene, California Department of Water Resources, Environmental Services Office, Sacramento (May 8, 1992) from a table developed by Frank Fisher, California Department of Fish and Game, Inland Fisheries Branch, Red Bluff (revised February 2, 1992). Fork lengths with overlapping run assignments were placed with the latter spawning run.

maximum rate of 10 fish, per run, per day for genetic analyses (Appendix 1) and potential run identification corrections.

Green Sturgeon and Lamprey species were measured for total length (TL) to the nearest mm. Identification of Green Sturgeon larvae was possible based on meristic traits for individuals > 46 mm TL and identified to genus for all individuals <46 mm but assumed to be Green Sturgeon based on spawning adult data (Poytress et al. 2015; Mora et al. 2018). Lamprey species were identified to the genus level during the ammocoete stage and described as ammocoetes. Adult and macropthalmia (eyed juveniles) were identified to the genus and species level using dentition patterns, specifically by the number of inner lateral horny plates on the sucking disk (Moyle 2002).

Other data collected at each trap servicing included: length of time sampled, velocity of water immediately in front of the cone at a depth of 0.6 m (2.4 m diameter cone) or 0.37 m (1.5 m diameter cone), and depth of cone "opening" submerged. Water velocity was measured using a General Oceanic® Model 2030 flowmeter. These data were used to calculate the volume of water sampled by traps (X). The percent river volume sampled by traps ($\%Q$) was estimated as the ratio of river volume sampled to total river volume passing RBDD. River volume (Q) was obtained from the California Data Exchange Center's Bend Bridge gauging station at RK 415 (USGS site no. 11377100, http://waterdata.usgs.gov/usa/nwis/uv?site_no=11377100). Daily river volume at RBDD was adjusted from Bend Bridge river flows by subtracting daily TCCA diversions, when diversions occurred.

Sampling Effort.—Weekly RST sampling effort was quantified by assigning a value of 1.00 to a week consisting of four 2.4 m diameter RSTs sampling 24 hours daily, 7 days per week. After 6/30/2020, a value of 1.00 was assigned to a week consisting of four 1.5 m diameter and one 2.4 m diameter traps sampling 24 hours daily, 7 days per week. Weekly values <1.00 represented occasions when less than all traps were sampling, one or more traps were structurally modified to sample only one-half the normal volume of water or when less than 7 days per week were sampled.

Mark-Recapture Trials.—Chinook salmon collected as part of daily samples were marked with bismark brown staining solution (Mundie and Traber 1983) prepared at a concentration of 21.0 mg/L of water. Fish were stained for a period of 45-50 minutes, removed, and allowed to recover in fresh water. Marked fish were held for 6-24 hours before being released approximately four RKM upstream from RBDD after official sunset. Recapture of marked fish was recorded for up to three days after release. Trap efficiency was calculated based on the proportion of recaptures to total fish released (i.e., mark-recapture trials). Trials were conducted as fish numbers and staffing levels allowed under a variety of river discharge levels and trap effort combinations.

Trap Efficiency Modeling.—To develop a trap efficiency model, mark-recapture trials were conducted as noted above. Estimated trap efficiency (i.e., the proportion of the juvenile population passing RBDD captured by traps; $\hat{T}_d$) was modeled with $\%Q$ to develop a simple least-squares regression equation (eq. 5). The equation (slope and intercept) was then used to estimate daily trap efficiencies based on daily proportion of river volume sampled. Each successive year of mark-recapture trials was added annually to the original trap efficiency model developed by Martin et al. (2001) on July 1 of each year. Since 2014, the trap efficiency model has been updated to include only trials with wild fish sampled during monitoring activities with the RBDD gates in the raised position (Poytress 2016, Voss and Poytress 2020). The model for BY2019 relied on 84 mark-recapture trials using wild fish and conducted with the RBDD gates raised between 2002 and 2019 ($r^2 = 0.66$, $P < 0.001$, df = 83; Figure 3).

Daily Passage Estimates ($\hat{P}_d$).—The following procedures and formulae were used to derive daily and weekly estimates of total numbers of unmarked Chinook and *O. mykiss* passing RBDD. We defined C_{di} as catch at trap i ($i = 1,\ldots,t$) on day d ($d = 1,\ldots,n$), and X_{di} as volume sampled at trap i ($i = 1,\ldots t$) on day d ($d = 1,\ldots n$). Daily salmonid catch and water volume sampled were expressed as:

1.

$$C_d = \sum_{i=1}^{t} C_{di}$$

and,

2.

$$X_d = \sum_{i=1}^{t} X_{di}$$

The *%Q* was estimated from the ratio of water volume sampled (X_d) to river discharge (Q_d) on day *d*.

3.

$$\%\hat{Q}_d = \frac{X_d}{Q_d}$$

Total salmonid passage was estimated on day d ($d = 1,\ldots,n$) by

4.

$$\hat{P}_d = \frac{C_d}{\hat{T}_d}$$

where,

5.

$$\hat{T}_d = (\alpha)(\%\hat{Q}_d) + b$$

and, $\hat{T}_d$ = estimated trap efficiency on day *d*.

Weekly Passage ($\hat{P}$).—Population totals for numbers of Chinook and *O. mykiss* passing RBDD each week were derived from $\hat{P}_d$ where there are *N* days within the week:

6.

$$\hat{P} = \frac{N}{n}\sum_{d=1}^{n}\hat{P}_d$$

Estimated Variance.—

7.

$$Var(\hat{P}) = \left(1 - \frac{n}{N}\right)\frac{N^2}{n}s^2_{\hat{P}_d} + \frac{N}{n}\left[\sum_{d=1}^{n} Var(\hat{P}_d) + 2\sum_{i\neq j}^{n} Cov(\hat{P}_i, \hat{P}_j)\right]$$

The first term in eq. 7 is associated with sampling of days within the week.

8.

$$s^2_{\hat{P}_d} = \frac{\sum_{d=1}^{n}\left(\hat{P}_d - \hat{\bar{P}}\right)^2}{n-1}$$

The second term in eq. 7 is associated with estimating $\hat{P}_d$ within the day.

9.

$$Var(\hat{P}_d) = \frac{\hat{P}_d\,(1-\hat{T}_d)}{\hat{T}_d} + Var\,(\hat{T}_d)\frac{\hat{P}_d(1-\hat{T}_d) + \hat{P}_d^2\hat{T}_d}{\hat{T}_d^3}$$

where,

10. $Var(\hat{T}_d)$ = error variance of the trap efficiency model

The third term in eq. 7 is associated with estimating both $\hat{P}_i$ and $\hat{P}_j$ with the same trap efficiency model.

11.

$$Cov(\hat{P}_i, \hat{P}_j) = \frac{Cov(\hat{T}_i, \hat{T}_j)\hat{P}_i\hat{P}_j}{\hat{T}_i\hat{T}_j}$$

where,

12. $Cov(\hat{T}_i, \hat{T}_j) = Var(\hat{\alpha}) + \chi_i Cov(\hat{\alpha}, \hat{\beta}) + \chi_j Cov(\hat{\alpha}, \hat{\beta}) + \chi_i\chi_j Var(\hat{\beta})$

for some

$$\hat{T}_i = \hat{\alpha} + \hat{\beta}\chi_i$$

Confidence intervals (CI) were constructed around $\hat{P}$ using eq. 13.

13.

$$P \pm t_{\frac{\alpha}{2},n-1}\sqrt{Var(\hat{P})}$$

Annual JPI's were estimated by summing $\hat{P}$ across weeks.

14.

$$JPI = \sum_{week=1}^{52} \hat{P}$$

Relative Abundance.—Catch per unit volume (CPUV; Gaines and Martin 2002; Poytress et al. 2014) was used as an index of relative abundance (RA) for Green Sturgeon and Lamprey species at RBDD.

15.

$$RA_{dt} = \frac{C_{dt}}{V_{dt}}$$

RA_{dt} = Relative abundance on day *d* by trap *t* (catch/acre-foot),
C_{dt} = number of fish captured on day *d* by trap *t*, and
V_{dt} = volume of water sampled on day *d* by trap *t*.

The volume of water sampled (V_{dt}) was estimated for each trap as the product of one-half the cross sectional area (wetted portion) of the cone, water velocity (ft/s) directly in front of the cone at a depth of 0.6 m (2.4 m cone) or 0.37 m (1.5 m cone), cone modified (multiplied by 0.5) or not (multiplied by 1.0), and duration of sampling.

Fry-Equivalent Chinook Production Estimates.—The ratio of Chinook fry (<46 mm FL) to pre-smolt/smolts (>45 mm FL) passing RBDD was variable among years. Therefore, we standardized juvenile production by estimating a fry-equivalent JPI for among-year comparisons. Fry-equivalent JPI's for spring, fall, and late-fall Chinook were estimated by the summation of fry JPI and a weighted (1.7:1) pre-smolt/smolt JPI (inverse value of 59% fry-to-pre-smolt/smolt survival; Hallock undated). Rotary trap JPI's could then be directly compared to determine variability in production between years.

A run-specific, annually calculated fry-to-smolt survival hindcast estimate based on O'Farrell et al. (2018) was employed for winter Chinook in 2019 as the best available science. This survival estimate was employed, as recommended by the Interagency Ecological Program's Winter-Run Project Work Team, for the production of a winter run juvenile production estimate to guide incidental take at the Sacramento-San Joaquin Delta pumping facilities in 2019 (NMFS 2020). O'Farrell's method incorporates summation of fry JPI and a weighted (2.15:1) pre-smolt/smolt JPI (inverse value of 46.5% fry-to-pre-smolt/smolt survival) for estimation of

BY2019 winter Chinook fry-equivalents. All BY2019 winter Chinook fry equivalent production estimates were calculated using O'Farrell's estimate of fry-to-smolt survival and reported within the following text, tables and graphics.

Egg-to-fry survival estimates.— Annual juvenile winter and fall Chinook egg-to-fry (ETF) survival rates were estimated by calculating fry-equivalent JPI's and dividing by the estimated number of eggs deposited in-river. Winter Chinook adult data were derived from carcass survey estimates (D. Killam, CDFW, personal communication). Fall Chinook female spawner data were estimated using adult escapement estimates derived from the California Department of Fish and Wildlife's (CDFW) Grandtab data set (Azat 2020) and calculating female spawners based on sex ratios obtained from Coleman National Fish Hatchery (CNFH). Average female winter Chinook fecundity data were obtained from the Livingston Stone National Fish Hatchery (LSNFH) and fall Chinook fecundity estimates were obtained from CNFH annual spawning records.

Results

Sampling effort.— A pause in sampling activities occurred from 3/25/2020 through 6/30/2020 in order to protect project employee health and safety during the COVID-19 pandemic. During that time, traps were removed from the river. Just prior to resuming sampling operations, four new 1.5 m diameter and one 2.4 m diameter RSTs were installed across the RBDD transect. This new five-trap configuration provides a temporary solution to sampling a location that has become shallower since the RBDD gates were permanently placed in the raised position. One result is an estimated 12.5% daily reduction in sample volume area as compared to prior years' four 2.4 m RST transect configurations.

Weekly sampling effort throughout the BY2019 winter Chinook salmon emigration period ranged from 0.00 to 1.00 ($\bar{x}$ = 0.61; *N* = 52 weeks; Table 1). Weekly sampling effort ranged from 0.61 to 1.00 ($\bar{x}$ = 0.87; *N* = 26 weeks) between July and the end of December, the period of greatest juvenile winter Chinook emigration, and 0.00 to 1.00 ($\bar{x}$ = 0.35; *N* = 26 weeks) during the latter half of the emigration period (Table 1).

Weekly sampling effort throughout the BY2019 spring Chinook emigration period ranged from 0.00 to 1.00 ($\bar{x}$ = 0.59; *N* = 52 weeks; Table 2). Weekly sampling effort ranged from 0.00 to 1.00 ($\bar{x}$ = 0.69; *N* = 26 weeks) between mid-October and mid-April, the period of greatest juvenile spring Chinook emigration, and 0.00 to 1.00 ($\bar{x}$ = 0.49; *N* = 26 weeks) during the latter half of the emigration period (Table 2).

Weekly sampling effort throughout the BY2019 fall Chinook emigration period ranged from 0.00 to 1.00 ($\bar{x}$ = 0.58; *N* = 52 weeks; Table 3). Weekly sampling effort ranged from 0.00 to 1.00 ($\bar{x}$ = 0.49; *N* = 26 weeks) between December and the end of May, the first half of the juvenile fall Chinook 2019 brood year, and 0.00 to 1.00 ($\bar{x}$ = 0.67; *N* = 26 weeks) during the latter half of the emigration period (Table 3).

Weekly sampling effort throughout the BY2019 late-fall Chinook emigration period ranged from 0.00 to 1.00 ($\bar{x}$ = 0.78; *N* = 52 weeks; Table 4). Weekly sampling effort ranged from 0.25 to 1.00 ($\bar{x}$ = 0.82; *N* = 26 weeks) between April and the end of September, the first half of the juvenile late-fall Chinook 2019 brood year, and 0.00 to 1.00 ($\bar{x}$ = 0.75; *N* = 26 weeks) during the latter half of the emigration period (Table 4).

Weekly sampling effort throughout the BY2019 *O. mykiss* emigration period ranged from 0.00 to 1.00 ($\bar{x}$ = 0.70; *N* = 52 weeks; Table 5). Weekly sampling effort ranged from 0.00 to 1.00 ($\bar{x}$ = 0.54; *N* = 26 weeks) between January and the end of June, the first half of the juvenile *O. mykiss* 2019 brood year, and 0.64 to 1.00 ($\bar{x}$ = 0.87; *N* = 26 weeks) during the latter half of the emigration period (Table 5).

The high variance in sampling effort throughout the reporting period was attributed to several sources. They included intentional reductions in effort resulting from sampling < 4 traps prior to March 25, 2020 through June 30, 2020 due to the COVID-19 pandemic and sampling < 5 traps following the break in trapping operations. Additionally, cone modification(s), staffing limitations, unintentional reductions in effort resulting from high flows and debris loads, and Section 10(a)(1)(A) permit catch limitations influenced sample effort variance relative to each species sampled (Tables 1-5).

Mark-recapture trials.—Fifteen mark-recapture trials were conducted during this report period to estimate and validate RST efficiency using 2.4-m RST's. Ten trials were conducted during the fall of 2019 using naturally produced winter Chinook. Five trials using naturally produced fall Chinook were conducted from January through February 2020. Sacramento River discharge sampled during the fifteen trials ranged from 5,109 to 10,322 cfs. Estimated *%Q* during trap efficiency trials ranged from 1.80% to 4.31% ($\bar{x}$ = 2.49%; Table 6).

Trials (*N* =15) were conducted using three or four RSTs sampling with unmodified cones for seven of the fifteen trials. All trials were conducted using Chinook sampled from RSTs, and trap efficiencies ranged from 1.51% to 5.31% ($\bar{x}$ = 2.58%). The number of marked fish released per trial ranged from 617 to 1,745 ($\bar{x}$ = 1,133) and the number of marked fish recaptured ranged from 13 to 62 ($\bar{x}$ = 28). All fish were released after sunset and 98.4% of recaptures occurred within the first 24 hours, and 100% within 48 hrs.

Fork lengths of a sub-sample of fish marked and released ranged from 30 to 78 mm ($\bar{x}$ = 37.6 mm). Fork lengths of recaptured marked fish ranged from 29 to 60 mm ($\bar{x}$ = 36.5 mm). The distribution of fork lengths of fish marked and released in mark-recapture trials was commensurate with the distribution of fork lengths of fish recaptured by RSTs and fish used were largely considered fry size class (90.6% fry, 9.4% pre-smolts).

Fish collected and used for all trials were obtained from all three spatial zones, east-margin, mid-channel and west-margin traps. Overall, the horizontal distribution of recaptured marked fish followed the catch distribution of unmarked fish. Mid-channel traps re-captured the most marked fish for thirteen of the fifteen trials while capturing the most unmarked fish during fourteen of the fifteen trials.

Trap efficiency modeling.— Five trials conducted during BY2018 using naturally produced winter Chinook (N=3) and fall Chinook (N=2) were included into the BY2019 model (Figure 3). An 84-trial model (r^2 = 0.66, P < 0.001, df = 83) was employed for passage estimation during the entire BY2019 winter Chinook and various portions of the BY 2019 spring, fall, late-fall Chinook, and *O. mykiss* outmigration periods covered in this report (Figure 4). The fifteen trials conducted during BY2019 will be used to update the model for BY 2020 data and result in a 99-trial model.

Genetic corrections to LAD run assignments.—Genetic tissue samples from up to ten Chinook salmon per run, according to LAD, were collected on a daily basis and contributed to two genetic sampling projects: "Improving Vital Rates Estimation Using Parentage-Based Mark Recapture Methods" and "Central Valley Salmonid Coordinated Genetic Monitoring Project". Samples collected from LAD winter and spring Chinook were analyzed (see Appendix I) to evaluate the accuracy of field-based run assignments used to generate Chinook passage and production estimates. Genetic run assignment data indicated that winter Chinook were incorrectly assigned using LAD criteria to spring Chinook for a period of 34 days during BY2019 from mid-October thru late November.

Based upon genetic data, LAD spring Chinook captured between October 16 and November 18, 2019 were re-assigned to the winter Chinook category and included in the passage and production estimates detailed in this report. Consequently, genetic re-assignment resulted in a net reduction for spring Chinook and in turn, an increase in winter Chinook passage and production estimates for BY 2019. These re-assignments are reflected in the estimates reported herein. A genetic reassignment memo dated January 16, 2020 further outlines details of genetic-based revisions made to BY2019 winter and spring Chinook real-time biweekly passage estimates (Appendix II)[6].

Winter Chinook fork length evaluations.— BY2019 winter Chinook fork lengths ranged between 28 and 161 mm (Figure 5a). Winter Chinook were weighted (82.1%) to the fry size-class category (<46mm) with 94.9% of those measuring less than 40 mm (Figure 6a). The remaining 17.9% were attributed to the pre-smolt/smolt category (>45 mm) with 99.5% of the fish sampled between 46 and 100 mm.

Winter Chinook passage.—BY2019 winter Chinook juvenile estimated passage at RBDD was 3,813,589 fry and pre-smolt/smolts combined (Table 1). Fry sized juveniles (<46 mm FL) comprised 80.0% of total estimated winter Chinook passage (Table 1). Fry passage occurred from July through early December (weeks 27 thru 48; Figure 5a). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 20.0% of total passage and the first observed emigration past RBDD occurred in late August (week 34; Table 1). Weekly pre-smolt/smolt passage estimates

---

[6] Genetic reassignment memo and affected biweekly reports can be found at the following web address: https://www.fws.gov/redbluff/RBDD%20JSM%20Biweekly/2019/rbdd_jsmp_2019.html

for the brood year concluded in late March (week 13; Figure 5b) when sampling activities ceased due to the COVID-19 global pandemic.

Winter Chinook JPI to adult comparisons.—The BY2019 winter Chinook fry-equivalent JPI was 4,691,764 with the lower and upper 90% CI extending from 2,630,095 to 6,753,433 juveniles, respectively (Table 7). Adult females contributing to in-river spawning of BY2019 winter Chinook were estimated to have been 4,884 individuals (D. Killam, CDFW, pers. comm.). The estimated ETF survival rate was 17.7%, based on the BY2019 winter Chinook fry-equivalent JPI, estimated number of female spawners and egg deposition in-river. The range of ETF survival based on 90% CI's was 9.9% to 25.5% (Table 7).

Adult female spawner estimates derived from winter Chinook carcass surveys and RST data from brood years 1996-2019 were used to evaluate the linear relationship between the estimates. Twenty-two observations were evaluated using the carcass survey data as the winter Chinook carcass survey did not start until 1996 and rotary trapping at RBDD was not conducted in 2000 and 2001. Rotary trap JPI's were significantly correlated in trend to adult female spawner estimates ($r^2 = 0.87$, $P < 0.0001$, df = 21; Figure 7).

Spring Chinook fork length evaluations.— BY2019 spring Chinook fork lengths ranged between 29 and 92 mm (Figure 6b). Spring Chinook were weighted to the pre-smolt/smolt size-class category (>45mm) with 21.9% spring Chinook designated as fry with 84.6% measuring less than 40 mm FL (Figure 8a). The majority of the catch (79.1%) was attributed to the pre-smolt/smolt category (>45 mm) with fish between 46 and 80 mm comprising 92.3% of this size class.

Spring Chinook passage.—Including genetic corrections, BY2019 spring Chinook juvenile estimated passage at RBDD was 161,444 fry and pre-smolt/smolts combined (Table 2). Fry sized juveniles (<46 mm FL) comprised 20.9% of total estimated spring Chinook passage (Table 2). Fry passage occurred from the end of November through early January (weeks 47 thru 1; Table 2). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 79.1% of total passage and the first observed emigration past RBDD occurred in early December (week 49; Table 2). Detection of pre-smolt/smolt passage for the brood year ended in late March (week 13; Figure 8b) due to the cessation of sampling from late March until June 30, 2020 during the start of the COVID-19 pandemic. On average, spring Chinook passage typically ends in early June. As a result, BY2019 spring Chinook data is incomplete and should be viewed cautiously.

The fry-equivalent rotary trap JPI for BY2019 was 250,801 with the lower and upper 90% CI extending from 52,518 to 449,084 juveniles, respectively (Table 2). Spring Chinook ETF survival rates were not estimated due to inaccuracies with run designation and adult counts as noted in Poytress et al. (2014).

Fall Chinook fork length evaluations.—BY2019 fall Chinook fork lengths ranged between 27 and 175 mm (Figure 6c). BY2019 fall Chinook were composed of 95.2% in the fry size-class category (<46 mm) with 98.4% of those fry measuring less than 40 mm FL (Figure 9a). The remaining 4.8% were attributed to the pre-smolt/smolt category (>45 mm) with fish between 50 and 100 mm comprising 85.3% of the size group.

Fall Chinook passage.—BY2019 fall Chinook juvenile estimated passage at RBDD was 7,326,883 fry and pre-smolt/smolts combined (Table 3). Fry sized juveniles (<46 mm FL) comprised 95.2% of total estimated fall Chinook passage (Table 3). Fry passage began in December and was detected through the end of March (weeks 49 thru 13; Figure 9b) when sampling ceased due to the COVID-19 pandemic cessation in sampling. As a result, BY2019 fall Chinook data is incomplete and should be viewed cautiously. Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 4.8% of total passage. The first observed pre-smolt/smolt passage occurred in late January (week 3; Table 3). Following the break in sampling brought about by COVID-19, pre-smolt/smolt passage continued through the end of November (week 47; Table 3).

Fall Chinook JPI to adult comparisons.—The fry-equivalent rotary trap JPI for BY2019 was 7,575,182 with the lower and upper 90% CI extending from 2,718,701 to 12,431,662 juveniles, respectively (Table 3). The total number of adult BY2019 fall Chinook females contributing to in-river spawning upstream of RBDD was estimated to be 24,421 individuals. The estimated ETF survival rate was 6.4%, based on the incomplete BY2019 fall Chinook fry-equivalent JPI, estimated number of female spawners and eggs deposited in-river. The range of ETF survival based on 90% CI's was 2.3% to 10.6% (Table 8).

Late-Fall Chinook fork length evaluations.—BY2019 late-fall Chinook were sampled between 30 and 171 mm (Figure 6d). BY2019 late-fall Chinook sampled were heavily weighted to the pre-smolt/smolt size-class category (>45 mm). Only 14.3% of all fish sampled as late-fall were designated fry (<46 mm), with 94.0% of the fry measuring less than 40 mm FL (Figure 10a). The remaining 85.7% of juveniles were attributed to the pre-smolt/smolt category, with fish between 60 and 120 mm comprising 88.6% of that value.

Late-fall Chinook passage.—BY2019 late-fall Chinook juvenile estimated passage at RBDD was 152,086 fry and pre-smolt/smolts combined (Table 4). Fry sized juveniles (<46 mm FL) comprised 60.9% of total estimated late-fall Chinook passage (Table 4). Fry passage occurred from April through early August (weeks 14 thru 31; Figure 10b). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 39.1% of total passage and the first observed emigration past RBDD occurred in July (week 28; Table 4). Weekly pre-smolt/smolt passage for the brood year ended in January (week 2; Figure 10b). The fry-equivalent rotary trap JPI for BY2019 was 193,758 with the lower and upper 90% CI extending from 37,292 to 350,225 juveniles, respectively (Table 4). Late-fall Chinook ETF survival rates were not estimated due to inaccuracies in adult count data as noted in Poytress et al. (2014).

O. mykiss fork length evaluations.—BY2019 juvenile *O. mykiss* were sampled between 21 and 280 mm (Figure 11a). Sub-yearling (41-138mm) and yearling (139-280 mm) *O. mykiss* were amongst the first sampled at the beginning of calendar year 2019 (Table 5). *O. mykiss* fry (<41mm) captures were highly variable, with the first fry of the year captured in late April, with a fork length of 25 mm; a 23 mm fry was captured 13 weeks later (late July; Figure 11a). Fry captures continued through week 33 (mid-August). Sub-yearling (41-138mm) captures began in January (week 2; Table 5) and continued through the end of the calendar year. Yearling captures occurred sporadically through the end of December (Table 5).

O. mykiss passage.—BY2019 *O. mykiss* juvenile total estimated passage at RBDD was 24,472 fry, sub-yearling and yearlings combined (Table 5). Fry sized juveniles (<41 mm) comprised only 5.3% of total *O. mykiss* passage. Fry passage occurred from late April through early September (weeks 17 thru 36; Figure 11b). Sub-yearling/yearling sized juveniles (≥41 mm) comprised 94.7% of total passage and the first observed emigration past RBDD occurred in week 2 (January; Table 5). Weekly sub-yearling/yearling passage for the brood year ended during week 52 (late December).

Green Sturgeon data.—Similar to observations in prior years (Poytress et al 2014), sturgeon catch in the RSTs was primarily composed of recently emerged, post-exogenous feeding larvae with a mean total length of 28.1 mm and median of 27.0 mm (Table 9). Sturgeon captured during calendar year 2019 ranged in length from 17 to 116 mm (Figure 12a). In addition to the 4,299 larval sturgeon captured in the traps during calendar year 2019, four juvenile sturgeon exhibited fully developed morphometric features (lateral scutes) and were able to be positively identified in the field as Green Sturgeon.

Green Sturgeon larval captures began in mid-May and continued through early August of 2019 (Figure 12b). Capture of juvenile Green Sturgeon in the RSTs began in August and continued through mid-September. Yearly Green Sturgeon CPUV for 2019 was 22.2 fish/ac-ft (Table 9); this value is well above the 18-year mean of 6.7 fish/ac-ft and is the third highest value since the program began operating RSTs at the RBDD. A spike in Green Sturgeon larvae abundance was observed in years 2016 and 2017 with CPUV values of 31.0 fish/ac-ft and 30.3 fish/ac-ft (Table 9; Figure 12c), respectively.

Lamprey species data.—Capture of multiple lamprey species occurred in water year 2020 (WY2020; October 1, 2019 – September 30, 2020). Sampling due to the COVID-19 pandemic ceased March 24, 2020 and data for lamprey should be considered incomplete for WY2020 and viewed cautiously. Lamprey species sampled during WY2020 included Pacific Lamprey (*Entosphenus tridentata*), Kern Brook Lamprey (*Lampetra hubbsi*) and River Lamprey (*Lampetra ayresi*). Unidentified lamprey ammocoetes and Pacific Lamprey composed 99.9% of all captures, 21.5% and 78.5% respectively. Two individual Kern Brook Lamprey and one River Lamprey were captured in the rotary traps during WY2020.

Annual catch of unidentified lamprey ammocoetes during WY2020 was 929 (Table 10) and ranged in total length from 38 mm to 148 mm ($\bar{x}$ = 90 mm; Figure 13a). Annual catch of Pacific Lamprey was 3,396 (Table 11) and ranged in total length from 42 mm to 160 mm ($\bar{x}$ = 118 mm, Figure 14a).

Lamprey captures occurred throughout the water year when traps were sampled, beginning in early October and continuing thru the end of September (Figures 13b and 14b).

Cessation of sample collection due to the COVID-19 pandemic resulted in a data gap from the end of March thru the end of June. Lamprey CPUV for WY2020 was 22.4 fish/ac-ft for unidentified lamprey ammocoetes (Table 10, Figure 13c) and 92.7 fish/ac-ft for Pacific lamprey (Table 11, Figure 14c). Despite the break in sampling, both of these abundance values fall above the 17-year averages of 14.6 ± 18.6 fish/ac-ft for unidentified lamprey ammocoetes and 54.4 ± 65.9 fish/ac-ft for Pacific lamprey.

Discussion

Sampling effort. —Fluctuating river flows resulted in moderate sampling effort for the reporting period of January 1, 2019 through November 30, 2020 ($\bar{x}$ = 0.64). Mean sampling effort for BY2019 winter, spring, fall, late-fall Chinook and *O. mykiss* was 0.61, 0.59, 0.58, 0.78 and 0.70, respectively (Tables 1-5). During the primary juvenile winter Chinook salmon capture and passage period of July through December of 2019, mean sampling effort was fairly high (0.87), whereas the latter half of the brood year was markedly lower and more variable, averaging only 0.35.

Decreased sampling effort during the latter half of the 2019 winter Chinook brood year was due to hatchery releases upstream and the cessation of sampling activities between March 24 and June 30, 2020 in order to protect staff health and safety during the COVID-19 pandemic. Releases of steelhead and late-fall Chinook in late December and mid-January, respectively, resulted in reduced effort due to sampling traps with 50% modifications in order to reduce handling and stress on elevated catches of marked hatchery salmonids. Some traps remained sampling with modifications through early February. Sampling activities ceased on March 24 due to CNFH releases of approximately 6.3 million fall Chinook into Battle Creek on March 23-24, 2020, which coincided with shutting down sampling operations due to the COVID-19 pandemic. Traps were not sampled again until June 30, 2020. As a result, BY2019 fall and spring run and WY2020 lamprey data are truncated for 3 months with no interpolations estimated for the prolonged missed sampled period due to the pandemic. The unsampled period impacted BY2019 spring and fall Chinook passage estimates and abundance indices for WY2020 lamprey species and should not be used for inter-annual comparisons.

Trap Efficiency and genetic-based run corrections.—Following mark-recapture trials conducted in the fall of 2019 with naturally produced winter Chinook fry, it was discovered that sampling four traps across the RBDD transect produced efficiency values that were higher than our regression model predicted due to a high rate of efficiency of one trap sampling the thalweg (Appendix II). Passage estimates for weeks 33 through 44 (mid-August to early November), the peak of winter Chinook passage were therefore revised using data from three traps rather than four to align predicted or modeled efficiencies with those observed during mark-recapture trials in the fall of 2019 (i.e., excluding the thalweg trap). Further, revisions were made following genetic analyses of fin clips taken from juvenile LAD spring and winter Chinook in the fall of 2019 (Appendix II).

Genetic results indicated that field assigned (by LAD) BY2019 spring Chinook prior to November 19, 2019 were genetically winter Chinook. Subsequently, when incorporating trap efficiency and genetic revisions, 155,066 LAD spring Chinook were estimated to be winter Chinook based on genetic identification during the period of October 16 thru November 18, 2019. A substantial amount of positive bias (49.0%) would have occurred without revisions to spring passage estimates given that total BY2019 spring Chinook passage was estimated at 161,444 through March 31 (week 13). However, mean cumulative weekly passage thru March 31 (week 13) for the last 18 years of passage data is 64.6% +/- 20.4% which would result in a total passage estimate of 249,913. If expanded based on this 18-year mean without the genetic correction, the estimate would still have resulted in a substantial amount of positive bias (38.3%). For BY2019 winter Chinook, after revisions due to trap efficiency adjustments (September and October 2019) and the addition of LAD spring Chinook genetic reassignments (October 16 thru November 18) were incorporated, a net reduction of 65,039 (1.7%) to the BY2019 passage estimate resulted, and thus did not substantially affect the brood year total.

Patterns of abundance.—Juvenile winter Chinook began to emerge in early July in low numbers. Catch and subsequent passage generally increased, peaking in mid-October (Table 1; Figure 5b). Fry passage declined thereafter and ceased after the first week of December.

An experimental, pulsing water release from Keswick Reservoir was conducted as a pilot operation (USBR 2020; page 11) from 10/15/2019 to 10/31/2019. This effort "was an attempt to meet multi-objective purposes in the system [namely rice decomposition water deliveries] while continuing to minimize fishery impacts". A series of five peak release flows were realized over the span of the 16-day period in October and releases oscillated generally between 6,500 and 8,000 cfs (Figure 15). During the pulse flow experiment (weeks 42-44; Table 1 & Figure 15.) a total of 979,077 or 25.7% of BY2019 winter Chinook passed the transect. During this three-week range that included the pulses, 14.7% of the BY typically would pass based on the 17-year average. Spikes in daily passage rates associated with peak flows during the experiment were nearly double the long-term daily averages (Figure 16). The spike in passage at this time is not unlike spikes in passage occurring during the first freshet of the fall season in years prior (Poytress et al 2007). By the end of the pulse flow experiment and thru week 44, 89.6% of BY2019 winter Chinook passage had occurred. This cumulative passage value fell within one standard deviation (+/- 14.0%) of the 17-year mean of 80.7% (66.7 – 94.7%) thru week 44.

Winter Chinook fry out-migrants represented 80.0% of total winter Chinook passage, with pre-smolt/smolts representing the remaining 20.0%. Through the end of December 2019, 99.1% of the total annual passage estimate for BY2019 winter Chinook was collected (Table 1). The effects of lower sampling effort ($\bar{x}$ = 0.35) during the second half of the brood year were considered immaterial for this run. Cessation of sampling from March 24, 2020 through June 30, 2020 (COVID-19) likely did not result in a substantial impact to the overall winter Chinook 2019 brood year estimate as, on average, 99.8% (+/- 0.2%) of winter Chinook passage for the brood year would have occurred by March 24th based on the past 17 years of cumulative passage data. Overall, interpolation for missed days of sampling accounted for only 3.9% of the total BY2019 estimate of 3,813,589 winter Chinook passing the RBDD.

Capture of BY2019 juvenile spring Chinook began on October 16, 2018 according to LAD criteria; however, genetic assignment results from tissue samples collected between mid-October and December of 2019 indicated spring Chinook passage began in late November of 2019. Sampling effort was relatively high throughout the fry passage period of weeks 47 thru 1 ($\bar{x}$ = 0.83, Table 2). A pronounced peak of fry passage, accounting for 43.6% of total spring Chinook fry passage occurred in mid-December (week 49; Table 2) following a flow event which increased flows four-fold and turbidity almost 40-fold over two days prior (Figure 17). Sampling effort during the remainder of the brood year was lower ($\bar{x}$ = 0.55; Table 2) and driven by the COVID-19 cessation of sampling. On average, 53.0% (+/- 23.6%) of spring Chinook brood year passage occurs through March 24, based on the prior 17 years of passage data[7]. In most years, spring Chinook passage is complete by the first week of June and no further catch of brood year 2019 spring Chinook occurred after sampling began again on June 30, 2020. Through the end of March (week 13; Table 2), interpolation for missed days of sampling accounted for 33.4% of the total BY2019 estimate of 161,444 spring Chinook passing the RBDD. Expanding the brood year estimate using the 17-year, average cumulative passage figure of 53.0%, results in a projected brood year estimate of 304,611 for BY2019 spring Chinook.

Spring Chinook fry out-migrants represented 20.9% of total passage, with pre-smolt/smolts representing the remaining 79.1%. This low percentage of fry out-migrants is substantially less than the 54% average noted in Poytress et al. (2014), but likely a result of genetic assignments in contrast to assignments made solely using LAD criteria.

Fall Chinook fry passage accounted for 95.2% of the total passage for brood year 2019, but is positively biased due to lack of sampling between weeks 13 and 26. Passage of fry began the first week of December, increasing through the end of the month. Fry passage sampling effort was moderate, averaging 0.75 and was largely influenced by a number of runoff events throughout the passage period of weeks 48 to 12, with a peak in fry passage during week 4 (Table 3; Figures 9b & 17).

Fall Chinook passage in the pre-smolt/smolt size category, which comprised 4.8% of total brood year passage, began in mid-January. A spike and peak in pre-smolt/smolt passage occurred in late March (Table 3), just prior to CNFH fall Chinook production releases and cessation in sampling due to COVID-19. The break in sampling lasted from weeks 13-26 and, on average, 21.5% of fall run passage was not sampled or included in the fall Chinook passage estimates[7]. The break in sampling brought about by COVID-19 imparted a negative bias on the fry-equivalent value for BY2019 and thus affected the ETF survival estimate. Incorporating the missing 21.5% 17-year average passage value into the estimate results in a fry equivalent JPI of 9,649,913. This projected estimate would increase the ETF survival estimate from 6.4% to 8.2%, which is still well below the long-term average of 13.3%, but within one standard deviation.

---

[7] Average brood year passage figures for spring and fall Chinook exclude 75% unmarked CNFH fall production fish that fell within spring LAD and fall LAD during applicable brood years (Voss and Poytress 2020).

Late-fall Chinook fry passage was variable, and at times sporadic, occurring from April through early August (Table 4; Figure 10b). Fry passage accounted for 60.9% of the brood year total, which is above the reported mean value of 38% (Poytress et al. 2014). Late-fall Chinook passage in the pre-smolt/smolt size category, which comprised 39.1% of total brood year passage, began in early July and continued in a variable fashion through early January. Although sampling effort was moderate for the brood year ($\bar{x}$ = 0.78), interpolation for missed samples accounted for 28.8% of the total brood year estimate. BY2019 late-fall Chinook passage estimates were unaffected by the COVID-19 cessation to sampling as the latest observed capture during any brood year since monitoring began at RBDD occurred on March 6, 2004 during BY2003.

O. mykiss passage began the second week in January (Table 5), with the first fry observed at the end of April 2019 when passage peaked. Passage remained variable for all size classes throughout the rest of the calendar year. Total passage for the brood year was 24,472 and interpolation accounted for only 11.6% of the total.

Bias associated with unmarked CNFH fall Chinook.— Releases of 25% marked (adipose fin clip) brood year 2019 fall Chinook into Battle Creek (Figure 1) began in late March. No samples were collected from March 24, 2020 through June 30, 2020 due to the COVID-19 pandemic. Therefore, no attempts to eliminate bias associated with unmarked CNFH fall Chinook were made to passage estimates for either BY2019 spring or fall Chinook.

Winter Chinook JPI and ETF survival estimate.—The BY2019 winter Chinook fry-equivalent JPI value of 4,691,764 was the highest value reported since 2009. Adult escapement for BY2019 was estimated at 7,852 in-river adults (NMFS 2020). This adult estimate was three times the number estimated to return for BY2018 and was primarily composed of BY2016 returns, which had more favorable river conditions (first year post-drought) than the prior three brood years. However, the fry-equivalent based ETF survival rate for BY2019 was estimated at 17.7% (Table 7), below the 21-year average ETF survival rate of 24.0%.

Following a cycle of wet weather in early 2019, Shasta Reservoir reached top of conservation pool by the end of April, providing adequate cold-water pool availability for temperature compliance for BY2019 winter Chinook. The Sacramento River Temperature Management Plan proposed a 56˚F daily average temperature (DAT) compliance point at Balls Ferry (RKM 444.5) while also targeting a 53.5˚F DAT at the Clear Creek gauging station (RKM 466; USBR 2019).

With adequate water temperatures, lower than average ETF survival estimates for BY2019 winter Chinook (as well as BY2019 fall Chinook) may have been attributed to thiamine deficiency complex. Thiamine deficiency was discovered to be problematic at CNFH with elevated mortality rates of BY2019 fall Chinook fry exhibiting "anorexia and sporadic spinning behavior prior to death" (Foott 2020). Several diagnostic investigations by the USFWS California-Nevada Fish Health Center (CNFHC) examining the symptomatic fry yielded no instance of viral or parasitic infection and a very low rate of observed bacterial infections; histological analyses of tissues also appeared normal. In late January of 2020, CNFHC conducted an experimental 4-hr thiamine treatment bath for symptomatic fry, yielding positive results. The following day, treated fry exhibited normal swimming behavior and began to feed while control groups continued a spinning swimming behavior and elevated mortality rates.

Following the results of the experimental treatment bath, it was recommended to develop large-scale thiamine treatment of yolk-sac fry at CNFH as well as injection of winter Chinook adults returning to LSNFH in 2020 (Foott 2020). It was hypothesized that shift in diet within the adult salmonid population in the ocean environment may have led to the thiamine deficiency complex across multiple runs of Chinook salmon (NMFS 2021). At this time, the magnitude of the effect of thiamine deficiency complex on BY2019 salmon runs in the upper Sacramento River has not been estimated nor has the impact to past or future brood years been determined.

Acknowledgments

The USBR provided financial support allowing the project to reach its goals and objectives (Interagency Agreement No. R15PG00067). Numerous individuals helped with development and implementation of this project including, but not limited to Leonard Cheskiewicz, Casey Collins, Alexa Davis, Lauren Estenson, Josh Gruber, Lucas Lagoon, Robert Larson, Lily Olmo, Chad Praetorius, David Ryan, Kathryn Sykes, Stephen Tentinger, and Joel Wils. Valerie Emge and Jim Smith provided programmatic support.

Literature Cited

Azat, J. 2020. GrandTab 2020.05.22. California Central Valley Chinook Population Database Report. California Department of Fish and Wildlife. http://www.dfg.ca.gov/fish/Resources/Chinook/CValleyAssessment.asp

Borthwick, S. M. and R. R. Corwin. 2001. Fish entrainment by Archimedes lifts and an internal helical pump at Red Bluff Research Pumping Plant, Upper Sacramento River, California: February 1997 – May 2000. Red Bluff Research Pumping Plant Report Series, Volume 13. U.S. Bureau of Reclamation, Red Bluff, CA.

Foott, J.S. 2020. Fall-run Chinook fry loss not associated with infectious agent. U.S. Fish and Wildlife Service, California – Nevada Fish Health Center, Anderson, CA. January 23, 2020. Memorandum.

Gaines, P.D. and C. D. Martin. 2002. Abundance and Seasonal, Spatial and Diel Distribution Patterns of Juvenile Salmonids Passing the Red Bluff Diversion Dam, Sacramento River. Red Bluff Research Pumping Plant Report Series, Volume 14, U.S. Fish and Wildlife Service, Red Bluff, CA.

Gaines, P.D. and W.R. Poytress. 2004. Brood-year 2003 winter Chinook juvenile production indices with comparisons to adult escapement. U.S. Fish and Wildlife Service report to California Bay-Delta Authority. San Francisco, CA.

Goodman, D.H. and S.B. Reid. 2012. Pacific Lamprey (*Entosphenus tridentatus*) Assessment and Template for Conservation Measures in California. U.S. Fish and Wildlife Service, Arcata, California. 117 pp.

Goodman, D.H. and S.B. Reid. 2018. Regional Implementation Plan for Measures to Conserve Pacific Lamprey (*Entosphenus tridentatus*), California – San Joaquin Regional Management Unit. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata Fisheries Technical Report Number TR 2018-35 Arcata, California.

Greene, S. 1992. Daily fork-length table from data by Frank Fisher, California Department of Fish and Game. California Department of Water Resources, Environmental Services Department, Sacramento.

Hallock, R.J., W.F. Van Woert, and L. Shapolov. 1961. An Evaluation of Stocking Hatchery-reared Steelhead Rainbow Trout (*Salmo gairdnerii gairdnerii*) in the Sacramento River System. California Department of Fish and Game. Fish Bulletin 114. 74 p.

Johnson, R. R. and C. D Martin. 1997. Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing Red Bluff Diversion Dam, Sacramento River, July 1994

- June 1995. Red Bluff Research Pumping Plant Report Series, Volume 2. U. S. Fish and Wildlife Service, Red Bluff, CA.

Martin, C.D., P.D. Gaines and R.R. Johnson. 2001. Estimating the abundance of Sacramento River juvenile winter Chinook Salmon with comparisons to adult escapement. Red Bluff Research Pumping Plant Report Series, Volume 5. U.S. Fish and Wildlife Service, Red Bluff, CA.

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

Mora, E. A., R.D. Battleson, S. T. Lindley, M. J. Thomas, R. Bellmar, L. J. Zarri, and A. P. Klimley. 2018. Estimating the Annual Spawning Run Size and Population Size of the Southern Distinct Population Segment of Green Sturgeon. Transactions of the American Fisheries Society 147:

Moyle, P. B. 2002. Inland fishes of California. University of California press. Berkeley, California.

Mundie, J.H. and R.E. Traber. 1983. Movements of Coho salmon Onchorhynchus kisutch fingerlings in a stream following marking with a vital stain. Canadian Journal of Fisheries and Aquatic Science 40:1318-1319.

National Marine Fisheries Service (NMFS). 2009. Biological Opinion and Conference Opinion on the Long-term Operations of the Central Valley Project and State Water Project. National Marine Fisheries Service Southwest Region. File no. 2008/09022.

National Marine Fisheries Service (NMFS). 2019. Biological Opinion on Long-term Operation of the Central Valley Project and State Water Project. National Marine Fisheries Service West Coast Region. File no. 2016-0069.

National Marine Fisheries Service (NMFS). 2020. Letter from Maria Rea (NMFS) to Ms. Kristin White (USBR) dated 2/3/2020. National Marine Fisheries Service signed 2019 Juvenile Production Estimate letter.

National Marine Fisheries Service (NMFS). 2021. Thiamine Deficiency in West Coast Salmon. NMFS Southwest Fisheries Science Center Report to the Pacific Fishery Management Council. Agenda Item E.1. Attachment 1. March 2021.

O'Farrell, M.R., W. H. Satterthwaite, A. N. Hendrix and M.S. Mohr. 2018. Alternative Juvenile Production Estimate (JPE) Forecast Approaches for Sacramento River Winter-Run Chinook Salmon. San Francisco Estuary & Watershed Science. Volume 16, Issue 4, Article 4. https://doi.org/10.15447/sfews.2018v16iss4art4

Poytress, W. R. 2007. Brood-year 2005 winter Chinook juvenile production indices with comparisons to juvenile production estimates derived from adult escapement. Report of U.S. Fish and Wildlife Service to California Bay-Delta Authority, San Francisco, CA.

Poytress, W. R., J. J. Gruber, F. D. Carrillo and S. D. Voss. 2014. Compendium Report of Red Bluff Diversion Dam Rotary Trap Juvenile Anadromous Fish Production Indices for Years 2002-2012. Report of U.S. Fish and Wildlife Service to California Department of Fish and Wildlife and US Bureau of Reclamation.

Poytress, W. R., J. J. Gruber, J. P. Van Eenennaam and M. Gard. 2015. Spatial and Temporal Distribution of Spawning Events and Habitat Characteristics of Sacramento River Green Sturgeon. Transactions of the American Fisheries Society, 144:6, 1129-1142.

Poytress, W. R. 2016. Brood-year 2014 winter Chinook juvenile production indices with comparisons to juvenile production estimates derived from adult escapement. Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation, Sacramento, CA.

Snider, B., B. Reavis, and S. Hamelburg, S. Croci, S. Hill, and E. Kohler. 1997. 1996 upper Sacramento River winter-run Chinook Salmon escapement survey. California Department of Fish and Game, Environmental Services Division, Sacramento, CA.

United States Bureau of Reclamation (USBR). 2019. Letter from Bureau of Reclamation, Central Valley Operations Office to Erik Ekdahl (CA State Water Resources Control Board) received 5/15/2019. 2019 Sacramento River Temperature Management Plan per Water Rights order 90-5.

United States Bureau of Reclamation (USBR). 2020. 2020 Seasonal Report for the Shasta Cold Water Pool Management. Central Valley Project, California-Great Basin Region.

United States Fish and Wildlife Service (USFWS). 1995. Working Paper on Restoration Needs. Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California, Vol. 2. Section 9. May, 1995. Prepared for the US Fish and Wildlife Service under the direction of the Anadromous Fish Restoration Program Core Group. Stockton, CA.

United States Fish and Wildlife Service (USFWS). 1997. Comprehensive Assessment and Monitoring Program (CAMP) Implementation Plan. March, 1997. Prepared by Central Valley Fish and Wildlife Restoration Program Office, Sacramento, CA. Prepared with technical assistance from Montgomery Watson, Jones & Stokes Associates, Inc., and CH2M Hill, Sacramento, CA.

United States Fish and Wildlife Service (USFWS). 2001. Final Restoration Plan for the Anadromous Fish Restoration Program. A plan to increase natural production of anadromous fish in the Central Valley of California. Prepared for the Secretary of the

Interior by the United States Fish and Wildlife Service with the assistance from the Anadromous Fish and Restoration Program Core Group under authority of the Central Valley Project Improvement Act.

United States Fish and Wildlife Service (USFWS). 2011. Upper Sacramento River winter Chinook Salmon carcass survey 2010 annual report. USFWS, Red Bluff Fish and Wildlife Office, Red Bluff, California.

Vogel, D.A. and K.R. Marine. 1991. Guide to upper Sacramento River Chinook Salmon life history. CH2M Hill for the U.S. Bureau of Reclamation Central Valley Project, Redding, CA.

Voss, S. D., and W. R. Poytress. 2019. Brood year 2017 juvenile salmonid production and passage indices at the Red Bluff Diversion Dam. Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation, Sacramento, CA.

Voss, S. D., and W. R. Poytress. 2020. Brood year 2018 juvenile salmonid production and passage indices at the Red Bluff Diversion Dam. Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation, Sacramento, CA.

Tables

Table 1.— Sampling effort, weekly passage estimates, median fork length (Med FL) and juvenile production indices (JPI's) for winter Chinook salmon passing Red Bluff Diversion Dam (RK 391) for the period 7/1/2019 through 6/30/2020 (brood year 2019). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 2.4-m diameter rotary-screw traps sampling 24 hours daily, 7 days per week. Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry-equivalents and include genetic corrections. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry to pre-smolt/smolt survival rate (46.5% or approximately 2.15:1; O'Farrell 2018).

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
27 (Jul)	0.93	268	34	0	-	268	34	268
28	1.00	444	34.5	0	-	444	34.5	444
29	1.00	1,242	34	0	-	1,242	34	1,242
30	1.00	7,522	34	0	-	7,522	34	7,522
31 (Aug)	1.00	13,558	34	0	-	13,558	34	13,558
32	1.00	27,983	34	0	-	27,983	34	27,983
33	0.86	72,797	34.5	0	-	72,797	34.5	72,797
34	0.96	172,223	35	404	47	172,628	35	173,093
35 (Sep)	1.00	274,214	35	1,147	47.5	275,361	35	276,680
36	0.89	299,634	35	1,093	48	300,726	35	301,983
37	0.89	231,250	35	1,291	48	232,541	35	234,026
38	0.93	359,909	35	2,544	49	362,453	35	365,379
39	0.75	350,080	35	11,849	51	361,928	35	375,555
40 (Oct)	0.82	272,911	35	20,445	52	293,356	35	316,869
41	0.68	236,327	36	80,164	54	316,491	36	408,686
42	0.75	365,325	36	88,697	55	454,022	36	556,031
43	0.61	253,652	36	105,571	55	359,223	37	480,637
44 (Nov)	0.79	86,119	36	79,713	54	165,832	45	257,507
45	1.00	17,220	36	34,690	55	51,910	51	91,806
46	1.00	5,810	37	36,109	56	41,920	55	83,448
47	1.00	1,280	45	56,864	58	58,144	58	123,542
48 (Dec)	0.64	237	45	49,960	60	50,197	60	107,654
49	0.70	0	-	117,302	61	117,302	61	252,207
50	0.88	0	-	22,307	65	22,307	65	47,962
51	0.84	0	-	7,785	67	7,785	67	16,738
52	0.73	0	-	9,721	69	9,721	69	20,900

Table 1 – (continued)

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
1 (Jan)	1.00	0	-	2,633	72	2,633	72	5,662
2	0.79	0	-	940	74	940	74	2,021
3	0.48	0	-	10,581	75.5	10,581	75.5	22,749
4	0.36	0	-	7,650	84	7,650	84	16,449
5 (Feb)	0.50	0	-	3,419	84	3,419	84	7,351
6	0.57	0	-	401	84.5	401	84.5	861
7	0.73	0	-	391	87	391	87	841
8	1.00	0	-	182	99.5	182	99.5	391
9 (Mar)	1.00	0	-	219	102	219	102	470
10	1.00	0	-	462	98	462	98	994
11	0.79	0	-	1,056	111	1,056	111	2,270
12	0.80	0	-	6,256	106	6,256	106	13,450
13	0.00	0	-	1,739	-	1,739	-	3,738
14 (Apr)	0.00	-	-	-	-	-	-	-
15	0.00	-	-	-	-	-	-	-
16	0.00	-	-	-	-	-	-	-
17	0.00	-	-	-	-	-	-	-
18 (May)	0.00	-	-	-	-	-	-	-
19	0.00	-	-	-	-	-	-	-
20	0.00	-	-	-	-	-	-	-
21	0.00	-	-	-	-	-	-	-
22 (Jun)	0.00	-	-	-	-	-	-	-
23	0.00	-	-	-	-	-	-	-
24	0.00	-	-	-	-	-	-	-
25	0.00	-	-	-	-	-	-	-
26	0.00	-	-	-	-	-	-	-
BY total		3,050,004		763,584		3,813,589		4,691,764
90% CI (low : high)		(1,734,019 : 4,365,990)		(400,423 : 1,126,745)		(2,152,984 :5,474,193)		(2,630,095 : 6,753,433)

Table 2— Sampling effort, weekly passage estimates, median fork length (Med FL) and juvenile production indices (JPI's) for spring Chinook salmon passing Red Bluff Diversion Dam (RK 391) for the period 10/16/2019 through 10/15/2020 (brood year 2019). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 2.4-m diameter rotary-screw traps sampling 24 hours daily, 7 days per week; shaded values indicate shift to four 1.5-m diameter and one 2.4-m diameter rotary-screw traps. Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry-equivalents with unmarked hatchery fish removed and genetic corrections. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry to pre-smolt/smolt survival rate (59% or approximately 1.7:1; Hallock undated).

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
42	0.75	0	-	0	-	0	-	0
43	0.61	0	-	0	-	0	-	0
44 (Nov)	0.79	0	-	0	-	0	-	0
45	1.00	0	-	0	-	0	-	0
46	1.00	0	-	0	-	0	-	0
47	1.00	4,038	35	0	-	4,038	35	4,038
48 (Dec)	0.64	8,675	34	0	-	8,675	34	8,675
49	0.70	14,746	36	479	46	15,225	36	15,561
50	0.88	5,127	37	456	47	5,583	37	5,902
51	0.84	745	39	455	50	1,199	40	1,518
52	0.73	194	39	585	48	779	47.5	1,189
1 (Jan)	1.00	266	43.5	260	55	526	47.5	708
2	0.79	0	-	627	50	627	50	1,066
3	0.48	0	-	4,486	48	4,486	48	7,626
4	0.36	0	-	6,144	53	6,144	53	10,445
5 (Feb)	0.50	0	-	1,599	53	1,599	53	2,719
6	0.57	0	-	2,348	57	2,348	57	3,991
7	0.73	0	-	1,378	60	1,378	60	2,342
8	1.00	0	-	1,224	62	1,224	62	2,082
9 (Mar)	1.00	0	-	1,942	65	1,942	65	3,302
10	1.00	0	-	5,041	69	5,041	69	8,569
11	0.79	0	-	16,791	72	16,791	72	28,545
12	0.80	0	-	63,978	74	63,978	74	108,763
13	0.00	0	-	19,859	-	19,859	-	33,760
14 (Apr)	0.00	-	-	-	-	-	-	-
15	0.00	-	-	-	-	-	-	-

Table 2—(continued)

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
16	0.00	-	-	-	-	-	-	-
17	0.00	-	-	-	-	-	-	-
18 (May)	0.00	-	-	-	-	-	-	-
19	0.00	-	-	-	-	-	-	-
20	0.00	-	-	-	-	-	-	-
21	0.00	-	-	-	-	-	-	-
22 (Jun)	0.00	-	-	-	-	-	-	-
23	0.00	-	-	-	-	-	-	-
24	0.00	-	-	-	-	-	-	-
25	0.00	-	-	-	-	-	-	-
26	0.00	-	-	-	-	-	-	-
27 (Jul)	0.93	0	-	0	-	0	-	0
28	1.00	0	-	0	-	0	-	0
29	1.00	0	-	0	-	0	-	0
30	1.00	0	-	0	-	0	-	0
31 (Aug)	1.00	0	-	0	-	0	-	0
32	1.00	0	-	0	-	0	-	0
33	0.86	0	-	0	-	0	-	0
34	0.96	0	-	0	-	0	-	0
35 (Sep)	0.93	0	-	0	-	0	-	0
36	0.70	0	-	0	-	0	-	0
37	0.70	0	-	0	-	0	-	0
38	0.71	0	-	0	-	0	-	0
39	0.63	0	-	0	-	0	-	0
40 (Oct)	0.68	0	-	0	-	0	-	0
41	0.54	0	-	0	-	0	-	0
BY total		33,791		127,653		161,444		250,801
90% CI (low : high)		(13,214 : 54,368)		(21,601 : 233,704)		(35,412 : 287,476)		(52,518 : 449,084)

Table 3.— Sampling effort, weekly passage estimates, median fork length (Med FL) and juvenile production indices (JPI's) for fall Chinook salmon passing Red Bluff Diversion Dam (RK 391) for the period 12/1/2019 through 11/30/2020 (brood year 2019). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 2.4-m diameter rotary-screw traps sampling 24 hours daily, 7 days per week; shaded values indicate shift to four 1.5-m diameter and one 2.4-m diameter rotary-screw traps. Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry-equivalents with unmarked hatchery fish removed. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry to pre-smolt/smolt survival rate (59% or approximately 1.7:1; Hallock undated).

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
48 (Dec)	0.64	1,105	33	0	-	1,105	33	1,105
49	0.70	85,310	33	0	-	85,310	33	85,310
50	0.88	43,254	34	0	-	43,254	34	43,254
51	0.84	42,213	35	0	-	42,213	35	42,213
52	0.73	219,732	35	0	-	219,732	35	219,732
1 (Jan)	1.00	212,173	36	0	-	212,173	36	212,173
2	0.79	333,077	36	0	-	333,077	36	333,077
3	0.48	1,544,641	36	170	46	1,544,811	36	1,544,930
4	0.36	2,618,705	36	2,645	47	2,621,350	36	2,623,201
5 (Feb)	0.50	798,439	36	2,721	47	801,160	36	803,065
6	0.57	455,199	36	2,501	49	457,699	36	459,450
7	0.73	241,061	36	1,746	48	242,808	36	244,030
8	1.00	182,586	36	2,601	51	185,187	36	187,008
9 (Mar)	1.00	90,656	36	2,548	52	93,205	36	94,988
10	1.00	22,475	36	8,934	55	31,409	37	37,663
11	0.79	10,656	36	32,220	57	42,876	54	65,430
12	0.80	42,985	38	146,881	57	189,865	56	292,682
13	0.00	27,904	-	42,174	-	70,078	-	99,600
14 (Apr)	0.00	-	-	-	-	-	-	-
15	0.00	-	-	-	-	-	-	-
16	0.00	-	-	-	-	-	-	-
17	0.00	-	-	-	-	-	-	-
18 (May)	0.00	-	-	-	-	-	-	-
19	0.00	-	-	-	-	-	-	-
20	0.00	-	-	-	-	-	-	-
21	0.00	-	-	-	-	-	-	-

Table 3—(continued)

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
22 (Jun)	0.00	-	-	-	-	-	-	-
23	0.00	-	-	-	-	-	-	-
24	0.00	-	-	-	-	-	-	-
25	0.00	-	-	-	-	-	-	-
26	0.00	-	-	-	-	-	-	-
27 (Jul)	0.93	0	-	43,047	81	43,047	81	73,179
28	1.00	0	-	32,195	81	32,195	81	54,732
29	1.00	0	-	11,511	83	11,511	83	19,569
30	1.00	0	-	6,078	80.5	6,078	80.5	10,333
31 (Aug)	1.00	0	-	8,592	88	8,592	88	14,607
32	1.00	0	-	4,571	89	4,571	89	7,771
33	0.86	0	-	788	94	788	94	1,339
34	0.96	0	-	451	94	451	94	767
35 (Sep)	0.93	0	-	531	103	531	103	903
36	0.70	0	-	258	106	258	106	439
37	0.70	0	-	148	116	148	116	252
38	0.71	0	-	0	-	0	-	0
39	0.63	0	-	115	121	115	121	196
40 (Oct)	0.68	0	-	230	127	230	127	391
41	0.54	0	-	94	134.5	94	134.5	159
42	0.63	0	-	650	135.5	650	135.5	1,105
43	0.50	0	-	44	130	44	130	74
44 (Nov)	0.73	0	-	91	140.5	91	140.5	155
45	1.00	0	-	88	148	88	148	149
46	1.00	0	-	0	-	0	-	0
47	1.00	0	-	89	164	89	164	151
BY total		6,972,169		354,713		7,326,883		7,575,182
90% CI (low : high)		(2,514,680 : 11,429,658)		(108,523 : 600,903)		(2,635,708 : 12,018,057)		(2,718,701 : 12,431,662)

Table 4.— Sampling effort, weekly passage estimates, median fork length (Med FL) and juvenile production indices (JPI's) for late-fall Chinook salmon passing Red Bluff Diversion Dam (RK 391) for the period 4/1/2019 through 3/31/2020 (brood year 2019). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 2.4-m diameter rotary-screw traps sampling 24 hours daily, 7 days per week. Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry-equivalents. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry to pre-smolt/smolt survival rate (59% or approximately 1.7:1; Hallock undated).

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
14 (Apr)	0.50	16,937	34	0	-	16,937	34	16,937
15	0.25	25,972	34.5	0	-	25,972	34.5	25,972
16	0.70	40,725	35	0	-	40,725	35	40,725
17	0.77	6,603	35	0	-	6,603	35	6,603
18 (May)	0.57	1,056	34	0	-	1,056	34	1,056
19	0.89	108	34	0	-	108	34	108
20	0.64	116	33	0	-	116	33	116
21	0.82	47	39	0	-	47	39	47
22 (Jun)	0.43	0	-	0	-	0	-	0
23	0.75	0	-	0	-	0	-	0
24	1.00	44	40	0	-	44	40	44
25	1.00	0	-	0	-	0	-	0
26	0.82	505	40	0	-	505	40	505
27 (Jul)	0.93	186	40	0	-	186	40	186
28	1.00	169	37	42	64	212	37	241
29	1.00	43	38	181	66	223	63	350
30	1.00	0	-	140	66	140	66	238
31 (Aug)	1.00	43	45	176	68	219	65	342
32	1.00	0	-	92	72	92	72	156
33	0.86	0	-	310	69.5	310	69.5	527
34	0.96	0	-	1,687	64.5	1,687	64.5	2,869
35 (Sep)	1.00	0	-	609	57.5	609	57.5	1,035
36	0.89	0	-	739	54.5	739	54.5	1,256
37	0.89	0	-	929	65	929	65	1,580
38	0.93	0	-	1,505	64	1505	64	2,558
39	0.75	0	-	3,810	66	3,810	66	6,477

Table 4—(continued)

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
40 (Oct)	0.82	0	-	3,689	70	3,689	70	6,271
41	0.68	0	-	14,418	71	14,418	71	24,511
42	0.75	0	-	7,567	74.5	7,567	74.5	12,864
43	0.61	0	-	8,393	76	8,393	76	14,268
44 (Nov)	0.79	0	-	2,378	79	2,378	79	4,043
45	1.00	0	-	1,184	90	1,184	90	2,012
46	1.00	0	-	679	106.5	679	106.5	1,155
47	1.00	0	-	1,014	109	1,014	109	1,724
48 (Dec)	0.64	0	-	1,236	109	1,236	109	2,102
49	0.70	0	-	5,632	119	5,632	119	9,575
50	0.88	0	-	1,298	125.5	1,298	125.5	2,206
51	0.84	0	-	864	121	864	121	1,470
52	0.73	0	-	738	124.5	738	124.5	1,255
1 (Jan)	1.00	0	-	152	135	152	135	258
2	0.79	0	-	69	134.5	69	134.5	117
3	0.48	0	-	0	-	0	-	0
4	0.36	0	-	0	-	0	-	0
5 (Feb)	0.50	0	-	0	-	0	-	0
6	0.57	0	-	0	-	0	-	0
7	0.73	0	-	0	-	0	-	0
8	1.00	0	-	0	-	0	-	0
9 (Mar)	1.00	0	-	0	-	0	-	0
10	1.00	0	-	0	-	0	-	0
11	0.79	0	-	0	-	0	-	0
12	0.80	0	-	0	-	0	-	0
13	0.00	0	-	0	-	0	-	0
BY total		92,555		59,531		152,086		193,758
90% CI (low : high)		(-5,433 : 190,543)		(23,303 : 95,760)		(18,080 : 286,093)		(37,292 : 350,225)

Table 5.— Sampling effort, weekly passage estimates and median fork length (Med FL) for *O. mykiss* passing Red Bluff Diversion Dam (RK 391) for the period 1/1/2019 through 12/31/2019 (brood year 2019). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 2.4-m diameter rotary-screw traps sampling 24 hours daily, 7 days per week. Results include total estimated passage (fry, sub-yearling and yearlings combined).

Week	Sampling Effort	Total Est. passage	Total Med FL	Week (cont.)	Sampling Effort (cont.)	Total Est. passage (cont.)	Total Med FL (cont.)
1 (Jan)	0.36	0	-	27 (Jul)	0.93	239	26
2	0.36	99	169.5	28	1.00	216	67
3	0.16	0	-	29	1.00	270	66.5
4	0.43	0	-	30	1.00	580	66
5 (Feb)	0.29	0	-	31 (Aug)	1.00	484	59
6	0.71	87	101	32	1.00	543	55.5
7	0.43	0	-	33	0.86	526	61
8	1.00	28	181	34	0.96	718	55
9 (Mar)	0.00	0	-	35 (Sep)	1.00	983	58
10	0.00	0	-	36	0.89	612	57
11	0.00	0	-	37	0.89	134	63.5
12	0.84	0	-	38	0.93	172	64
13	0.21	0	-	39	0.75	118	63.5
14 (Apr)	0.50	0	-	40 (Oct)	0.82	129	87
15	0.25	0	-	41	0.68	110	81
16	0.70	0	-	42	0.75	126	86
17	0.77	5,385	60	43	0.61	68	83
18 (May)	0.57	3,178	63	44 (Nov)	0.79	114	84
19	0.89	1,235	68.5	45	1.00	53	78.5
20	0.64	1,265	67.5	46	1.00	80	89
21	0.82	1,189	72	47	1.00	24	148.5
22 (Jun)	0.43	1,109	72.5	48 (Dec)	0.64	0	-
23	0.75	198	46.5	49	0.70	803	123.5
24	1.00	716	75	50	0.88	519	179
25	1.00	403	69	51	0.84	1432	78
26	0.82	483	73.5	52	0.73	45	92
				BY total		24,472	
				90% CI (low : high)		(5,950 : 42,995)	

Table 6.—Summary of results from mark-recapture trials conducted in 2019 (*N* = 15) to evaluate rotary-screw trap efficiency at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Results include the run of Chinook salmon used, number of fish released, mean fork length at release (Release FL), number recaptured, mean fork length at recapture (Recapture FL), combined trap efficiency (TE%), percent river volume sampled by rotary-screw traps (%Q), number of traps sampling during trials, and modification status as to whether or not traps were structurally modified to reduce volume sampled by 50% (Traps modified).

Trial#	Year	Run	Number Released	Release FL (mm)	Number Recaptured	Recapture FL (mm)	TE (%)	%Q	Number of traps sampling	Traps modified
1	2019	winter	889	35.1	26	34.9	2.92	2.05	3	No
2	2019	winter	962	35.2	23	35.0	2.39	2.15	3	No
3	2019	winter	1,031	35.4	27	35.3	2.62	1.81	3	Yes
4	2019	winter	1,018	34.9	32	35.3	3.14	1.80	3	Yes
5	2019	winter	1,044	35.5	28	35.5	2.68	2.55	3	No
6	2019	winter	955	35.7	17	35.9	1.78	2.11	3	Yes
7	2019	winter	1,127	36.0	17	35.9	1.51	2.05	3	Yes
8	2019	winter	940	36.6	35	38.3	3.72	2.82	3	No
9	2019	winter	947	40.3	17	39.6	1.80	2.08	3	Yes
10	2019	winter	617	53.0	13	49.8	2.11	3.42	3	No
11	2020	fall	1,168	35.4	62	36.0	5.31	3.90	4	No
12	2020	fall	1,745	35.9	28	35.9	1.60	1.83	4	Yes
13	2020	fall	1,717	36.2	23	35.6	1.34	1.85	4	Yes
14	2020	fall	1,743	36.8	41	36.4	2.35	2.59	4	Yes
15	2020	fall	1,087	36.7	37	36.2	3.40	4.31	4	No

Table 7.— Winter Chinook fry-equivalent juvenile production indices (JPI), lower and upper 90% confidence intervals (CI), estimated adult female spawners above RBDD (Estimated Females), estimates of female fecundity, calculated juveniles per estimated female (Estimated Recruits/Female) and egg-to-fry survival estimates (ETF) with associated lower and upper 90% confidence intervals (L90 CI : U90 CI) by brood year (BY) for Chinook sampled at RBDD rotary traps between July 2002 and June 2020.

BY	Fry Equivalent JPI	Lower 90% CI	Upper 90% CI	Estimated Females[1]	Fecundity[2]	Estimated Recruits/Female	ETF Survival Rate (%)	L90 CI : U90 CI
2002	7,635,469	2,811,132	13,144,325	5,670	4,923	1,347	27.4	(10.1 : 47.1)
2003	5,781,519	3,525,098	8,073,129	5,179	4,854	1116	23.0	(14.0 : 32.1)
2004	3,677,989	2,129,297	5,232,037	3,185	5,515	1155	20.9	(12.1 : 29.8)
2005	8,943,194	4,791,726	13,277,637	8,807	5,500	1,015	18.5	(9.9 : 27.4)
2006	7,298,838	4,150,323	10,453,765	8,626	5,484	846	15.4	(8.8 : 22.1)
2007	1,637,804	1,062,780	2,218,745	1,517	5,112	1,080	21.1	(13.7 : 28.6)
2008	1,371,739	858,933	1,885,141	1,443	5,424	951	17.5	(11.0 : 24.1)
2009	4,972,954	2,790,092	7,160,098	2,702	5,519	1,840	33.5	(18.7 : 48.0)
2010	1,572,628	969,016	2,181,572	813	5,161	1,934	37.5	(23.1 : 52.0)
2011	996,621	671,779	1,321,708	424	4,832	2,351	48.6	(32.8 : 64.5)
2012	1,814,244	1,227,386	2,401,102	1,491	4,518	1,217	26.9	(18.2 : 35.6)
2013	2,481,324	1,539,193	3,423,456	3,577	4,596	694	15.1	(9.4 : 20.8)
2014	523,872	301,197	746,546	1,681	5,308	312	5.9	(3.4 : 8.4)
2015	440,951	288,911	592,992	2,022	4,819	218	4.5	(3.0 : 6.1)
2016	640,149	429,876	850,422	653	4,131	980	23.7	(15.9 : 31.5)
2017	734,432	471,292	997,572	367	4,109	2,001	48.7	(31.3 : 66.2)
2018	1,477,529	824,706	2,130,352	1,080	5,141	1,368	26.6	(14.9 : 38.4)
2019	4,691,764	2,630,095	6,753,433	4,884	5,424	961	17.7	(9.9 : 25.5)
					Average	1,188	24.0	(14.4 : 33.8)
					Standard Deviation	559	12.1	(8.1 : 16.6)

[1]Estimated females derived from carcass survey data; includes annual estimates of pre-spawn mortality.

[2]Female fecundity estimates typically based on annual average values from LSNFH winter Chinook spawning data. The exception being 2016 and 2017 values based on total egg deposition by size class (See Voss and Poytress 2019).

Table 8.— Fall Chinook fry-equivalent juvenile production indices (JPI), lower and upper 90% confidence intervals (CI), estimated adult female spawners above RBDD (Estimated Females), estimates of female fecundity, calculated juveniles per estimated female (Estimated Recruits/Female) and egg-to-fry survival estimates (ETF) with associated lower and upper 90% confidence intervals (L90 CI : U90 CI) by brood year (BY) for Chinook sampled at RBDD rotary traps between December 2002 and November 2020. Brood years 2006 through 2019 include estimates with unmarked hatchery fish removed to reduce bias to JPI estimates.

BY	Fry Equivalent JPI	Lower 90% CI	Upper 90% CI	Estimated Females[1]	Fecundity[2]	Estimated Recruits/Female	ETF Survival Rate (%)	L90 CI : U90 CI
2002	18,683,720	1,216,244	51,024,926	211,035	5,407	89	1.6	(0.1 : 4.5)
2003	30,624,209	10,162,712	55,109,506	79,509	5,407	385	7.1	(2.4 : 12.8)
2004	18,421,457	6,224,790	33,728,746	31,045	5,407	593	11.0	(3.7 : 20.1)
2005	22,739,315	4,235,720	49,182,045	37,738	5,407	603	11.1	(2.1 : 24.1)
2006	19,586,600	7,629,345	31,543,855	42,730	5,407	458	8.5	(3.3 : 13.7)
2007	12,822,401	6,546,684	19,098,118	16,996	5,407	754	14.0	(7.1 : 20.8)
2008	9,371,141	4,750,252	13,992,030	16,644	5,362	563	10.5	(5.3 : 15.7)
2009	8,498,417	3,071,022	13,925,813	6,531	5,318	1,301	24.5	(8.8 : 40.1)
2010	9,119,714	4,552,856	13,686,573	7,008	5,167	1,301	25.2	(12.6 : 37.8)
2011	6,457,455	3,490,844	9,424,066	9,260	5,945	697	11.7	(6.3 : 17.1)
2012	24,659,091	16,408,286	32,909,895	32,635	5,242	756	14.4	(9.6 : 19.2)
2013	33,201,448	5,766,067	60,636,829	39,422	5,390	842	15.6	(2.7 : 28.5)
2014	4,387,348	2,407,113	6,367,583	35,345	5,453	124	2.3	(1.2 : 3.3)
2015	19,406,341	214,690	38,597,991	23,302	4,971	833	16.8	(0.2 : 33.3)
2016	9,886,303	-2,666,309	22,438,916	5,240	4,778	1,887	39.5	(-10.6 : 89.6)
2017	1,723,831	980,638	2,467,025	4,437	4,455	389	8.7	(5.0 : 12.5)
2018	6,837,157	1,108,574	12,565,741	11,631	5,442	588	10.8	(1.8 : 19.9)
2019	7,575,182	2,718,701	12,431,662	24,421	4,815	310	6.4	(2.3 : 10.6)
					Average	693	13.3	(3.5 : 23.5)
					Standard Deviation	443	9.0	(4.9 : 19.4)

[1]Estimated females derived from carcass survey; sex ratios used to determine female spawners based on RBDD fish ladder data between 2003 and 2007 and CNFH data between 2008 and 2018.
[2]Female fecundity estimates for years 2002 thru 2007 based on average values from CNFH fall Chinook spawning data collected between 2008 and 2012 (Poytress 2014).
[3]2019 included a prolonged cessation of sampling from 3/25/2020 to 6/30/2020 due to the COVID-19 pandemic.

Table 9.— Green Sturgeon annual capture, catch per unit volume (CPUV; fish /acre-ft) and total length (mm) summaries for sturgeon captured by RBDD rotary traps between calendar year 2013 and 2019.

Year	Catch	CPUV	Min TL	Max TL	Mean	Median
2013	443	2.9	20	45	28.5	27
2014	319	3.5	21	246	29.1	27
2015	515	3.4	21	54	29.7	29
2016	2871	31.0	20	312	31.3	28
2017	4927	30.3	17	261	29.6	27
2018	79	0.7	21	317	38.7	26
2019	4303	22.2	17	116	28.1	27
Mean	1922.4	13.4	19.6	193.0	30.7	27.3
SD	2071.0	13.8	1.8	118.4	3.7	1.0
CV	107.7%	102.8%	9.3%	61.4%	11.9%	3.5%

Table 10.— Unidentified Lamprey ammocoetes annual capture, catch per unit volume (CPUV; fish /acre-ft) and total length (mm) summaries for ammocoetes captured by RBDD rotary traps between water year (WY) 2014 and 2020. WY2020 included non-sampling period from 3/25/2020 to 6/30/2020 due to the COVID-19 pandemic.

WY	Catch	CPUV	Min TL	Max TL	Mean	Median
2014	203	3.3	46	166	100	103
2015	826	6.3	13	142	97	102
2016	1644	19.3	21	165	104	109
2017	4934	34.2	8	198	93	94
2018	2954	76.0	10	175	86	87
2019	3006	34.5	6	177	89	90
2020	929	22.4	38	148	90	91
Mean	2070.9	28.0	20.3	167.3	94.0	96.6
SD	1652.1	24.4	15.8	18.8	6.6	8.1
CV	79.8%	87.2%	77.7%	11.2%	7.0%	8.4%

Table 11.— Pacific Lamprey macropthalmia and adult annual capture, catch per unit volume (CPUV; fish /acre-ft) and total length (mm) summaries for macropthalmia captured by RBDD rotary traps between water year (WY) 2014 and 2020. WY2020 included non-sampling period from 3/25/2020 to 6/30/2020 due to the COVID-19 pandemic.

WY	Catch	CPUV	Min TL	Max TL	Mean	Median
2014	1051	88.0	85	560	137	126
2015	78	0.9	40	490	165	128
2016	2858	105.8	98	590	130	123
2017	579	9.4	80	512	141	119
2018	4798	265.1	80	567	125	118
2019	210	4.5	76	511	128	122
2020	3396	92.7	42	160	118	118
Mean	1852.9	80.9	71.6	484.3	135.0	122.0
SD	1834.0	93.2	22.0	147.4	15.2	4.0
CV	99.0%	115.2%	30.8%	30.4%	11.3%	3.2%

Figures

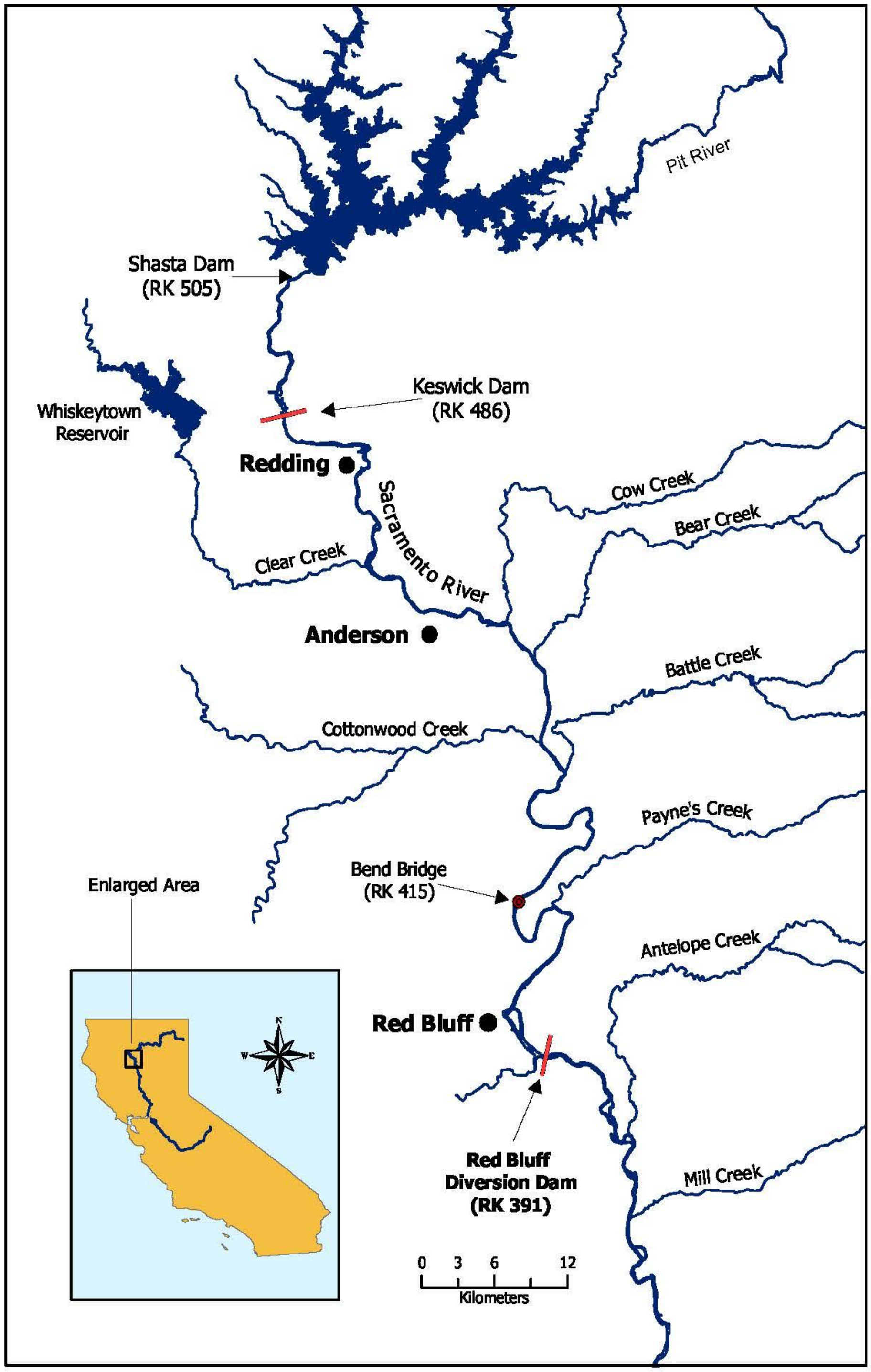


Figure 1. Location of Red Bluff Diversion Dam sample site on the Sacramento River, California, at river kilometer 391 (RKM 391)

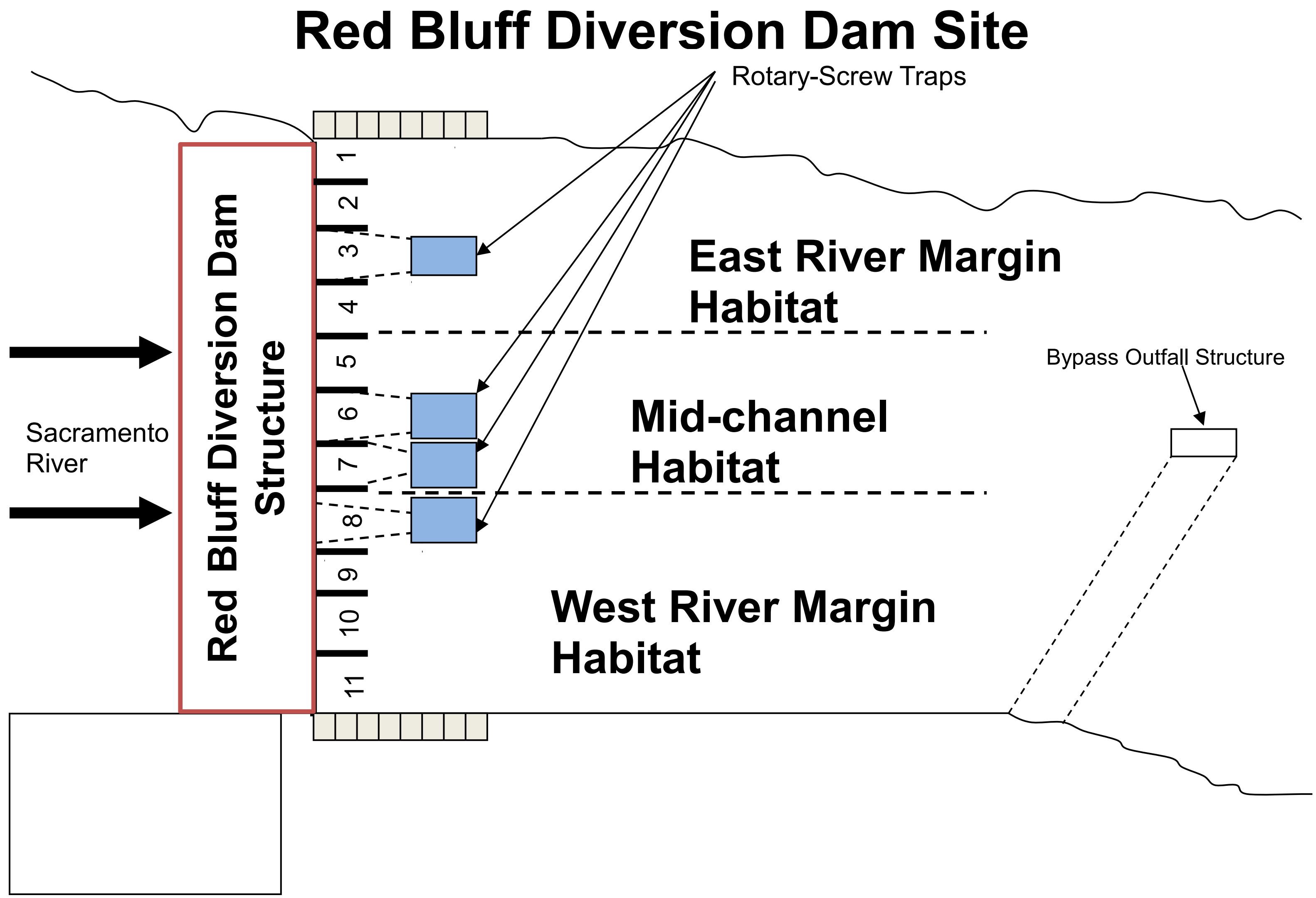


Figure 2. Rotary-screw trap sampling transect schematic of Red Bluff Diversion Dam site (RK 391) on the Sacramento River, CA.

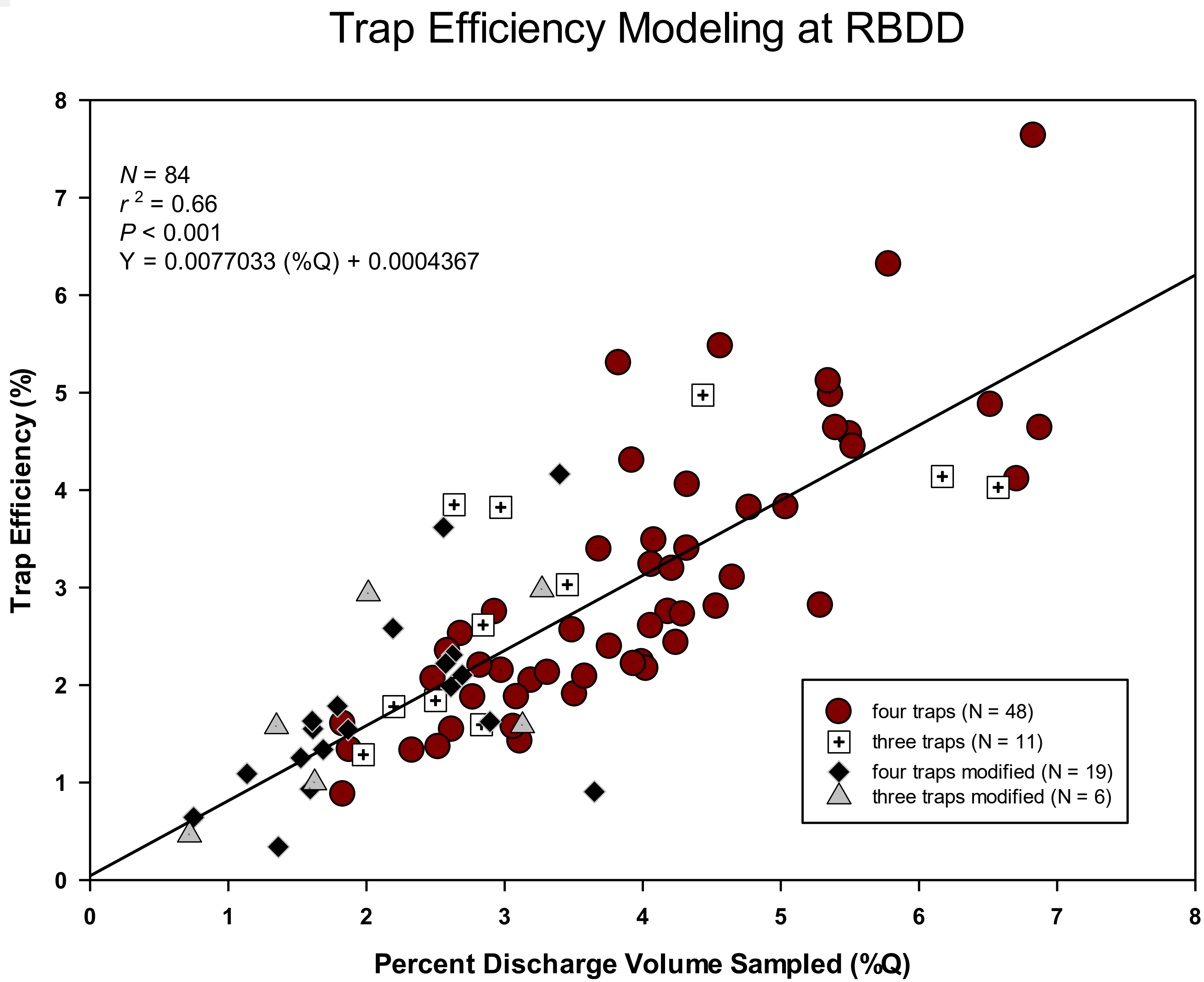


Figure 3. Trap Efficiency model for combined 2.4 m diameter rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four traps (N=48), three traps (N=11), or with traps modified to sample one-half the normal volume of water (N=25).

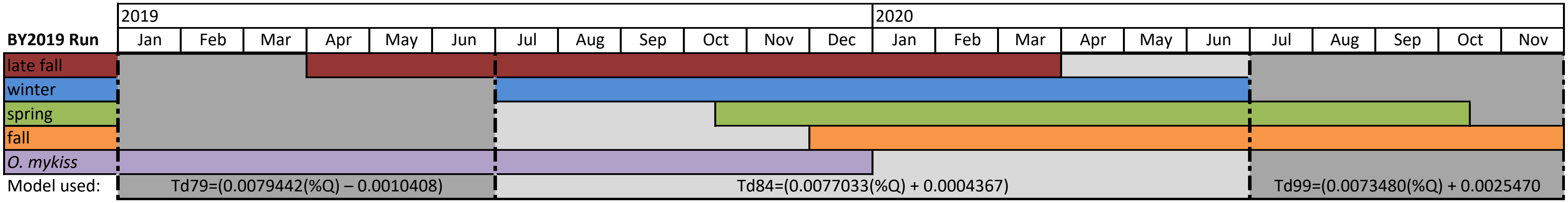


Figure 4.—Summary of trap efficiency models used for passage estimates during brood year 2019 for juvenile winter, spring, fall, late-fall Chinook salmon and *O. mykiss* from 01/01/2019, the start of the *O. mykiss* 2019 brood year through 11/30/2020, the end of the 2019 fall Chinook brood year.

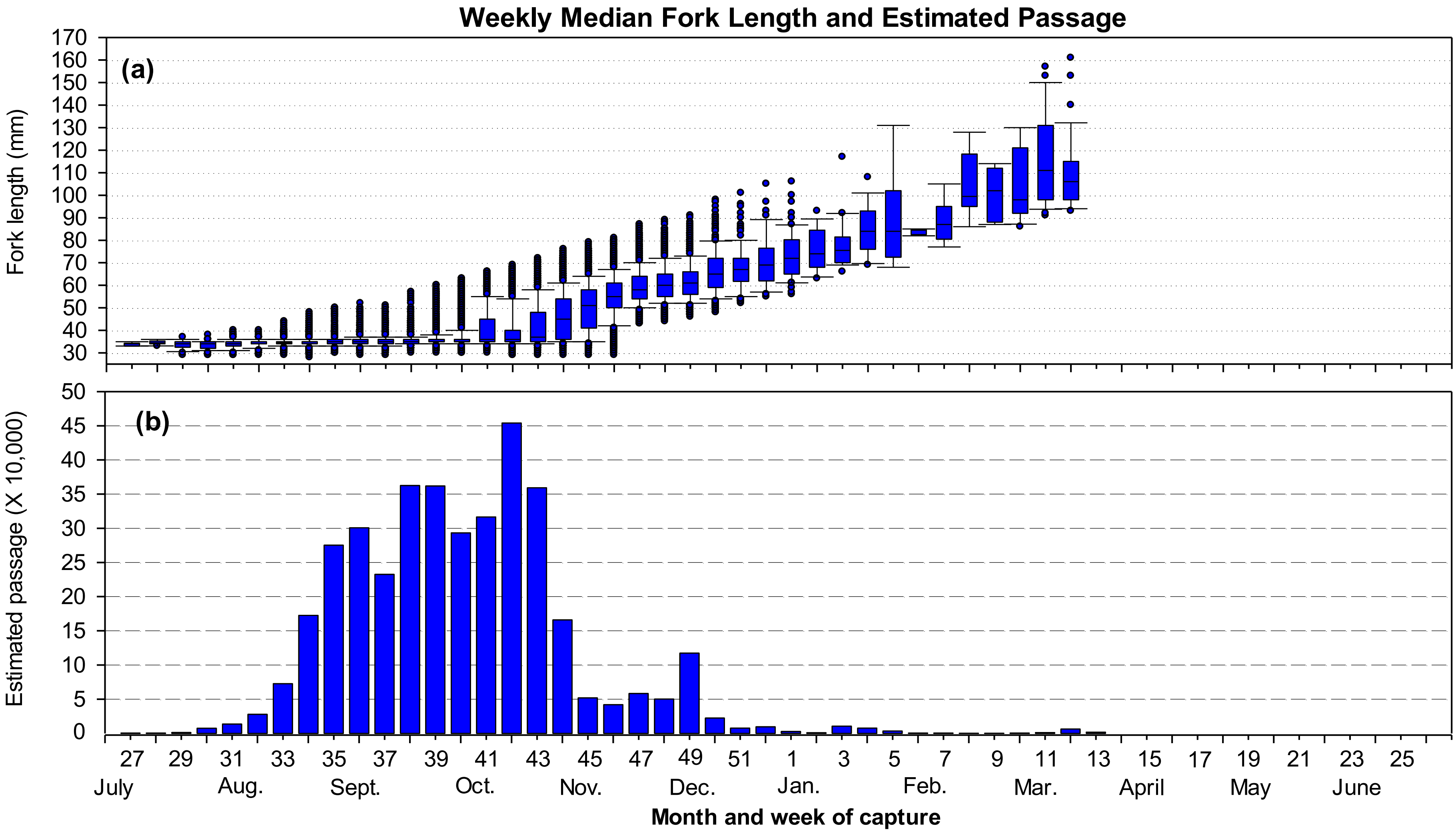


Figure 5. Weekly median fork length (a) and estimated passage (b) of brood year 2019 juvenile winter Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Winter Chinook salmon were sampled by rotary-screw traps for the period 7/1/2019 through 6/30/2020. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers. Shaded region represents cease to sampling due to COVID-19 pandemic from 3/25/2020-6/30/2020.

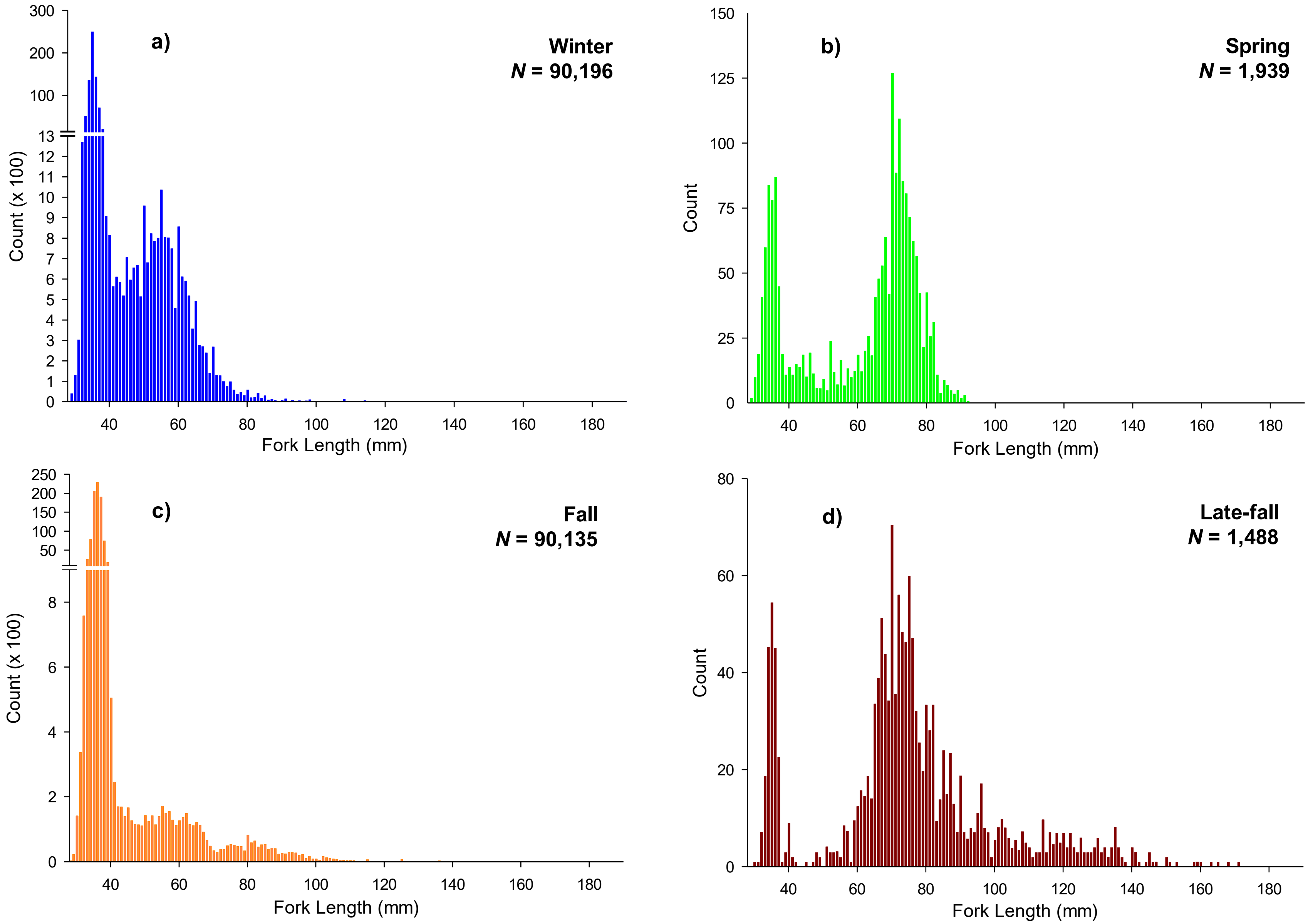


Figure 6. Fork length frequency distribution of brood year 2019 juvenile a) winter, b) spring, c) fall and d) late-fall Chinook salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fork length data were expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from 4/1/2019 through 11/30/2020; a cease to sampling occurred from 3/25/2020-6/30/2020 due to COVID-19.

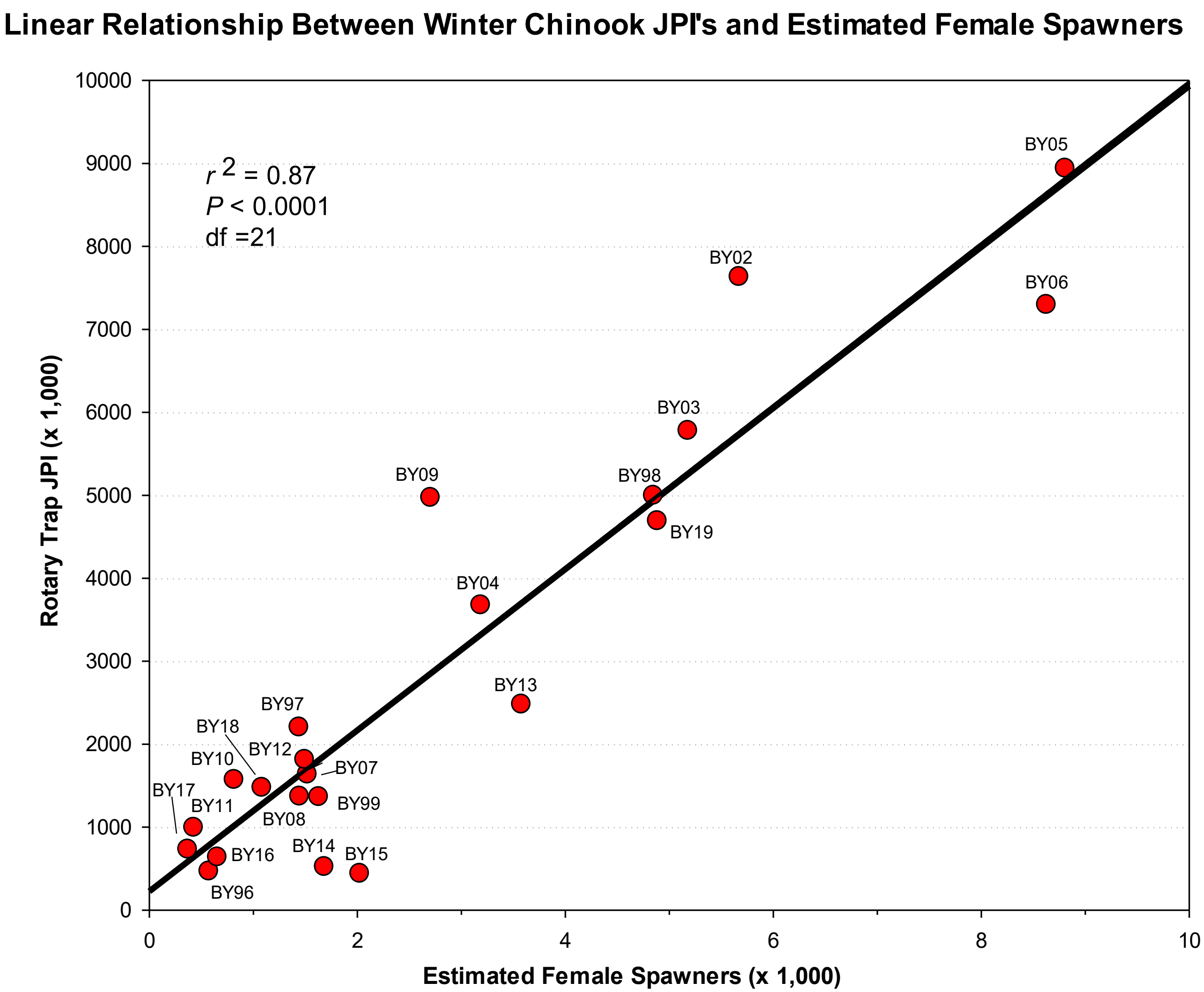


Figure 7. Linear relationship between rotary-screw trap juvenile winter Chinook fry-equivalent production indices (Rotary Trap JPI) and carcass survey derived estimated female spawners.

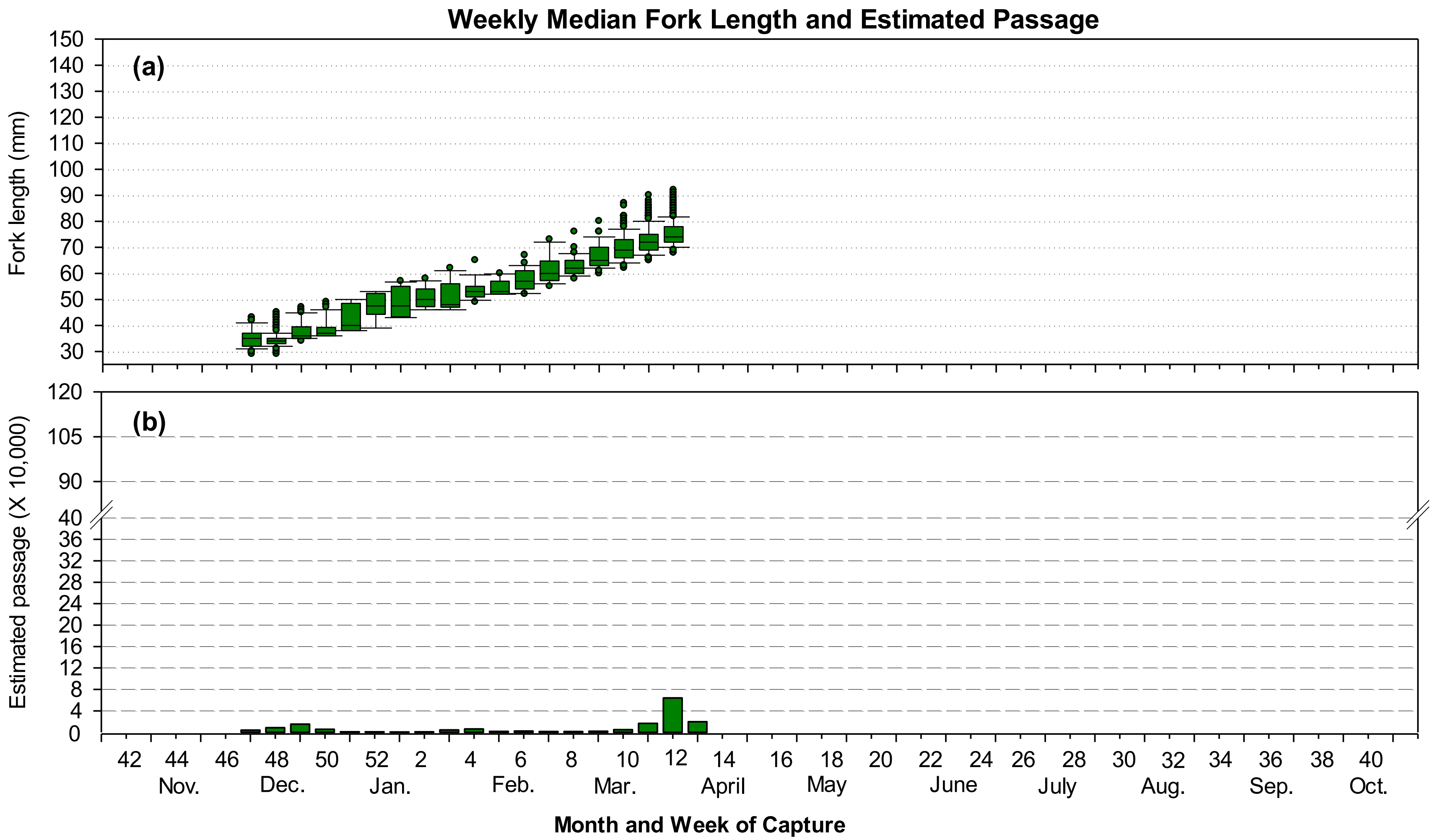


Figure 8. Weekly median fork length (a) and estimated passage (b) of brood year 2019 juvenile spring Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Spring Chinook salmon were sampled by rotary-screw traps for the period 10/16/2019 through 10/15/2020. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers. Shaded region represents cease to sampling due to COVID-19 pandemic from 3/25/2020-6/30/2020.

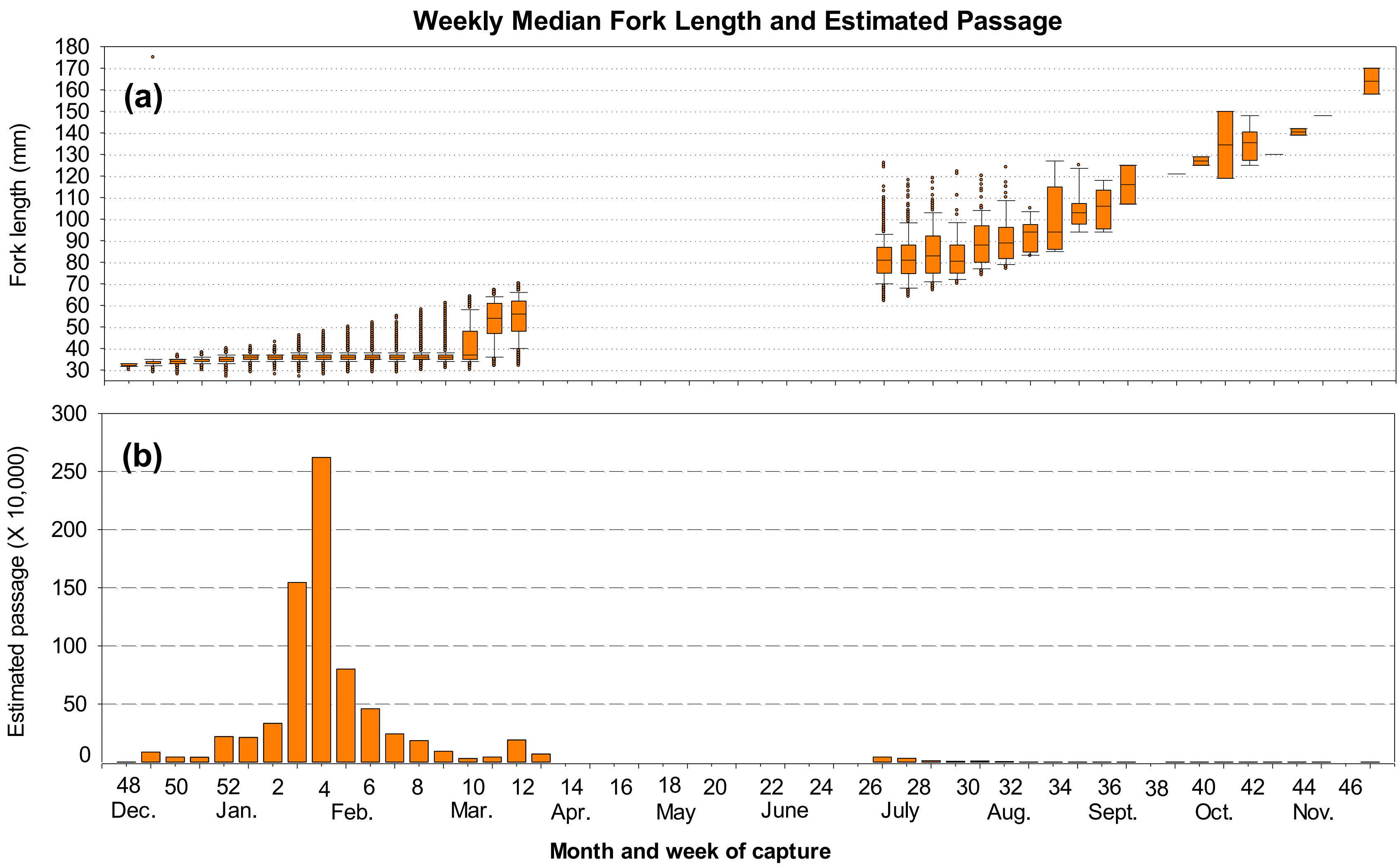


Figure 9. Weekly median fork length (a) and estimated passage (b) of brood year 2019 juvenile fall Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fall Chinook salmon were sampled by rotary-screw traps for the period 12/1/2019 through 11/30/2020. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers. Shaded region represents cease to sampling due to COVID-19 pandemic from 3/25/2020-6/30/2020.

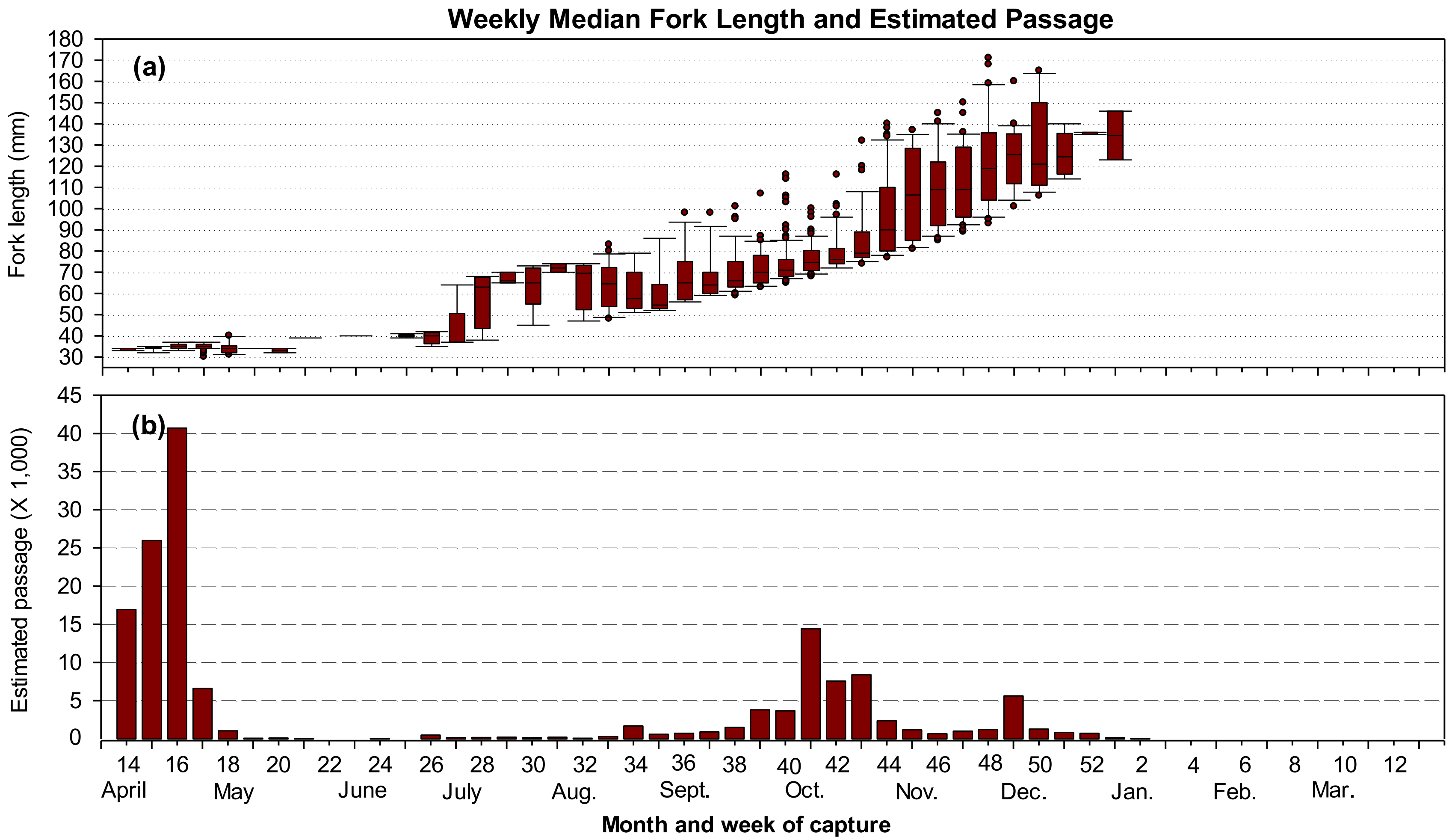


Figure 10. Weekly median fork length (a) and estimated passage (b) of brood year 2019 juvenile late-fall Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Late-fall Chinook salmon were sampled by rotary-screw traps for the period 4/1/2019 through 3/31/2020. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers. Shaded region represents cease to sampling due to COVID-19 pandemic from 3/25/2020-6/30/2020.

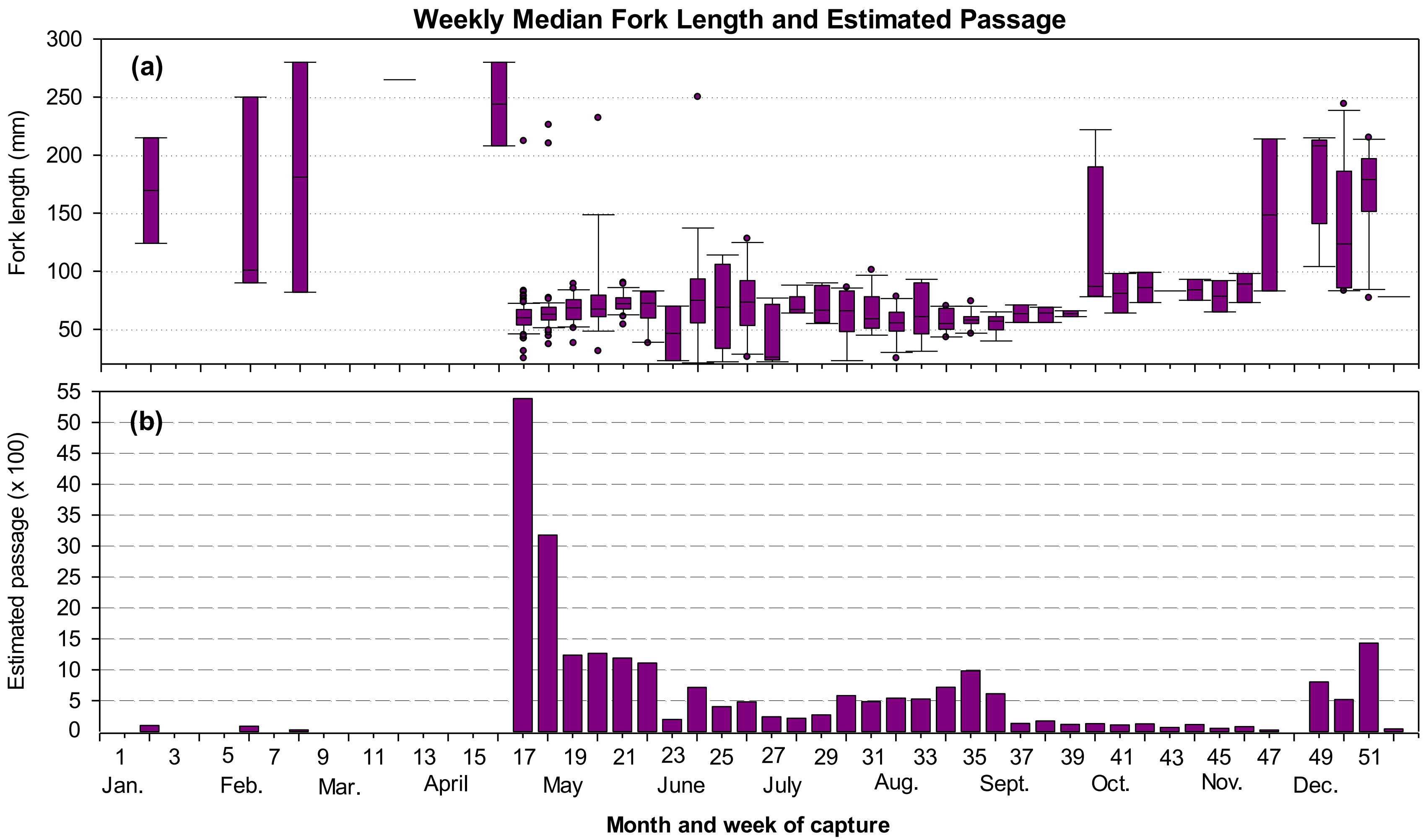


Figure 11. Weekly median fork length (a) and estimated passage (b) of brood year 2019 juvenile *O. mykiss* passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. *O. mykiss* were sampled by rotary-screw traps for the period 1/1/2019 through 12/31/2019. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

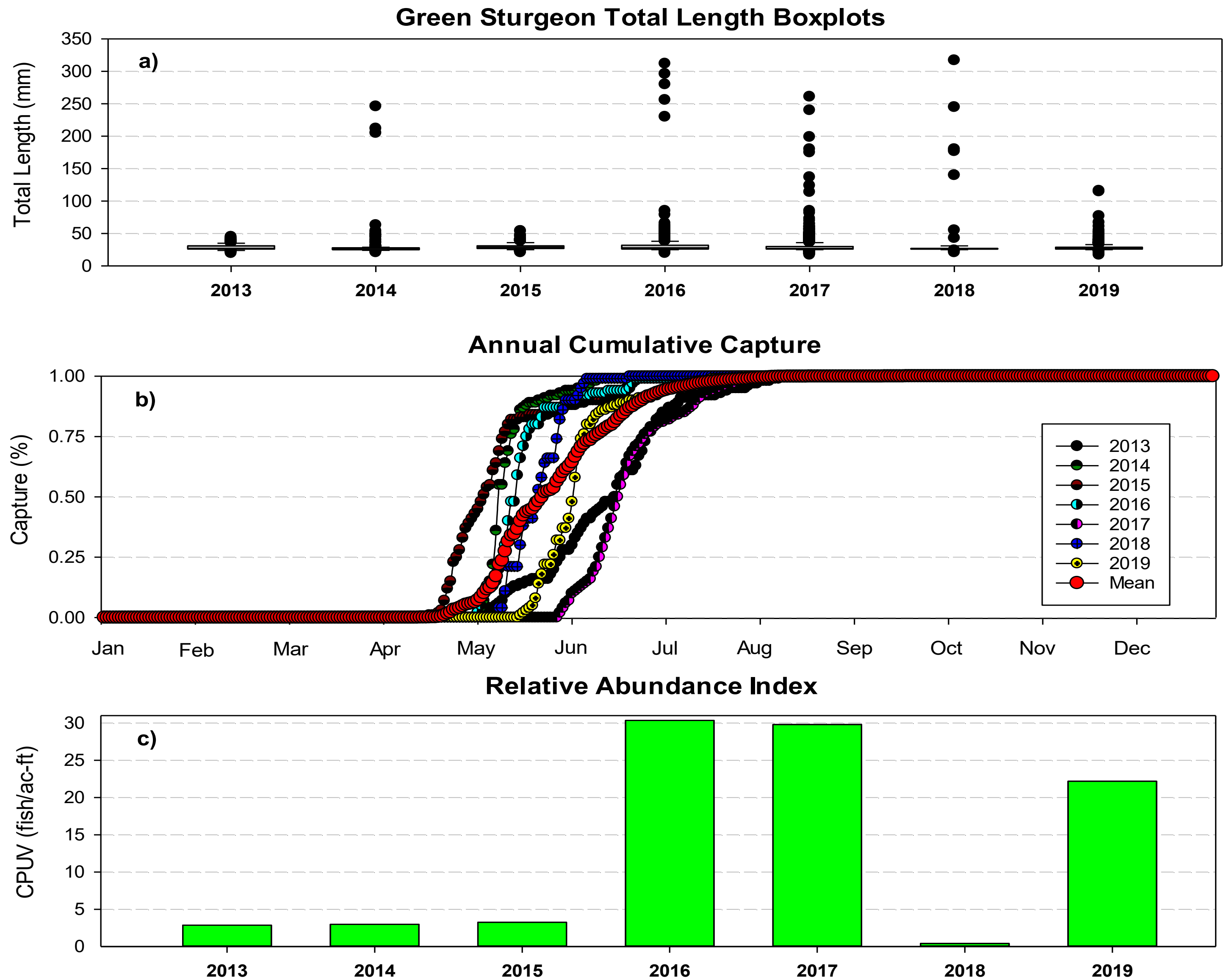


Figure 12. Green Sturgeon a) annual total length capture boxplots, b) annual cumulative capture trends with 17-year mean trend line, and c) relative abundance indices. All fish captured by rotary trap at RBDD (RK 391) on the upper Sacramento River, CA between 2013 and 2019.

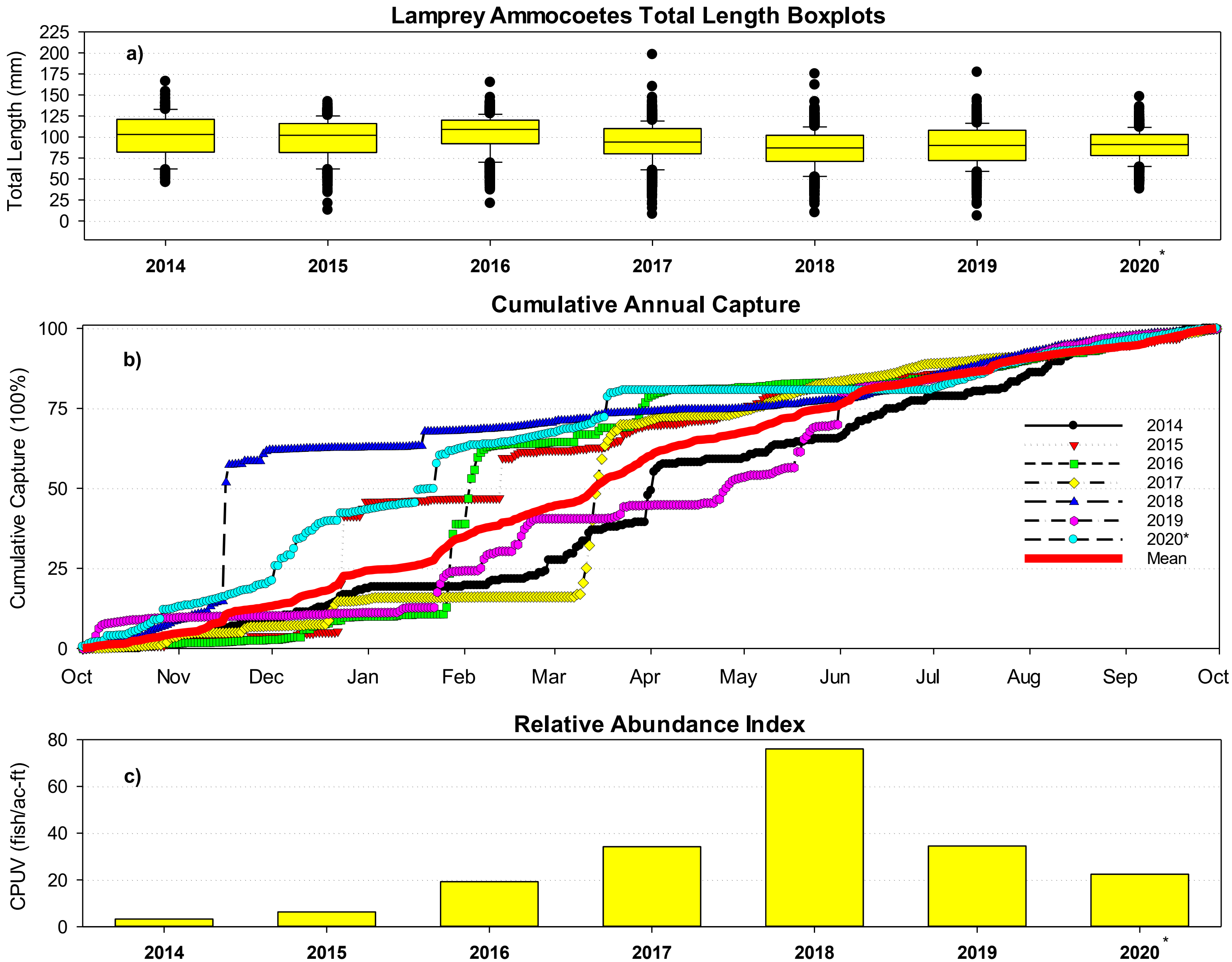


Figure 13. Unidentified lamprey ammocoetes a) total length distribution box plots, b) cumulative annual capture trends, and c) relative abundance indices from rotary traps collected between 10/1/2013 and 9/30/2020 by water year from the Sacramento River, CA at the RBDD (RK 391). *Water year 2020 included a prolonged cessation of sampling from 3/25/2020 to 6/30/2020 due to the COVID-19 global pandemic.

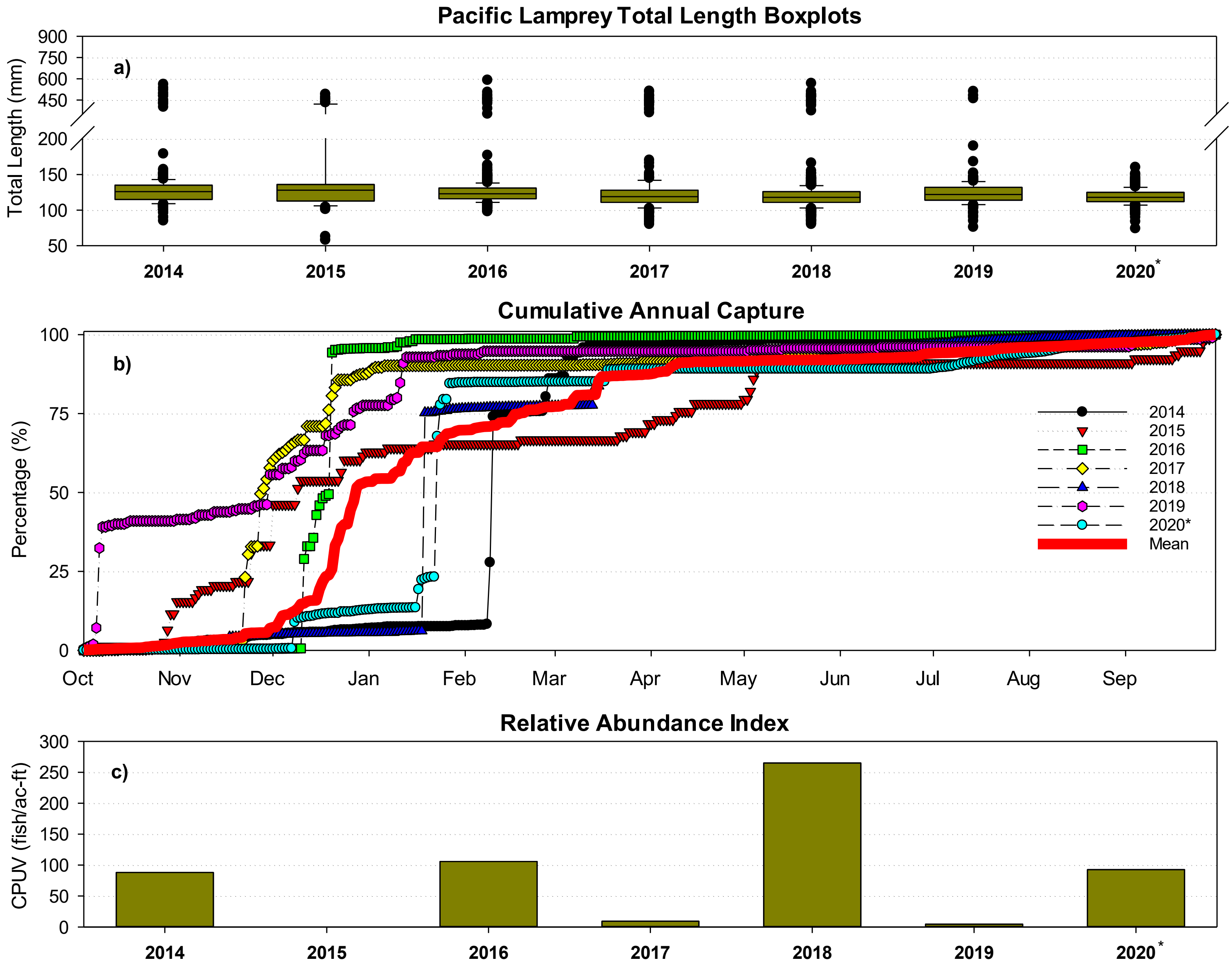


Figure 14. Pacific Lamprey (macropthalmia and adults) a) total length distribution box plots, b) cumulative annual capture trends, and c) relative abundance indices from rotary traps collected between 10/1/2013 and 9/30/2020 by water year from the Sacramento River, CA at the RBDD (RK 391). *Water year 2020 included a prolonged cessation of sampling from 3/25/2020 to 6/30/2020 due to the COVID-19 global pandemic.

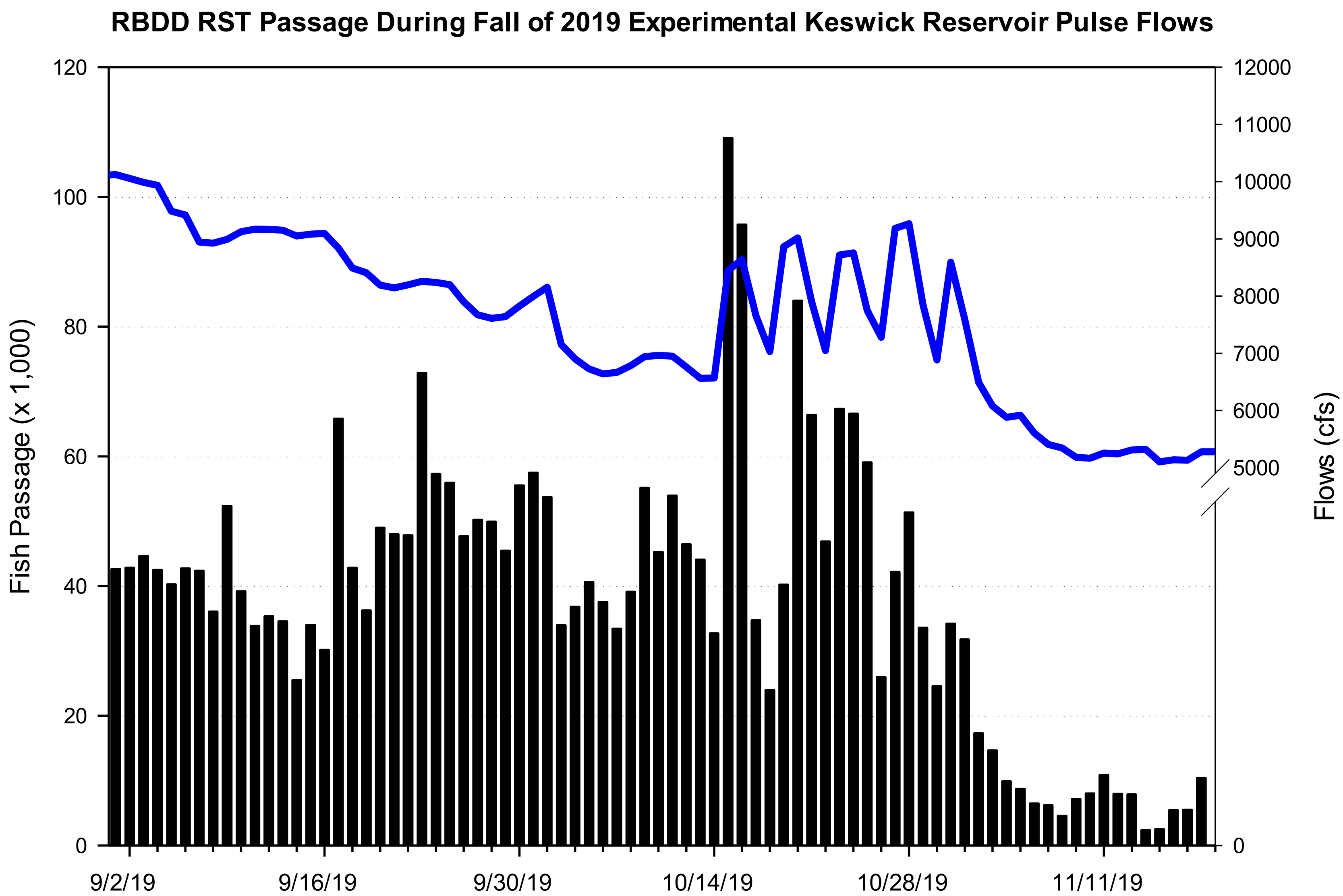


Figure 15. Winter Chinook salmon daily passage at Red Bluff Diversion Dam rotary traps during fall of 2019 experimental pulse flow regime from Keswick Reservoir. Flows (right axis) represent mean daily flows at Bend Bridge minus diversions by Red Bluff pumping plant.

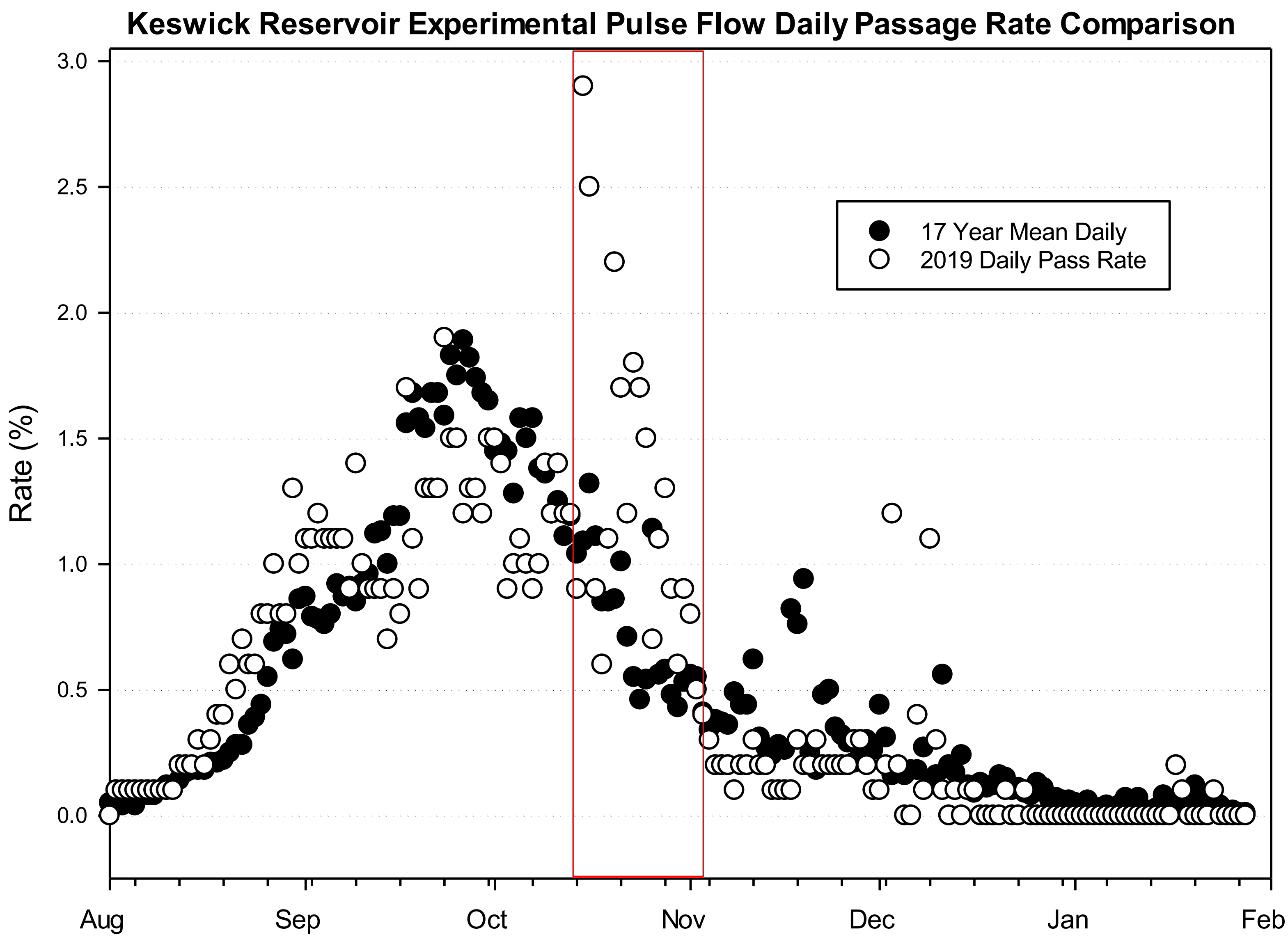


Figure 16. Winter Chinook brood year 2019 daily passage rates (%) and daily 17 year mean passage rates (%) at Red Bluff Diversion Dam rotary traps showing fall of 2019 experimental pulse flow regime from Keswick Reservoir within red box.

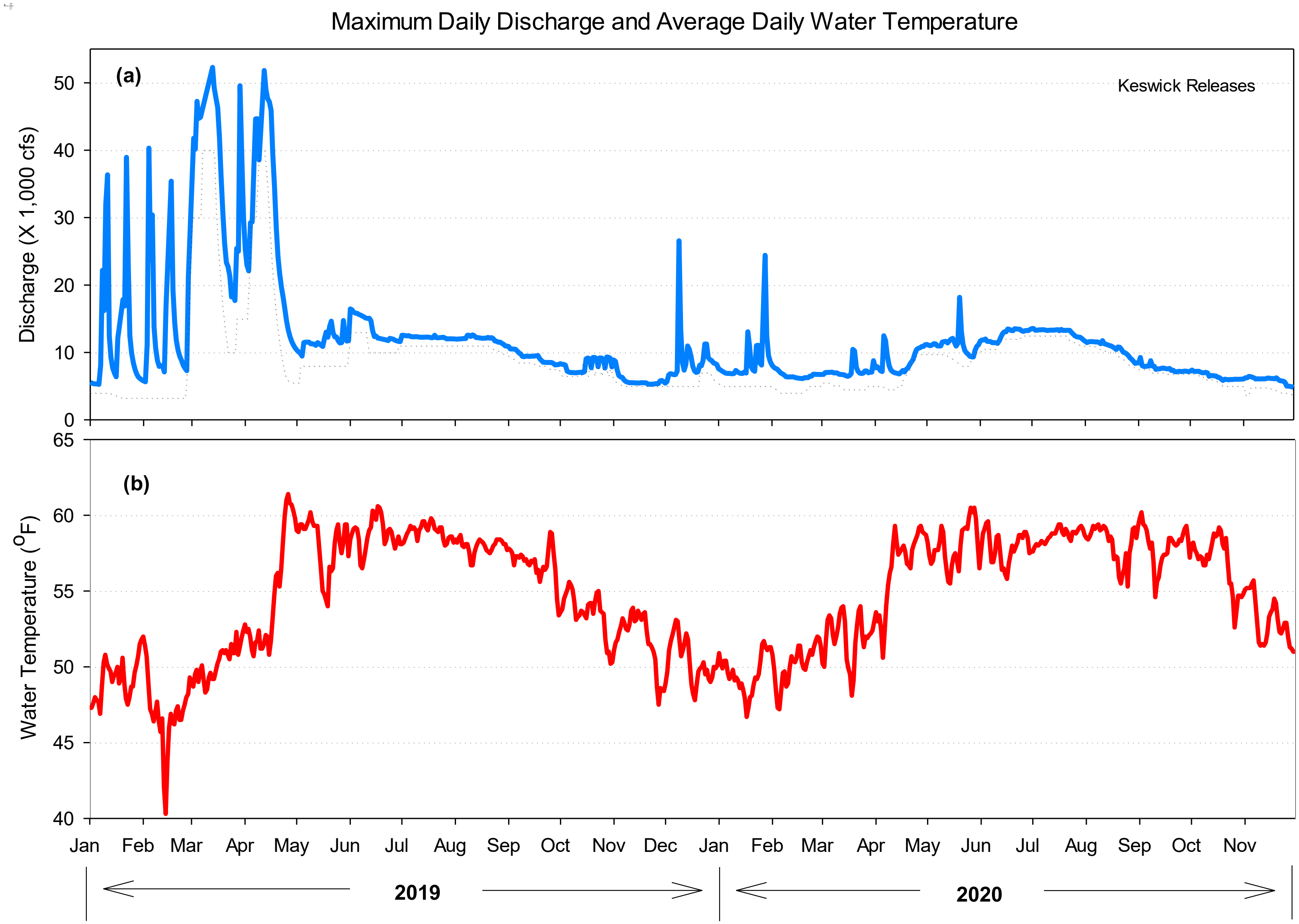


Figure 17. Sacramento River maximum daily discharge (a) observed at the California Data Exchange Center's Bend Bridge gauging station (blue line) showing water releases from Keswick Reservoir (cross-hatched gray shaded area) and average daily water temperatures (b) from rotary-screw traps at RBDD for the period 1/1/2019 through 11/30/2020. Shaded vertical region across both figures represents cease to sampling due to COVID-19 pandemic from 3/25/2020-6/30/2020.

Appendix I.

Appendix I. Genetic sampling and run assignment methodology (S. Blankenship, Cramer Fish Sciences, pers. communication 2019)

Genetic samples were genotyped using multi-locus single nucleotide polymorphisms (SNP's). The methods used to determine SNP genotypes were allele-specific polymerase chain reaction (ASP) and amplicon sequencing (GTSeq). Specific assays for each locus were developed by NOAA Southwest Fisheries Science Center (Clemento et al. 2011) and SNPType™ assays were obtained from Fluidigm Corp. (South San Francisco, CA) when conducting ASP. These same loci are available for use within a sequencing-based approach termed GTSeq (Campbell et al. 2014). Approximately 25% of the samples were genotyped using ASP and 75% using GTSeq, with the primary decision point being time. ASP is a faster process and is used in-season to report populations assignment. GTSeq is more amendable to post-season analysis. All laboratory procedures followed Blankenship et al. (2013). All genotypes were translated into HapMap nucleotide standards (A=1, C=2, G=3, T=4, insertion/deletion=5, and no data=0). Established QA/QC procedures and scoring rules were followed for each locus.

The genetic loci used were predominantly those markers that comprised the reference baseline constructed by NOAA Southwest Fisheries Science Center (Clemento et al. 2011). In total, 91 genetic loci overlap between the SNPType™ marker set and reference baselines. Population composition of mixture collections (i.e., captured juveniles) were estimated by using a partial Bayesian procedure based on the likelihood of unknown-origin genotypes being derived from genetic baseline reference populations given the allele frequencies for reference populations. The mixed stock analysis (MSA) procedure followed Blankenship et al. (2013), which results in a maximum likelihood solution for stock composition (Millar, 1987). Assignment posterior probabilities for a given genotype are estimated for each reference collection and reported by standard population aggregations (i.e., Winter; Spring; Fall/Late-Fall). We accomplished this by extracting the assignment data from the MSA and summing the final posterior probabilities over reference populations within a reporting group. Population assignment was conducted using the ONCOR software (Steven Kalinowski unpublished, Montana State University).

Appendix II.

United States Department of the Interior

FISH AND WILDLIFE SERVICE

In reply refer to:

Red Bluff Fish and Wildlife Office
10950 Tyler Road, Red Bluff, CA 96080
Phone: (530) 527-3043; FAX (530) 529-0292

Memorandum

To: File

From: Scott Voss, Fish Biologist, Red Bluff Fish and Wildlife Office, USFWS

Subject: Linear-model and genetic-based revisions to brood year 2019 juvenile winter and spring Chinook salmon passage and production estimates

Linear-model revision.–With sufficient numbers of winter-run fry captured by rotary traps, ten mark-recapture trials were performed during the peak winter Chinook salmon juvenile outmigration period from the end of August thru mid-November of 2019. Trials were performed to validate expected (i.e., linear-regression modeled) daily trap efficiencies in relation to observed trap efficiencies and ultimately to add trials to the linear model as part of efforts to continually improve the Red Bluff juvenile monitoring program's passage and production estimates. It is common for the program to verify the accuracy of modeled trap efficiency estimates and/or make changes to trapping operations to better align with predicted or estimated trap efficiencies as fish numbers allow. Of the ten trials performed during this period, five of them were conducted with 4 traps at 100% sampling capacity using naturally produced winter Chinook caught in the Red Bluff traps. The other five trials, also conducted with 4 traps, reduced the amount of water volume sampled by 50% for two mid-channel traps while two margin traps remained at 100% sampling capacity. Fish were marked and released as part of standard trial practices and four of five 100% sampling capacity trials resulted in values outside the prediction intervals (grey lines; Figure 1) of the existing 84 trial model while the mixed sampling capacity trials resulted in four of five trial values within the prediction intervals (grey lines) of the existing model and were deemed consistent with modeled efficiencies.

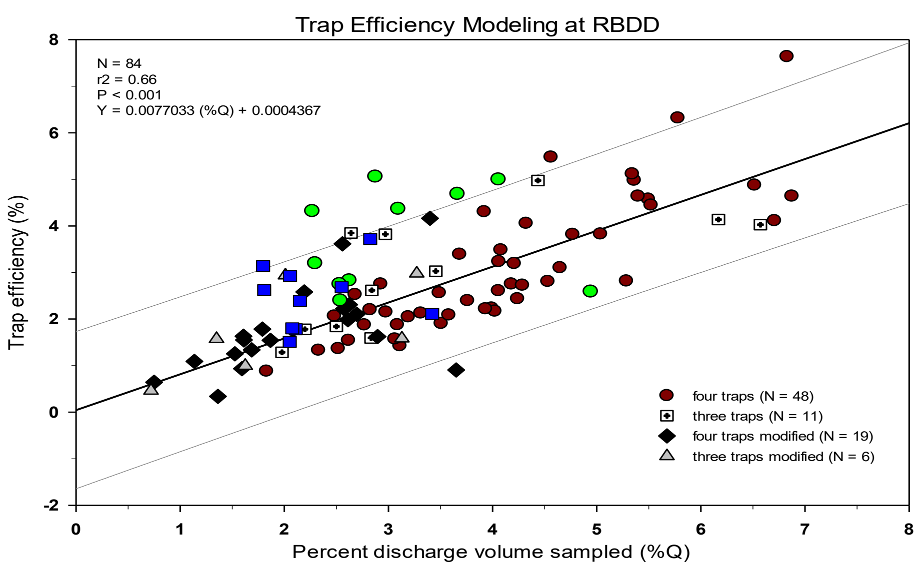


Figure 1. Trap efficiency model indicating fall of 2019 measured efficiency values plotted with (green circles) and without (blue squares) trap 6's recaptures.

The reason(s) why five of ten trials resulted in much greater efficiencies than would be predicted by the current model have not been fully determined. It is suspected that the arrangement of the traps across the transect, which varies within and between years, may have simply been sampling far more efficiently at the flows sampled, mean of 8,425 cfs, than previous trials have observed. Moreover, changes in channel morphology in the absence of US Bureau of Reclamation operation of the Red Bluff Diversion Dam (RBDD) may have occurred in recent years. It is possible that high flow events, as were seen in 2017 and 2019, resulted in channel changes upstream and at the RBDD sample site. Changes in stream channel configurations may have altered the migration routes juvenile salmon use during the fall period when the winter Chinook trap efficiency trials were conducted or simply increased the efficiency of the thalweg trap(s). Alternately, behavioral differences in migration patterns during peak fish abundance that could result in efficiencies greater than previously observed may have occurred.

Regardless of the actual reason(s) why the two trials were markedly different, the majority of the difference could be singled out to one of the four traps in operation. The trap in gate 6 (mid-channel or thalweg) appears to have been highly efficient at recapturing marked fish and, of the 4 traps was also sampling the greatest volume of water passing the transect (in absolute value and proportion). This situation likely resulted in the high efficiency values in relation to the percent of discharge sampled for the array of traps on the whole. Due to the consistency of the trial results under similar conditions and conducted during the peak period of winter run migration, the removal of trap 6's data from weeks 33 to 44 (August 13 to November 4) is expected to result in a more accurate depiction of modeled trap efficiency and subsequent calculations of daily passage.

The removal of trap 6 data from these calculations results in slightly lower daily passage estimates yet estimates that do not differ statistically (Mann-Whitney Rank Sum Test, U=2927, $P= 0.238$) with or without the inclusion of gate 6's data. The overall reduction in total passage for winter Chinook using 3-trap data versus 4 trap data is 5.75% for the 2019 brood year through November 4, 2019. The linear model used at the Red Bluff trapping location is flexible enough to allow for its use with 3 or 4 traps modified to sample 50 or 100% of their volume which has been done throughout the 20+ years of sampling at this location.

As a result, daily passage and production estimates tabulated in preliminary bi-weekly reports denoted as "revised" estimates will be posted in parallel with original reports and will include this adjustment for all salmonid passage estimates for the period of August 13 thru November 4 with results extending through December 31, 2019. Further adjustments to winter and spring Chinook due to genetics will be discussed below and be included as part of the revised estimates. Annual reporting of these findings and a final estimate for winter Chinook will discuss this information in greater detail after the conclusion of the outmigration year.

Genetic-based revision.–During the fall of 2019 and similar to years 2018 and 2017, we had fin clips genetically analyzed from juvenile spring Chinook, designated by length-at-date (LAD) criteria, to verify run designation. Using the data gathered from up to 10 spring Chinook salmon collected daily as part of our standardized genetic sampling (fin clips) plan, we were able to evaluate the accuracy of our field-based LAD run assignments used, in part, to generate the brood year 2019 winter and spring Chinook passage and production estimates. The LAD run assignment method has been the standard model used by the Red Bluff Fish and Wildlife Office for run assignment at the RBDD rotary-trap sampling site since 1995. Overall, genetic samples were taken from 2 out of 4 traps per day in a standardized rotation. For instance, when fish numbers were adequate in all traps, we would sample 10 of each run from 2 traps on day 1 and then do the same for the other 2 traps on day 2. During periods of low spring Chinook abundance, fin clips were collected from 3 or up to 4 traps per day to meet the targeted number of 10 fin clips per day.

Genetic samples (n = 307) were collected from LAD designated spring Chinook between October 16 and November 30, 2019. Prior to November 19, 2018, only 3 samples (1.3%) of 233 were not genetically identified as winter Chinook (1 spring, 2 fall; figure 2). As a result, genetically identified winter Chinook were incorrectly assigned to spring Chinook using LAD criteria for a period of 34 days. Incorrectly assigned spring Chinook using LAD during this time period (October 16 to November 18) contributed positive bias to spring run passage estimates and negative bias to winter run passage estimates. The genetic data indicated the need to revise our passage/production estimates for the two runs to more accurately portray juvenile passage and production in 2019 in a similar fashion as 2017 and 2018, but to a lesser degree in magnitude.

Similar to adjustments done in 2017 and 2018, I felt it necessary to reassign fish that, according to LAD criteria, fell into the spring run category to the winter run category based on the results of genetic analyses. I used the genetic data to determine that for the third consecutive year, the period of October 16 through November 18 was appropriate to reassign all spring run fish to winter run. Biweekly reports' passage data for both runs have been revised for the period of October 8, 2019 through November 18, 2019 to incorporate the revised daily estimates. This revision will be incorporated into passage estimates through the remainder of the brood year 2019 winter and spring Chinook outmigration period. These data will be used as the official passage and production estimates and be detailed in an annual report that will be completed in the coming year. Both sets of reports have been placed on the Red Bluff Fish and Wildlife Office's website biweekly report page for 2019 for interested parties to compare pre- and post-genetic correction passage estimates for each run.

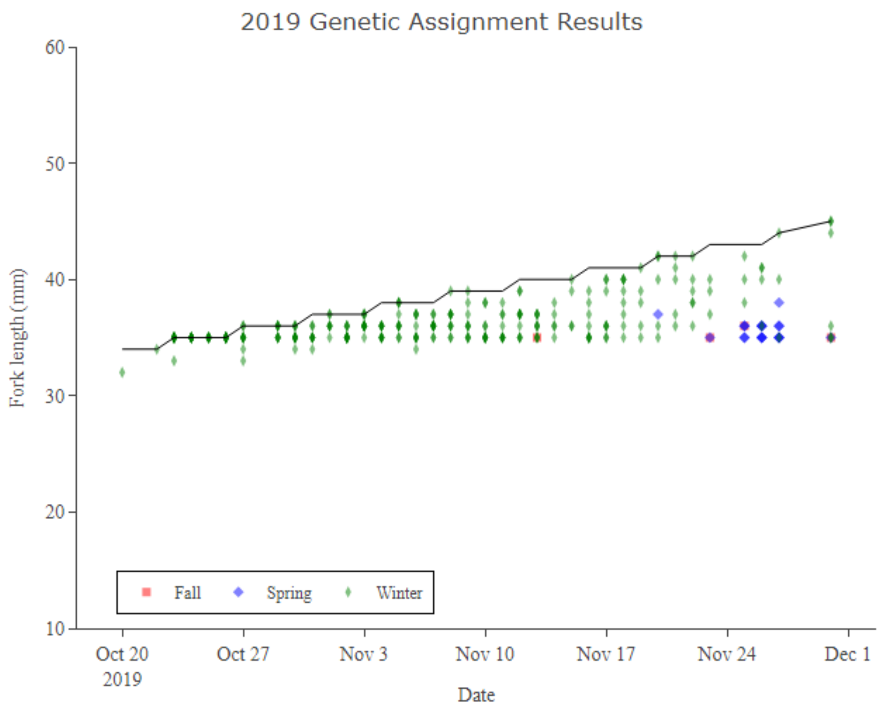


Figure 2. Genetic assignment results from fin clips taken from LAD spring Chinook from 10/16/2019 thru 11/30/2019. Solid black line represents the maximum size (mm) for LAD spring Chinook.