2020 RED BLUFF DIVERSION DAM ROTARY TRAP JUVENILE ANADROMOUS FISH ABUNDANCE ESTIMATES

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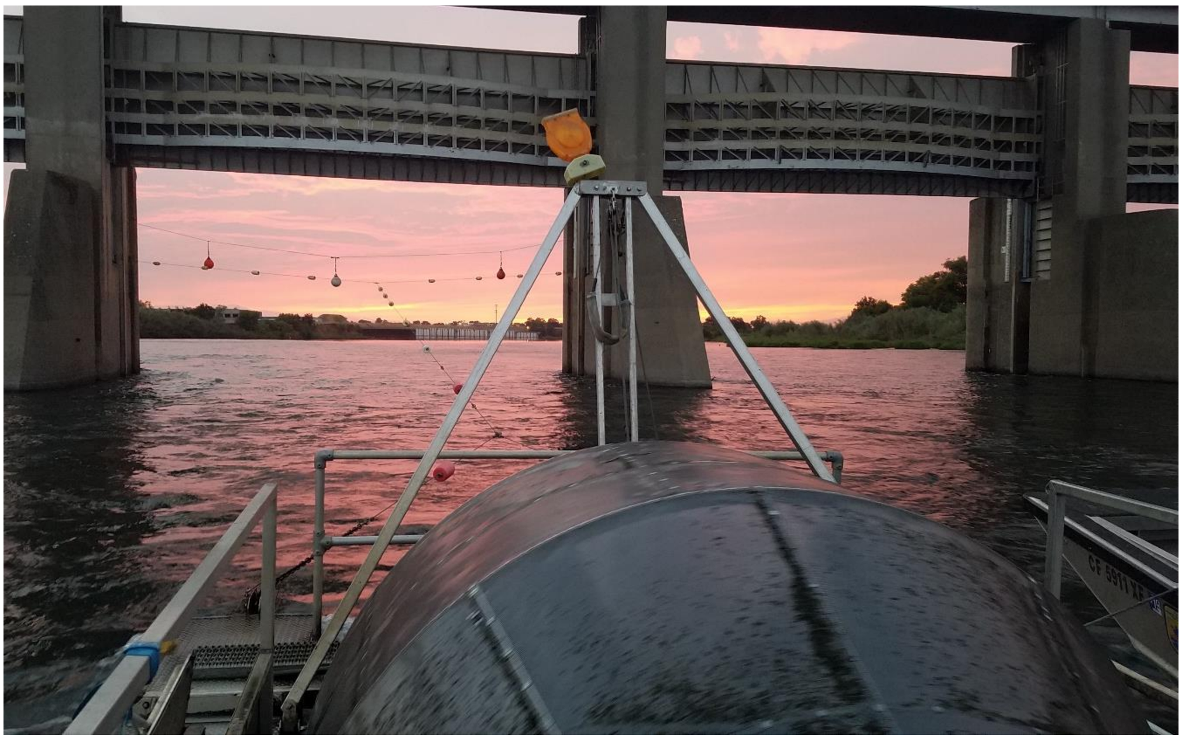

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Abstract.— Rotary-screw trap (RST) sampling was suspended from 3/25/2020 through 6/30/2020 in order to protect employee health and safety during the Coronavirus (COVID-19) global pandemic. During that time, traps were removed from the river. Just prior to resuming sampling operations, four new 1.5-m diameter and one 2.4-m diameter RSTs were installed across a transect downstream of Red Bluff Diversion Dam (RBDD) on the Sacramento River in Northern California. This new five-trap configuration provides a solution to sampling a location that has become shallower since the RBDD gates were permanently placed in the raised position. The non-sampled period impacted brood year (BY) 2020 late-fall Chinook Salmon *Oncorhynchus tshawytscha* passage estimates and abundance indices for steelhead/Rainbow Trout *O. mykiss* and Green Sturgeon *Acipenser medirostris*. No interpolation for missed samples was performed during this extended break in sampling; therefore, the data should be viewed cautiously and not used for interannual comparisons.

BY2020 juvenile winter Chinook Salmon estimated passage at RBDD was 1,735,721 for fry and pre-smolt/smolts combined. The fry-equivalent RST juvenile production index (JPI) was estimated at 2,270,968 with the lower and upper 90% confidence intervals (CI) extending from 1,493,511 to 3,048,424 juveniles, respectively. The estimated egg-to-fry (ETF) survival rate, based on the BY2020 winter Chinook fry-equivalent JPI was 11.7%, below the 19-year average ETF survival rate of 23.4%. The range of ETF survival rates based on the 90% CI was 7.7% to 15.6%.

Water Year 2020 was designated as dry for the Sacramento Valley and, with low inflow performance into Shasta Reservoir in early 2020, cold-water pool storage conditions did not allow for maintaining a daily average temperature (DAT) of 53.5˚F at the Clear Creek River (CCR) gage. In May of 2020, the Temperature Management Plan (TMP) proposed a Tier 3 performance expectation to target a DAT of between 53.5˚F and 56˚F during the critical egg incubation period at CCR with a DAT target of 56˚F at the Balls Ferry (BSF) gage (USBR 2020).

After several mark-recapture trials conducted in the fall of 2020 yielded observed efficiencies higher than modeled efficiencies for the third year in a row, further refinement of the RBDD trap efficiency model was warranted. It was decided to eliminate RBDD dam operation year trials from the 99-trial additive model. For this reporting period (BY2020), it resulted in using a 42-trial additive model using trial results from January

2012 to February 2020. 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 2020.

BY2020 juvenile spring Chinook Salmon estimated passage was 196,462 fry and pre-smolt/smolts combined. The fry-equivalent JPI for 2020 spring Chinook was 300,440 with the lower and upper 90% CI extending from 113,411 to 487,469 juveniles, respectively.

BY2020 juvenile fall Chinook Salmon estimated passage at RBDD was 7,772,752 fry and pre-smolt/smolts combined. The fry-equivalent JPI for 2020 fall Chinook was 8,670,945 with the lower and upper 90% CI extending from 4,766,887 to 12,575,004 juveniles, respectively. The estimated ETF survival rate was 8.1%, based on the BY2020 fall Chinook fry-equivalent JPI, estimated number of female spawners and eggs deposited in-river.

BY2020 juvenile late-fall Chinook Salmon estimated passage at RBDD was 27,180 fry and pre-smolt/smolts combined. The fry-equivalent JPI for BY2020 late-fall was 45,889 with the lower and upper 90% CI extending from 22,289 to 69,489 juveniles, respectively.

A total of 157 sturgeon were captured during calendar year 2020 and ranged in total length from 23 to 61 mm. Green Sturgeon larval captures began in early July, after the COVID-19 break in sampling, and continued through late August of 2020. Green Sturgeon are typically detected in early May with captures continuing through late August (Poytress et al. 2014); therefore, 2020 catch data for Green Sturgeon are considered incomplete. Annual, albeit truncated, sturgeon catch per unit volume (CPUV) for 2020 was 1.6 fish/ac-ft.

Lamprey species sampled during water year 2021 (WY2021) 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, 9.2% and 90.8% respectively. Lamprey CPUV for WY2021 was 18.0 fish/ac-ft and 477.2 fish/ac-ft for unidentified lamprey ammocoetes and Pacific lamprey, respectively. Both of these abundance values are above the 18-year averages of 15.0 ± 18.1 fish/ac-ft for unidentified lamprey ammocoetes and 56.5 ± 64.6 fish/ac-ft for Pacific lamprey.

Table of Contents

Table of Contents Continued

List of Tables

List of Tables continued

Table .... Page

List of Tables continued

List of Figures

List of Figures continued

Figure .... Page

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 (RKM) 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), which also funds many anadromous fish restoration actions 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.

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[1] The National Marine Fisheries Service first listed winter 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).

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 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 monitoring activities at RBDD since 1995 (Gaines and Martin 2002). 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) 2020, (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, 2020 through November 30, 2021. This report

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

includes JPI's for the 2020 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 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 reaching 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 RKM reach between Keswick Dam (RKM 486) and RBDD (RKM 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. During the years 2002-2008, USBR operators generally raised the RBDD gates from September 16 through May 14 and lowered them May 15 through September 15. 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. — Prior to June 30, 2020, 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 RSTs 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 (< 1.2 m), or river hydrology restricted our ability to sample with all traps (water velocity < 0.6 m/s).

Changes in river morphology after the decommissioning of the RBDD gates in 2011 resulted in variable river depths across the RST transect. Changes to the riverbed transect can occur annually or over multiple years, within or between all or some gates and can be subtle or significant in terms of sediment transport and deposition/erosion rates. Substrate aggradation has caused insufficient river depths across many gates for RST cones to sample, especially during periods of low flows (e.g., < 5kcfs). Insufficient depths lead to equipment damage and/or failure when 2.4-m RST cones interact heavily with river substrates. Oftentimes, RST cones created their own depression in the river bottom allowing continued sampling, but in some instances this resulted in conditions unfit to sample, and necessitated the use of smaller RSTs. 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.

[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 0700 on day 1 and ending at 0659 on day 2.

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 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 macrophthalmia (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 gaging station at RKM 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 Bismarck 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 45-60 minutes, removed, and allowed to recover in fresh water. Marked fish were held for 6-24 hours before being released

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[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.

approximately 4 km 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 were 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 had been updated to include naturally-produced fish sampled during monitoring activities without the RBDD gates in the lowered position (Poytress 2016; Voss and Poytress 2020). Initially, the model for BY2020 relied on 99 mark-recapture trials using wild fish and conducted with the RBDD gates raised between 2002 and 2020 (r^2 = 0.66, P < 0.001, df = 98), which added the 15 most recent trials conducted to the 84-trial model used during BY2019. Biweekly reports during BY2020 used the 99-trial model for near real-time estimates. After review of trap efficiency trial results conducted post-RBDD gate operations, it was determined to employ a 42-trial model using results from wild fish trials conducted from January 2012 to February 2020 (r^2 = 0.61, P < 0.001, df = 41; Figure 3). This document reports passage estimates using the 42-trial model.

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,…,t) on day d (d = 1,…,n), and X_{di} as volume sampled at trap i (i = 1,…t) on day d (d = 1,…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,…,*n*) by

4.

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

where,

5.

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

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

Weekly Passage ($\hat{\mathrm{P}}$)*.*—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.

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

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 2020 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 Chinook juvenile production estimate to guide incidental take at the Sacramento-San Joaquin Delta pumping facilities in 2020 (NMFS 2021). O'Farrell's method incorporates summation of fry JPI and a weighted (2.235:1) pre-smolt/smolt JPI (inverse value of 44.75% fry-to-pre-smolt/smolt survival) for estimation of BY2020 winter Chinook fry-equivalents. All BY2020 winter Chinook fry-equivalent production estimates reported within the following text, tables and graphics were calculated using O'Farrell's estimate of fry-to-smolt survival.

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 2021), 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.

Reducing bias associated with unmarked CNFH fall Chinook.—Annual releases of 75% unmarked fall Chinook from CNFH in the late winter to early spring months can impart positive bias to naturally produced spring and fall Chinook passage and production estimates (Voss and Poytress 2019). In most years, CNFH fall Chinook are released at lengths that overlap with the spring Chinook LAD size category. Therefore, captures of unmarked hatchery fish during and after CNFH fall Chinook production releases can affect fry to smolt size ratios, fry-equivalent values, as well as ETF survival rates for both spring and fall LAD Chinook. In an effort to reduce bias to spring and fall Chinook natural production and passage estimates, daily captures of *marked* (adipose fin clipped) hatchery fall Chinook assigned to spring or fall Chinook runs using LAD criteria were multiplied by a factor of 3 to estimate unmarked hatchery fish within daily catch. These adjusted daily values were then subtracted from unmarked Chinook catch totals and daily passage estimates for each run were subsequently calculated. If adjusted daily passage of unmarked hatchery Chinook was greater than the original unmarked Chinook daily passage value, that day was given a value of zero for natural Chinook passage. After daily passage estimates were recalculated to exclude unmarked hatchery Chinook passage, weekly passage estimates and confidence intervals were recalculated.

The efforts to reduce bias associated with unmarked CNFH fall Chinook fish were made post hoc to correct annual estimates and are not reflected in passage estimates reported within real-time biweekly reports. For clarity, passage and production estimates, using a 42-trial trap efficiency model, with and without the removal of hatchery fish are reported for fall and spring Chinook.

Results

Sampling effort.— RST sampling was suspended from 3/25/2020 through 6/30/2020 in order to protect employee health and safety during the Coronavirus (COVID-19) global 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 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' sampling configuration using four 2.4-m RSTs.

Weekly sampling effort throughout the BY2020 winter Chinook Salmon emigration period ranged from 0.40 to 1.00 ($\bar{x}$ = 0.90; *N* = 52 weeks; Table 1). Weekly sampling effort ranged from 0.86 to 1.00 ($\bar{x}$ = 0.99; *N* = 26 weeks) between July and the end of December, the period of greatest juvenile winter Chinook emigration, and 0.40 to 1.00 ($\bar{x}$ = 0.81; *N* = 26 weeks) during the latter half of the emigration period (Table 1).

Weekly sampling effort throughout the BY2020 spring Chinook emigration period ranged from 0.40 to 1.00 ($\bar{x}$ = 0.87; *N* = 52 weeks; Table 2). Weekly sampling effort ranged from 0.40 to 1.00 ($\bar{x}$ = 0.88; *N* = 26 weeks) between mid-October and mid-April, the period of greatest juvenile spring Chinook emigration, and 0.57 to 1.00 ($\bar{x}$ = 0.85; *N* = 26 weeks) during the latter half of the emigration period (Table 2).

Weekly sampling effort throughout the BY2020 fall Chinook emigration period ranged from 0.40 to 1.00 ($\bar{x}$ = 0.85; *N* = 52 weeks; Table 3). Weekly sampling effort ranged from 0.40 to 1.00 ($\bar{x}$ = 0.84; *N* = 26 weeks) between December and the end of May, the first half of the juvenile fall Chinook 2020 brood year, and 0.57 to 1.00 ($\bar{x}$ = 0.8; *N* = 26 weeks) during the latter half of the emigration period (Table 3).

Weekly sampling effort throughout the BY2020 late-fall Chinook emigration period ranged from 0.00 to 1.00 ($\bar{x}$ = 0.71; *N* = 52 weeks; Table 4). Weekly sampling effort ranged from 0.00 to 1.00 ($\bar{x}$ = 0.49; *N* = 26 weeks) between April and the end of September, the first half of the juvenile late-fall Chinook 2020 brood year, and 0.50 to 1.00 ($\bar{x}$ = 0.93; *N* = 26 weeks) during the latter half of the emigration period (Table 4).

Weekly sampling effort throughout the BY2020 *O. mykiss* emigration period ranged from 0.00 to 1.00 ($\bar{x}$ = 0.66; *N* = 52 weeks; Table 5). Weekly sampling effort ranged from 0.00 to 1.00 ($\bar{x}$ = 0.34; *N* = 26 weeks) between January and the end of June, the first half of the juvenile *O. mykiss* 2020 brood year, and 0.86 to 1.00 ($\bar{x}$ = 0.99; *N* = 26 weeks) during the latter half of the emigration period (Table 5).

Variability of weekly sampling effort throughout the reporting period was attributed to several sources. These sources of sampling variability include: intentional reductions in effort resulting from sampling < 4 traps prior to March 25, 2020 through June 30, 2020 due to the Coronavirus (COVID-19) global pandemic; sampling < 5 traps following the break in trapping operations; cone modification(s); staffing limitations; and unintentional reductions in effort resulting from high flows and debris loads.

Mark-recapture trials.—Twelve mark-recapture trials were conducted during this report period to estimate and validate RST efficiency using four 1.5-m RST's. Seven trials were conducted during the fall of 2020 using naturally produced winter Chinook. Five trials using naturally produced fall Chinook were conducted from January through February 2021. Sacramento River discharge sampled during the twelve trials ranged from 4,007 to 7,027 ft^3/s (cfs). Estimated *%Q* during trap efficiency trials ranged from 1.37% to 2.01% ($\bar{x}$ = 1.66%; Table 6).

Trials (*N* =12) were conducted using four 1.5-m RSTs sampling with unmodified cones for all twelve trials. All trials were conducted using Chinook sampled from RSTs, and trap efficiencies ranged from 1.16% to 3.28% ($\bar{x}$ = 2.18%). The number of marked fish released per trial ranged from 821 to 1,116 ($\bar{x}$ = 964) and the number of marked fish recaptured ranged from 11 to 30 ($\bar{x}$ = 21). All fish were released after sunset and 98.4% of recaptures occurred within the first 24 hours, and 100% within 72 hrs.

Sub-sampled fork lengths of fish marked and released ranged from 31 to 65 mm ($\bar{x}$ = 36.9 mm). Fork lengths of recaptured marked fish ranged from 31 to 58 mm ($\bar{x}$ = 36.7 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 (95.5% fry, 4.5% pre-smolts).

Fish collected and used for all trials were obtained from all three spatial zones across the transect, including the 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 as well as the most unmarked fish during all twelve trials.

Trap efficiency modeling.— Fifteen trials conducted during BY2019 using naturally produced winter Chinook (N=10) and fall Chinook (N=5) were included into the BY2020 model (Figure 3). A 99-trial model (r^2 = 0.61, P < 0.01, df = 98) was employed for passage estimation for the purpose of near real-time biweekly report production during BY2020 (Figure 4). However, after several mark-recapture trials were conducted in the fall of 2020, yielding observed efficiencies higher than modeled efficiencies for the third year in a row, further refinement of the RBDD trap efficiency model was warranted. Early trials within the existing 99-trial model did not produce a model reflective of current or recent river conditions post-RBDD gate operations. To improve the relevance of the additive model, trials prior to 2012 (RBDD gate operations era) were removed, resulting in a 42-trial model. In late fall of 2020 and following the recommendation of the IEP's winter Chinook Project Work Team, winter Chinook BY2020 fry-equivalent passage estimates were made using a 42-trial model in order to estimate egg-to-fry survival. All passage estimates reported herein use the 42-trial trap efficiency model (Figure 4) and will differ from preliminary real-time biweekly reports produced during BY2020.

Genetic corrections to LAD run assignments.—Genetic tissue samples from up to ten winter Chinook Salmon, according to LAD, were collected on a daily basis as part of a genetic sampling project known as "Improving Vital Rates Estimation Using Parentage-Based Mark Recapture Methods". In addition, samples from up to ten LAD spring Chinook per day 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 33 days during BY2020 from mid-October thru late November (Figure 5).

Based upon genetic data, LAD spring Chinook captured between October 16 and November 17, 2020 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 2020. These re-assignments are reflected in the estimates reported herein.

Winter Chinook fork length evaluations.— BY2020 winter Chinook fork lengths ranged between 28 and 155 mm (Figure 6a). Winter Chinook were weighted (76.8%) to the fry size-class category (<46mm) with 92.7% of those measuring less than 40 mm (Figure 7a). The remaining 23.2% were attributed to the pre-smolt/smolt category (>45 mm) with 99.4% of the fish sampled between 46 and 100 mm.

Winter Chinook passage.—BY2020 winter Chinook juvenile estimated passage at RBDD was 1,735,721 fry and pre-smolt/smolts combined (Table 1). Fry sized juveniles (<46 mm FL) comprised 75.0% of total estimated winter Chinook passage (Table 1). Fry passage occurred from July through early December (weeks 27 thru 48; Figure 6b). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 25.0% of total passage and the first observed emigration past RBDD occurred in early September (week 35; Table 1). Weekly pre-smolt/smolt passage estimates for the brood year concluded in late April (week 17; Figure 6b).

Winter Chinook JPI to adult comparisons.—The BY2020 winter Chinook fry-equivalent JPI was 2,270,968 with the lower and upper 90% CI extending from 1,493,511 to 3,048,424 juveniles, respectively (Table 7). Adult females contributing to in-river spawning of BY2020 winter Chinook were estimated to have been 3,904 individuals (D. Killam, CDFW, personal communication). The estimated ETF survival rate was 11.7%, based on the BY2020 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 7.7% to 15.6% (Table 7).

Adult female spawner estimates derived from winter Chinook carcass surveys and RST data from brood years 1996-2020 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 = 0.85, P < 0.0001, df = 21; Figure 8).

Spring Chinook fork length evaluations.— BY2020 spring Chinook fork lengths ranged between 30 and 118 mm (Figure 7b). Spring Chinook were weighted to the pre-smolt/smolt size-class category (>45mm) with 13.2% spring Chinook designated as fry with 86.4% measuring less than 40 mm FL (Figure 7b). The majority of the catch (86.8%) was attributed to the pre-smolt/smolt category (>45 mm) with fish between 46 and 90 mm comprising 93.7% of this size class.

Spring Chinook passage.—Including genetic corrections and removal of unmarked hatchery smolts, BY2020 spring Chinook juvenile estimated passage at RBDD was 196,462 fry and pre-smolt/smolts combined (Table 2). Fry sized juveniles (<46 mm FL) comprised 24.4% of total estimated spring Chinook passage (Table 2). Fry passage occurred from the end of November through early January (weeks 47 thru 2; Table 2). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 75.6% 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 June (week 33; Figure 9b).

The fry-equivalent RST JPI for BY2020 was 300,440 with the lower and upper 90% CI extending from 113,411 to 487,469 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.—BY2020 fall Chinook fork lengths ranged between 27 and 182 mm (Figure 7c). BY2020 fall Chinook were composed of 72.6% in the fry size-class category (<46 mm) with 95.0% of those fry measuring less than 40 mm FL (Figure 10a). The remaining 27.4% were attributed to the pre-smolt/smolt category (>45 mm) with fish between 50 and 100 mm comprising 97.0% of the size group.

Fall Chinook passage.—After removal of unmarked hatchery smolts, BY2020 fall Chinook juvenile estimated passage at RBDD was 7,772,752 fry and pre-smolt/smolts combined (Table 3). Fry sized juveniles (<46 mm FL) composed 83.5% of total estimated fall Chinook passage (Table 3). Fry passage began in December and was detected through early May (weeks 48 thru 19; Figure 10b). Pre-smolt/smolt sized juveniles (>45 mm FL) composed 16.5% of total passage. The first observed pre-smolt/smolt passage occurred in late January and continued through the end of November (weeks 3 thru 47; Table 3).

Fall Chinook JPI to adult comparisons.—The fry-equivalent RST JPI for BY2020 was 8,670,945 with the lower and upper 90% CI extending from 4,766,887 to 12,575,004 juveniles, respectively (Table 3). The total number of adult BY2020 fall Chinook females contributing to in-river spawning upstream of RBDD was estimated to be 20,802 individuals. The estimated ETF survival rate was 8.1%, based on the BY2020 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 4.4% to 11.7% (Table 8).

Late-Fall Chinook fork length evaluations.—BY2020 late-fall Chinook were sampled between 36 and 184 mm (Figure 7d). BY2020 late-fall Chinook sampled were heavily weighted to the pre-smolt/smolt size-class category (>45 mm). Due to the COVID-19 break in sampling from 3/25/2020 to 6/30/2020, only 1.4% of all fish sampled as late-fall were designated fry (<46 mm), with only nine individuals captured after sampling resumed (Figure 11a). The remaining 98.6% of juveniles were attributed to the pre-smolt/smolt category, with fish between 50 and 120 mm comprising 90.0% of that value.

Late-fall Chinook passage.—BY2020 late-fall Chinook juvenile estimated passage at RBDD was 27,180 fry and pre-smolt/smolts combined (Table 4). Since sampling was delayed by 13 weeks (COVID-19) during the primary fry migration period, fry sized juveniles (<46 mm FL) comprised only 1.7% of total estimated late-fall Chinook passage (Table 4). Fry passage was only detected for a period of two weeks, following the break in sampling due to COVID-19 (weeks 27 & 28; Figure 11b). Pre-smolt/smolt sized juveniles (>45 mm FL) composed 98.3% of total passage and the first observed emigration past RBDD also occurred in July following the COVID-19 break (week 28; Table 4). Weekly pre-smolt/smolt passage for the brood year ended in early February (week 5; Figure 11b). The fry-equivalent RST JPI for BY2020 was 45,889 with the lower and upper 90% CI extending from 22,289 to 69,489 juveniles, respectively (Table 4). Late-fall Chinook ETF survival rates were not estimated due to incomplete fry passage sampling (COVID-19) as well as due to inaccuracies in adult count data as noted in Poytress et al. (2014).

O. mykiss fork length evaluations.—BY2020 juvenile *O. mykiss* were sampled between 21 and 256 mm (Figure 12a). Sub-yearling (41-138 mm) and yearling (139-280 mm) *O. mykiss* were amongst the first sampled at the beginning of calendar year 2020 (Table 5). *O. mykiss* fry (<41 mm) captures were steady, with the first several fry of the year captured in late January continuing until, likely through, and after the COVID-19 break in sampling (Figure 12a). The last fry capture occurred in week 38 (mid-September). Sub-yearling (41-138 mm) captures began in January (week 1; 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.—BY2020 *O. mykiss* juvenile total estimated passage at RBDD was 39,758 fry, sub-yearling and yearlings combined (Table 5). Fry sized juveniles (<41 mm) comprised only 7.1% of total *O. mykiss* passage. Fry passage occurred from late January through mid September (weeks 3 thru 38; Figure 12b). Sub-yearling/yearling sized juveniles (≥41 mm) composed 92.9% of total passage and the first observed emigration past RBDD occurred in week 1 (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 comprised of recently emerged, exogenous feeding larvae with a mean total length of 26.4 mm and median of 26.0 mm (Table 9). A total of 157 sturgeon were captured during calendar year 2020 ranging in length from 23 to 61 mm (Figure 13a).

Green Sturgeon larval captures began in early July, after the COVID-19 break in sampling, and continued through late August of 2020 (Figure 13b). Green Sturgeon are typically detected in early May with captures continuing through late August (Poytress 2014), therefore 2020 sampling data for Green Sturgeon is considered incomplete. Annual, albeit truncated, Green Sturgeon CPUV for 2020 was 1.6 fish/ac-ft (Table 9; Figure 13c).

Lamprey species data.—Capture of multiple lamprey species occurred in water year 2021 (WY2021; October 1, 2020 – September 30, 2021). Lamprey species sampled during WY2021 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, 9.2% and 90.8% respectively. Two individual River Lamprey and one Kern Brook Lamprey were captured in the RSTs during WY2021.

Annual catch of unidentified lamprey ammocoetes during WY2021 was 647 (Table 10) and ranged from a minimum total length of 24 mm to a maximum length of 193 mm ($\bar{x}$ = 99 mm;

Figure 14a). Annual catch of Pacific Lamprey was 6,410 (Table 11) and ranged from a minimum total length of 62 mm to a maximum total length of 580 mm ($\bar{x}$ = 119 mm, Figure 15a).

Lamprey captures occurred throughout the water year, beginning in early October and continuing through the end of September (Figures 14b and 15b). Lamprey CPUV for WY2021 was 18.0 fish/ac-ft (Table 10, Figure 14c) and 477.2 fish/ac-ft (Table 11, Figure 15c) for unidentified lamprey ammocoetes and Pacific lamprey, respectively. Both of these abundance values are above the 18-year averages of 14.8 ± 18.0 fish/ac-ft and 77.9 ± 118.4 fish/ac-ft for unidentified lamprey ammocoetes and Pacific lamprey, respectively.

Discussion

Sampling effort. —Despite a break in sampling activities due to COVID-19 between March 24 and June 30, 2020, the program was able to put forth moderate sampling effort for the reporting period of January 1, 2020 through November 30, 2021 ($\bar{x}$ = 0.74). Mean sampling effort for BY2020 winter, spring, fall, late-fall Chinook Salmon and *O. mykiss* was 0.90, 0.87, 0.85, 0.71 and 0.66, respectively (Tables 1-5). During the primary juvenile winter Chinook capture and passage period of July through December of 2020, mean sampling effort was high (0.99), whereas the latter half of the brood year was more variable, yet still moderately high and averaged 0.81.

Outside of a few higher magnitude flow events near the beginning and end of the reporting period, storm activity had very little impact on sampling effort as discharge levels rarely topped the 15,000 cfs threshold during the winter months (Figure 16). Minimally decreased sampling effort during the latter half of the winter brood year was due to hatchery releases upstream as well as staffing restrictions due to COVID-19 exposures. Releases of late-fall Chinook in early January resulted in reduced effort due to sampling some traps with 50% modifications in order to reduce handling and stress on elevated catches of marked (hatchery origin) salmonids. Hatchery releases of approximately 11.8 million fall Chinook and, at times, concurrent releases of jump-start winter Chinook into Battle Creek from March 10 to April 8, 2021, resulted in 8 non-sample days, depending on the number of salmon released during each event and resultant catch associated within days after releases. Traps were not sampled from April 10-13, 2021 due to a COVID-19 exposure affecting multiple field staff. A prolonged COVID-19 related non-sampling period from March 25 to June 30, 2020, resulted in truncated data for BY2020 late fall Chinook, BY2020 *O. mykiss* and BY2020 Green Sturgeon with no interpolations estimated for the missed period.

Trap efficiency model adjustments— Greater observed trap efficiencies as compared to modeled results were first realized in winter Chinook fry trials conducted during the fall of 2018 (Voss and Poytress 2020). The fall of 2020 marked a third consecutive year of mark-recapture trials producing higher observed trap efficiencies than modeled values. As a result and during the fall of 2020, it was decided to eliminate the trials conducted pre-2012 RBDD dam operation from the 99-trial additive model and to instead employ a 42-trial additive model using only those trials after RBDD operations ceased (Figure 3, 4).

Changes in river morphology since the winter of 2016 have led to shallower conditions and trap efficiencies have increased across the transect. Higher efficiencies detected in shallow conditions have resulted from RSTs sampling a greater percentage of river depth while the 2.4-m RST cones were sampling similar volumes of water at commensurate river discharges. Worth noting is the 42-trial model used in this report employs trials conducted between January of 2012 and February of 2020, of which 22 trials were conducted prior to the channel morphology changes and increased efficiencies noted beginning in 2018.

The BY2021 passage and production estimates will employ a 32-trial hybrid configuration trap efficiency model incorporating 12 trials from this reporting period using the new 1.5-m RST array (Table 6) as well as 20 trials conducted during 2018 and 2019 using 2.4-m RSTs. This 32-trial model will be used as an additive model going forward while more robust statistical analyses are being conducted to determine what updates might be needed to produce the most practical, yet robust trap efficiency model for the RBDD transect in the post-RBDD operation era.

Genetic-based run corrections.—Genetic results indicated that field-assigned (by LAD) BY2020 spring Chinook prior to November 18, 2020 were genetically winter Chinook (Figure 5). Subsequently, when incorporating genetic revisions, 68,845 LAD spring Chinook were estimated to be winter Chinook based on genetic identification during the period of October 16 thru November 17, 2020. A substantial amount of positive bias (25.9%) would have occurred without revisions to spring passage estimates given that total BY2020 spring Chinook passage was estimated at 196,462. For BY2020 winter Chinook, the addition of LAD spring Chinook genetic reassignments (October 16 thru November 17) resulted in a net increase of 4.0% of the BY2020 passage estimate, 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 6b). Fry passage declined thereafter and ceased after the first week of December.

Winter Chinook fry out-migrants represented 75.0% of total winter Chinook passage, with pre-smolt/smolts representing the remaining 25.0%. Through the end of December 2020, 95.5% of the total annual passage estimate for BY2020 winter Chinook was collected (Table 1). Due to mild winter conditions and relatively high sampling effort ($\bar{x}$ = 0.81) during the second half of the brood year, passage interpolation was minimal. Overall, interpolation for missed days of sampling accounted for only 0.9% of the total BY2020 estimate of 1,735,721 winter Chinook passing the RBDD.

Capture of BY2020 LAD juvenile spring Chinook began on October 16, 2020; however, genetic assignment results from tissue samples collected between mid-October and mid-December of 2020 indicated spring Chinook passage began in late November of 2020. Sampling effort was high throughout the fry passage period of weeks 47 thru 2 ($\bar{x}$ = 0.96, Table 2). Sampling effort during the remainder of the brood year was more variable and only slightly lower ($\bar{x}$ = 0.83; Table 2) and driven by reduced effort due to either hatchery releases or staff shortages driven by COVID-19 exposures.

Fall Chinook fry passage accounted for 83.5% of the total passage for brood year 2020. Passage of fry began the first week of December, increasing through the end of the month and into early January. Fry passage sampling effort was moderate, averaging 0.85 and was largely influenced by a number of runoff events throughout the passage period of weeks 48 to 19, with a peak in fry passage during week 7 (Table 3; Figures 10b & 16).

Fall Chinook passage in the pre-smolt/smolt size category, which comprised 16.5% of total brood year passage, began in mid-January. A spike and peak in pre-smolt/smolt passage occurred in mid-May (Table 3). Sampling effort during the smolt passage period remained moderate at 0.83, but was more variable due to hatchery releases and staffing shortages caused by COVID-19. However, overall interpolation for missed samples accounted for only 1.6% of the brood year total, the lowest amount for any fall Chinook brood year in the last 18 years of sampling at RBDD.

Late-fall Chinook fry passage detection was heavily impacted by the cessation of sampling due to COVID-19 from March 25 to June 30, 2020. Fry sized juveniles were detected for a period of only two weeks once sampling resumed (Table 4; Figure 11b). No attempts were made to interpolate the missed sampling period and as a result, fry passage accounted for a minute 1.7% of the brood year total, well below the reported mean value of 38% (Poytress et al. 2014) which indicates a substantial amount of missed fry passage detection. Late-fall Chinook passage in the pre-smolt/smolt size category, which comprised 98.3% of total brood year passage, began in early July and continued in a variable fashion ending in early February. Sampling effort post COVID-19 break was high ($\bar{x}$ = 0.95), providing a nearly complete picture of pre-smolt/smolt passage with interpolation accounting for only 1.6% of the brood year following the COVID-19 disruption. Since no attempts were made to interpolate the un-sampled (COVID-19) portion of the fry passage period, BY2020 late fall Chinook data are incomplete and should be viewed cautiously.

O. mykiss passage began the first week in January (Table 5), with the first fry observed at the end of January 2020. Passage remained variable for all size classes throughout the rest of the calendar year with a peak occurring in early August. The COVID-19 break in sampling (weeks 14-26) impacted passage detection of this species and interpolation was not attempted for missed sampling due to COVID-19. Total passage for the brood year was 39,758 and although interpolation for periods sampled outside of the COVID-19 break was minimal, the data is truncated and should be viewed cautiously.

Bias associated with unmarked CNFH fall Chinook.— Releases of 25% marked (adipose fin clip) brood year 2020 fall Chinook into Battle Creek (Figure 1) began in mid-March and continued through early April of 2021 (weeks 10 thru 14; Table 12). When applicable, releases occurred coincident with elevated Battle Creek flows in an effort to increase the downstream movement and subsequent survival of production fish. During the release period, and including five weeks immediately following (weeks 10-19; Table 12), 54.4% of the marked CNFH fall Chinook captured fell into the spring LAD size category. Without the removal of unmarked hatchery fish, smolt passage estimates for the brood year were 1,106,572 with smolts accounting for 95.8% of the total brood year estimate (Table A1). Had unmarked hatchery fish not been removed, resultant total BY2020 spring Chinook estimates would have been almost six times higher, a substantial amount of positive bias.

During the release period, and including five weeks immediately following (weeks 10-19; Table 12), 45.6% of the marked CNFH fall Chinook captured fell into the fall LAD size category. Without removal of unmarked hatchery fish, smolt passage estimates for the brood year were 2,289,271 with smolts accounting for 26.1% of the total brood year estimate (Table A2). Also, the increased number of smolts estimated results in a higher fry equivalent JPI value of 10,381,378, and in turn, a slightly higher egg to fry survival rate of 9.7% (Table A3). This contrasts with the value of 8.1% (Table 8) when calculations were done to incorporate the removal of unmarked hatchery fish.

Winter Chinook JPI and ETF survival estimate.—The BY2020 winter Chinook fry-equivalent JPI value of 2,270,968 was the third highest value in the last ten years. Adult escapement for BY2020 was estimated at 6,195 in-river adults (NMFS 2021). However, the fry-equivalent based ETF survival rate for BY2020 was estimated at 11.7% (Table 7), the third lowest value in the last ten years and *half* the 19-year average ETF survival rate of 23.4%.

Water year 2020 was designated as dry for the Sacramento Valley and with low inflow performance into Shasta Reservoir in early 2020, cold-water pool storage conditions did not allow for maintaining a daily average temperature (DAT) of 53.5˚F at the Clear Creek River (CCR) gage. With input from Sacramento River Temperature Task Group members, a Temperature Tier Selection Protocol was developed in order to manage temperature performance that was estimated to be approximately 54˚- 56˚F at the CCR gage (USBR 2020). In May of 2020, the Temperature Management Plan (TMP) proposed a Tier 3 performance expectation to target DATs of between 53.5˚F and 56˚F during the critical egg incubation period at CCR with a DAT target of 56˚F at the Balls Ferry (BSF) gage (USBR 2020). In-season modeled estimates of temperature dependent mortality were 28% and 34% for (life) stage dependent and independent models, respectively (USBR 2020). Following the WY2020 temperature management season, USBR undertook an effort to refine their cold-water pool models using hindcast evaluations in order to improve predictive models in future years. Overall, the TMP was largely successful from a Tier 3 performance metric with an estimated hindcast temperature dependent mortality range of 3.0% to 7.2% for stage dependent and independent models in WY2020 (USBR 2020).

While increased water temperatures alone do not fully explain the lower than average winter Chinook ETF survival for BY2020, many factors may have contributed. One factor that may have contributed significantly to lower than expected ETF survival in 2020 was thiamine deficiency complex (TDC), as noted within the BY2019 annual report for winter Chinook (Voss and Poytress 2022). Egg mortality estimated due to TDC was modeled to be 23% for BY2020 winter Chinook Salmon (M. Daniels, NMFS, unpublished data). A brief report compiled by NMFS' Southwest Fisheries Science Center indicated that multiple stocks of BY2020 Chinook Salmon eggs across various Central Valley hatcheries were susceptible to TDC; however, effects of TDC are difficult to detect in naturally produced salmonids, therefore the magnitude of the effect is unknown and could be substantial to fish stocks of conservation concern (NMFS 2022).

Parasitic infection can also be a concern when water temperatures are elevated. From mid-September to late October 2020, the RBDD RSTs were sampled for wild winter Chinook to determine the prevalence and severity of infection of internal and external parasites. The USFWS California Nevada Fish Health Center (CANVFHC) performed histological analyses on 20 fish with a focus on the internal parasites *Ceratonova shasta* and *Parvicapsula minibicornis*. *Ceratonova shasta* was observed within the intestine of 35% of the sample group (7/20 fish; 6 rated as "early stage" and 1 rated as "diseased") and *P. minibicornis* was observed in the kidney of 53% of the sample group (9/17 fish; 8 rated as "early stage" and 1 rated as "diseased"; Foott 2020). While prevalence of infection rates of winter Chinook sampled from the RBDD RSTs may be seen as concerning, the prevalence of "diseased" state winter Chinook for *C. Shasta* (5%) and *P. minibicornis* (6%) is not as alarming but certainly could have contributed to additional losses of natural production of winter Chinook juveniles within the upper Sacramento River.

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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 (RKM 391) for the period 7/1/2020 through 6/30/2021 (brood year 2020). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 1.5 m and one 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 (44.75% or approximately 2.235:1; 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)	1.00	144	34	0	-	144	34	144
28	1.00	1,684	33	0	-	1,684	33	1,684
29	1.00	1,770	34	0	-	1,770	34	1,770
30	0.86	2,309	34.5	0	-	2,309	34.5	2,309
31 (Aug)	1.00	1,749	34	0	-	1,749	34	1,749
32	1.00	4,824	34	0	-	4,824	34	4,824
33	0.97	9,975	34	0	-	9,975	34	9,975
34	1.00	11,568	34	0	-	11,568	34	11,568
35 (Sep)	1.00	22,209	35	42	47	22,251	35	22,303
36	1.00	47,255	35	39	47	47,294	35	47,342
37	1.00	94,663	35	350	48	95,012	35	95,444
38	1.00	190,291	35	1,563	48	191,854	35	193,784
39	1.00	237,541	35	4,108	50	241,650	35	246,722
40 (Oct)	1.00	114,936	35	7,633	52	122,569	35	131,992
41	0.97	239,108	35	24,003	52	263,111	35	292,745
42	1.00	178,901	35	27,123	52	206,024	36	239,510
43	1.00	94,354	36	72,081	52	166,435	42	255,426
44 (Nov)	0.97	31,339	37	42,514	53	73,853	47	126,340
45	1.00	10,081	38	19,555	53	29,636	49	53,778
46	1.00	5,831	39	23,596	54	29,427	53	58,559
47	1.00	916	44	29,552	57	30,467	56	66,952
48 (Dec)	1.00	734	45	33,902	59	34,637	58	76,493
49	1.00	0	-	29,702	60	29,702	60	66,372
50	1.00	0	-	9,583	62	9,583	62	21,414
51	1.00	0	-	8,607	64	8,607	64	19,234
52	0.86	0	-	20,723	67	20,723	67	46,307

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)	0.94	0	-	43,398	69.5	43,398	69.5	96,977
2	0.91	0	-	4,352	74	4,352	74	9,726
3	1.00	0	-	3,845	76	3,845	76	8,593
4	0.90	0	-	6,964	78	6,964	78	15,562
5 (Feb)	0.76	0	-	17,357	80	17,357	80	38,786
6	0.94	0	-	905	88.5	905	88.5	2,021
7	0.91	0	-	42	100	42	100	93
8	0.94	0	-	265	105.5	265	105.5	592
9 (Mar)	1.00	0	-	88	110	88	110	198
10	1.00	0	-	94	107	94	107	211
11	0.71	0	-	1,251	108	1,251	108	2,794
12	0.50	0	-	0	-	0	-	0
13	0.77	0	-	116	144	116	144	259
14 (Apr)	0.40	0	-	0	-	0	-	0
15	0.41	0	-	0	-	0	-	0
16	0.77	0	-	91	139.5	91	139.5	204
17	0.87	0	-	95	132.5	95	132.5	212
18 (May)	0.84	0	-	0	-	0	-	0
19	0.84	0	-	0	-	0	-	0
20	0.77	0	-	0	-	0	-	0
21	0.86	0	-	0	-	0	-	0
22 (Jun)	0.83	0	-	0	-	0	-	0
23	0.89	0	-	0	-	0	-	0
24	0.74	0	-	0	-	0	-	0
25	0.77	0	-	0	-	0	-	0
26	0.80	0	-	0	-	0	-	0
BY total		1,302,183		433,538		1,735,721		2,270,968
90% CI (low : high)		(871,778 : 1,732,588)		(273,357 : 593,719)		(1,149,080 : 2,322,063)		(1,493,511 : 3,048,424)

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 (RKM 391) for the period 10/16/2020 through 10/15/2021 (brood year 2020). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 1.5 m and one 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 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	1.00	0	-	0	-	0	-	0
43	1.00	0	-	0	-	0	-	0
44 (Nov)	0.97	0	-	0	-	0	-	0
45	1.00	0	-	0	-	0	-	0
46	1.00	0	-	0	-	0	-	0
47	1.00	5,589	34	0	-	5,589	34	5,589
48 (Dec)	1.00	12,984	34	0	-	12,984	34	12,984
49	1.00	10,285	35	226	46	10,511	35	10,669
50	1.00	6,997	37	367	47	7,364	37	7,621
51	1.00	5,898	38	316	50	6,214	38	6,435
52	0.86	1,846	40	1,443	51	3,288	41	4,298
1 (Jan)	0.94	3,862	44	2,665	49	6,527	45	8,393
2	0.91	462	45	1,072	53	1,534	52	2,285
3	1.00	0	-	2,874	52	2,874	52	4,885
4	0.90	0	-	7,201	53	7,201	53	12,242
5 (Feb)	0.76	0	-	24,369	54	24,369	54	41,427
6	0.94	0	-	4,256	55	4,256	55	7,236
7	0.91	0	-	1,673	59	1,673	59	2,844
8	0.94	0	-	302	61	302	61	514
9 (Mar)	1.00	0	-	865	65	865	65	1,471
10	1.00	0	-	156	68	156	68	265
11	0.71	0	-	61,277	73	61,277	73	104,170
12	0.50	0	-	338	74	338	74	574
13	0.77	0	-	0	76	0	76	0
14 (Apr)	0.40	0	-	338	81	338	81	575
15	0.41	0	-	13,848	82	13,848	82	23,542

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	0.77	0	-	5,428	87	5,428	87	9,228
17	0.87	0	-	8,157	91	8,157	91	13,867
18 (May)	0.84	0	-	4,705	94	4,705	94	7,998
19	0.84	0	-	4,324	100	4,324	100	7,351
20	0.77	0	-	1,690	105	1,690	105	2,873
21	0.86	0	-	569	110	569	110	968
22 (Jun)	0.83	0	-	42	112	42	112	71
23	0.89	0	-	39	118	39	118	66
24	0.74	0	-	0	-	0	-	0
25	0.77	0	-	0	-	0	-	0
26	0.80	0	-	0	-	0	-	0
27 (Jul)	0.57	0	-	0	-	0	-	0
28	0.80	0	-	0	-	0	-	0
29	0.80	0	-	0	-	0	-	0
30	0.80	0	-	0	-	0	-	0
31 (Aug)	0.80	0	-	0	-	0	-	0
32	0.83	0	-	0	-	0	-	0
33	0.89	0	-	0	-	0	-	0
34	0.86	0	-	0	-	0	-	0
35 (Sep)	0.89	0	-	0	-	0	-	0
36	1.00	0	-	0	-	0	-	0
37	1.00	0	-	0	-	0	-	0
38	1.00	0	-	0	-	0	-	0
39	1.00	0	-	0	-	0	-	0
40 (Oct)	0.94	0	-	0	-	0	-	0
41	0.91	0	-	0	-	0	-	0
BY total		47,922		148,540		196,462		300,440
90% CI (low : high)		(29,968 : 65,876)		(47,088 : 249,991)		(77,992 : 314,932)		(113,411 : 487,469)

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 (RKM 391) for the period 12/1/2020 through 11/30/2021 (brood year 2020). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 1.5 m and one 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 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)	1.00	3,860	32	0	-	3,860	32	3,860
49	1.00	14,557	34	0	-	14,557	34	14,557
50	1.00	28,883	34	0	-	28,883	34	28,883
51	1.00	83,981	36	0	-	83,981	36	83,981
52	0.86	266,048	36	0	-	266,048	36	266,048
1 (Jan)	0.94	1,605,306	37	0	-	1,605,306	37	1,605,306
2	0.91	194,359	36	0	-	194,359	36	194,359
3	1.00	355,114	37	61	46	355,175	37	355,217
4	0.90	422,738	37	6,415	47	429,153	37	433,643
5 (Feb)	0.76	1,337,460	37	25,520	47	1,362,979	37	1,380,843
6	0.94	322,171	37	6,677	48	328,847	37	333,521
7	0.91	1,630,404	37	5,624	50	1,636,027	37	1,639,964
8	0.94	86,732	37	1,421	50	88,153	37	89,148
9 (Mar)	1.00	69,713	37	1,801	52	71,514	37	72,774
10	1.00	20,536	37	1,337	52	21,872	37	22,808
11	0.71	35,960	37	22,504	61	58,464	43	74,217
12	0.50	6,518	37	18,232	67	24,750	67	37,512
13	0.77	1,136	38	94	67	1,230	67	1,296
14 (Apr)	0.40	2,310	37	6,677	71	8,987	69	13,661
15	0.41	318	36	28,928	73	29,246	73	49,496
16	0.77	179	45	66,280	74	66,460	74	112,856
17	0.87	750	43	171,381	75	172,131	75	292,098
18 (May)	0.84	461	44.5	214,532	75	214,993	75	365,166
19	0.84	124	45	256,803	74	256,926	74	436,688
20	0.77	0	-	149,616	72	149,616	72	254,347
21	0.86	0	-	135,800	72	135,800	72	230,860

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)	0.83	0	-	40,316	70	40,316	70	68,538
23	0.89	0	-	19,636	72	19,636	72	33,381
24	0.74	0	-	14,069	76	14,069	76	23,917
25	0.77	0	-	37,953	77	37,953	77	64,520
26	0.80	0	-	21,592	78	21,592	78	36,707
27 (Jul)	0.57	0	-	7,803	82	7,803	82	13,264
28	0.80	0	-	4,813	85	4,813	85	8,183
29	0.80	0	-	5,423	87	5,423	87	9,219
30	0.80	0	-	3,770	95	3,770	95	6,408
31 (Aug)	0.80	0	-	985	93.5	985	93.5	1,674
32	0.83	0	-	472	98	472	98	803
33	0.89	0	-	495	101.5	495	101.5	841
34	0.86	0	-	289	110	289	110	491
35 (Sep)	0.89	0	-	191	114	191	114	325
36	1.00	0	-	292	114.5	292	114.5	497
37	1.00	0	-	177	123	177	123	302
38	1.00	0	-	428	128	428	128	728
39	1.00	0	-	422	116	422	116	717
40 (Oct)	0.94	0	-	307	126	307	126	522
41	0.91	0	-	310	130	310	130	528
42	0.89	0	-	181	136	181	136	308
43	0.71	0	-	1,480	140	1,480	140	2,517
44 (Nov)	0.89	0	-	1,442	147	1,442	147	2,452
45	0.87	0	-	421	158.5	421	158.5	716
46	0.89	0	-	127	151.5	127	151.5	215
47	0.83	0	-	36	158	36	158	61
BY total		6,489,617		1,283,134		7,772,752		8,670,945
90% CI (low : high)		(3,567,567 : 9,411,668)		(695,935 : 1,870,334)		(4,272,244 : 11,273,259)		(4,766,887 : 12,575,004)

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 (RKM 391) for the period 4/1/2020 through 3/31/2021 (brood year 2020). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 1.5 m and one 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). Shaded region reflects period of non-sampling due to COVID-19 pandemic from 3/25/2020 to 6/30/2020.

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)	0.00	-	-	-	-	-	-	-
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	-	-	-	-	-	-	-
27 (Jul)	1.00	194	38	735	60	929	60	1,444
28	1.00	258	37	1,633	63	1,891	62	3,034
29	1.00	0	-	688	65	688	65	1,170
30	0.86	0	-	969	66	969	66	1,647
31 (Aug)	1.00	0	-	1,564	68	1,564	68	2,659
32	1.00	0	-	1,080	68	1,080	68	1,836
33	0.97	0	-	784	73	784	73	1,332
34	1.00	0	-	275	75.5	275	75.5	467
35 (Sep)	1.00	0	-	198	78	198	78	337
36	1.00	0	-	202	72	202	72	343
37	1.00	0	-	150	83.5	150	83.5	255
38	1.00	0	-	452	84	452	84	768
39	1.00	0	-	1,278	66.5	1,278	66.5	2,172

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)	1.00	0	-	1,409	66	1,409	66	2,396
41	0.97	0	-	2,122	70.5	2,122	70.5	3,608
42	1.00	0	-	1,010	78	1,010	78	1,717
43	1.00	0	-	3,045	75.5	3,045	75.5	5,177
44 (Nov)	0.97	0	-	2,374	83	2,374	83	4,036
45	1.00	0	-	626	106	626	106	1,063
46	1.00	0	-	791	110	791	110	1,345
47	1.00	0	-	597	123	597	123	1,015
48 (Dec)	1.00	0	-	490	106	490	106	833
49	1.00	0	-	376	114.5	376	114.5	640
50	1.00	0	-	126	108	126	108	215
51	1.00	0	-	222	114	222	114	378
52	0.86	0	-	666	115	666	115	1,131
1 (Jan)	0.94	0	-	1,356	155	1,356	155	2,306
2	0.91	0	-	650	155	650	155	1,105
3	1.00	0	-	0	-	0	-	0
4	0.90	0	-	0	-	0	-	0
5 (Feb)	0.76	0	-	860	136	860	136	1,462
6	0.94	0	-	0	-	0	-	0
7	0.91	0	-	0	-	0	-	0
8	0.94	0	-	0	-	0	-	0
9 (Mar)	1.00	0	-	0	-	0	-	0
10	1.00	0	-	0	-	0	-	0
11	0.71	0	-	0	-	0	-	0
12	0.50	0	-	0	-	0	-	0
13	0.77	0	-	0	-	0	-	0
BY total		452		26,728		27,180		45,889
90% CI (low : high)		(-47 : 952)		(11,408 : 42,047)		(11,655 : 42,704)		(22,289 : 69,489)

Table 5.— Sampling effort, weekly passage estimates and median fork length (Med FL) for *O. mykiss* passing Red Bluff Diversion Dam (RKM 391) for the period 1/1/2020 through 12/31/2020 (brood year 2020). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 1.5 m and one 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). Shaded region reflects period of non-sampling due to COVID-19 pandemic from 3/25/2020 to 6/30/2020.

Week	Sampling Effort	Total Est. passage	Total Med FL	Week (cont.)	Sampling Effort (cont.)	Total Est. passage (cont.)	Total Med FL (cont.)
1 (Jan)	1.00	32	210	27 (Jul)	1.00	2,392	73
2	0.79	0	-	28	1.00	3,084	70
3	0.48	186	31	29	1.00	2,702	67
4	0.36	0	-	30	0.86	3,476	63.5
5 (Feb)	0.50	0	-	31 (Aug)	1.00	4,462	68.5
6	0.57	49	83	32	1.00	7,076	63
7	0.73	617	27	33	0.97	3,753	61
8	1.00	180	27	34	1.00	2,250	60
9 (Mar)	1.00	63	74	35 (Sep)	1.00	2,572	60
10	1.00	60	57.5	36	1.00	1,478	66
11	0.79	170	24	37	1.00	1,003	63
12	0.57	328	47.5	38	1.00	832	62.5
13	0.00	149	-	39	1.00	698	73
14 (Apr)	0.00	-	-	40 (Oct)	1.00	359	73.5
15	0.00	-	-	41	0.97	394	73
16	0.00	-	-	42	1.00	266	75
17	0.00	-	-	43	1.00	345	86.5
18 (May)	0.00	-	-	44 (Nov)	0.97	216	76.5
19	0.00	-	-	45	1.00	113	69
20	0.00	-	-	46	1.00	35	84
21	0.00	-	-	47	1.00	75	100
22 (Jun)	0.00	-	-	48 (Dec)	1.00	93	112.5
23	0.00	-	-	49	1.00	65	105.5
24	0.00	-	-	50	1.00	103	101
25	0.00	-	-	51	1.00	0	243
26	0.00	-	-	52	0.86	86	92
				BY total		39,758	
				90% CI (low : high)		(18,485 : 61,032)	

Table 6.—Summary of results from mark-recapture trials conducted in 2020 (N = 8) and 2021 (N = 4) to evaluate rotary-screw trap efficiency at Red Bluff Diversion Dam (RKM 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	2020	winter	866	35.4	12	35.2	1.39	1.37	4	No
2	2020	winter	973	35.9	22	35.5	2.26	1.42	4	No
3	2020	winter	853	35.4	28	34.9	3.28	1.57	4	No
4	2020	winter	868	35.3	22	35.5	2.53	1.47	4	No
5	2020	winter	821	38.4	11	35.0	1.34	1.44	4	No
6	2020	winter	917	37.4	16	36.8	1.74	1.48	4	No
7	2020	winter	1,037	40.3	12	43.5	1.16	1.52	4	No
8	2020	fall	1,028	37.0	21	36.9	2.04	2.01	4	No
9	2021	fall	1,012	36.5	31	36.3	3.06	2.00	4	No
10	2021	fall	1,012	37.0	21	37.4	2.08	1.88	4	No
11	2021	fall	1,116	37.0	28	36.4	2.51	1.82	4	No
12	2021	fall	1,070	37.5	30	37.1	2.80	1.99	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 2021.

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	1,116	23.0	(14.0 : 32.1)
2004	3,677,989	2,129,297	5,232,037	3,185	5,515	1,155	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)
2020	2,270,968	1,493,511	3,048,424	3,904	4,991	582	11.7	(7.7 : 15.6)
					Average	1,156	23.4	(14.1 : 32.8)
					Standard Deviation	561	12.1	(8.0 : 16.7)

[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 2021. Brood years 2006 through 2020 include estimates with unmarked hatchery fish removed to reduce bias to JPI estimates. *BY2019 has incomplete data collection due to COVID-19 and is excluded from Average and Standard Deviation calculations.

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)
2020	8,670,945	4,766,887	12,575,004	20,802	5,166	417	8.1	(4.4 : 11.7)
					Average	699	13.4	(3.7 : 23.6)
					Standard Deviation	438	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).

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 2020. *CY2020 has incomplete data collection due to incomplete sampling from COVID-19 and is excluded from Mean, SD and CV calculations.

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
2020*	157	1.6	23	61	26.4	26
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%

* Incomplete data collection due to COVID-19

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 2021. *WY2020 has incomplete data collection due to incomplete sampling from COVID-19 and is excluded from Mean, SD and CV calculations.

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
2021	647	18.0	24	193	99	103
Mean	2030.6	27.4	18.3	173.7	95.3	98.3
SD	1687.6	24.6	13.9	18.8	6.5	8.0
CV	83.1%	90.0%	76.1%	10.8%	6.8%	8.2%

Table 11.— Pacific Lamprey macrophthalmia 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 2021. *WY2020 has incomplete data collection due to incomplete sampling from COVID-19 and is excluded from Mean, SD and CV calculations.

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
2021	6410	477.2	62	580	119	117
Mean	2283.4	135.8	74.4	544.3	135.0	121.9
SD	2492.3	177.0	18.6	39.2	15.2	4.1
CV	109.1%	130.3%	25.0%	7.2%	11.2%	3.4%

Table 12.— Summary of Coleman National Fish Hatchery brood year 2020 fall Chinook released into Battle Creek from March 10 through April 8, 2021. Week number, release dates, total number of fish released per group, mean fork length (FL) of Chinook at release (mm), length-at-date (LAD) size ranges and percent of marked fall and spring Chinook captured in the RBDD rotary traps for each production release group. *Release on March 24, 2021 included 100% marked fall Chinook; all other releases were 25% marked fall Chinook.

Week	Release Date(s)	# Released	Mean FL of release group	Fall LAD range	Fall % captures	Spring LAD range	Spring % captures
10	3/10/2021	1,290,150	70.0	0 - 64	0.0%	65 - 87	100.0%
11	3/18/2021	4,985,813	65.0	0 - 66	11.1%	67 - 89	88.9%
12	3/24/2021	185,395*	75.0	0 - 71	46.7%	72 - 95	53.3%
13	--	--	--	0 - 72	19.8%	73 - 98	80.2%
14	4/8/2021	5,389,856	72.0	36 - 77	34.3%	78 - 105	65.7%
15	--	--	--	37 - 79	83.2%	80 - 107	16.8%
16	--	--	--	39 - 83	92.2%	84 - 112	7.8%
17	--	--	--	40 - 87	85.6%	88 - 119	14.4%
18	--	--	--	42 - 91	75.9%	92 - 123	24.1%
19	--	--	--	44 - 95	100.0%	96 - 129	0.0%
Total		**11,665,819**			**54.9%**		**45.1%**

Figures

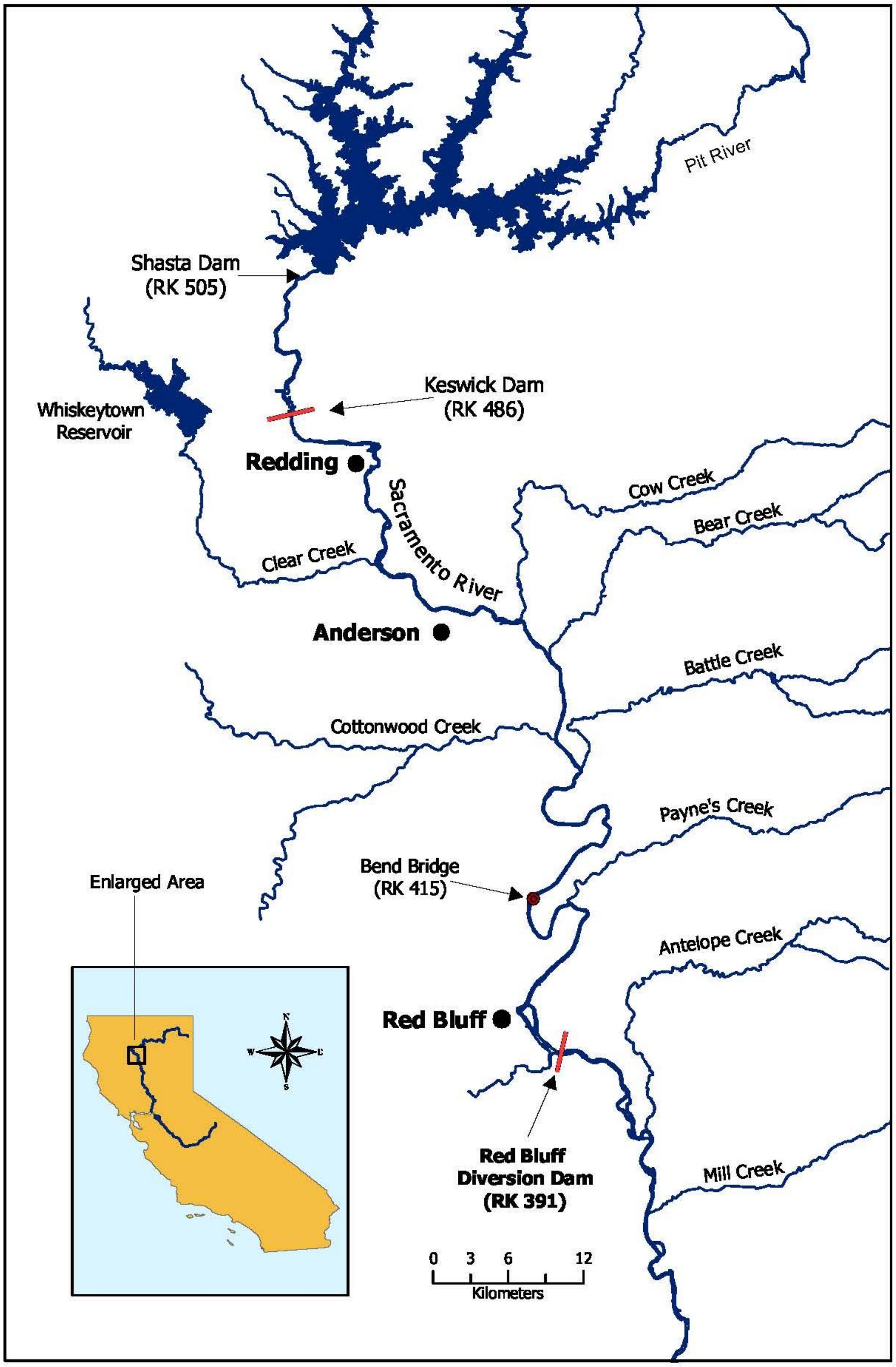

Figure 1. Location of Red Bluff Diversion Dam sample site on the Sacramento River, California, at river kilometer 391 (RKM 391)

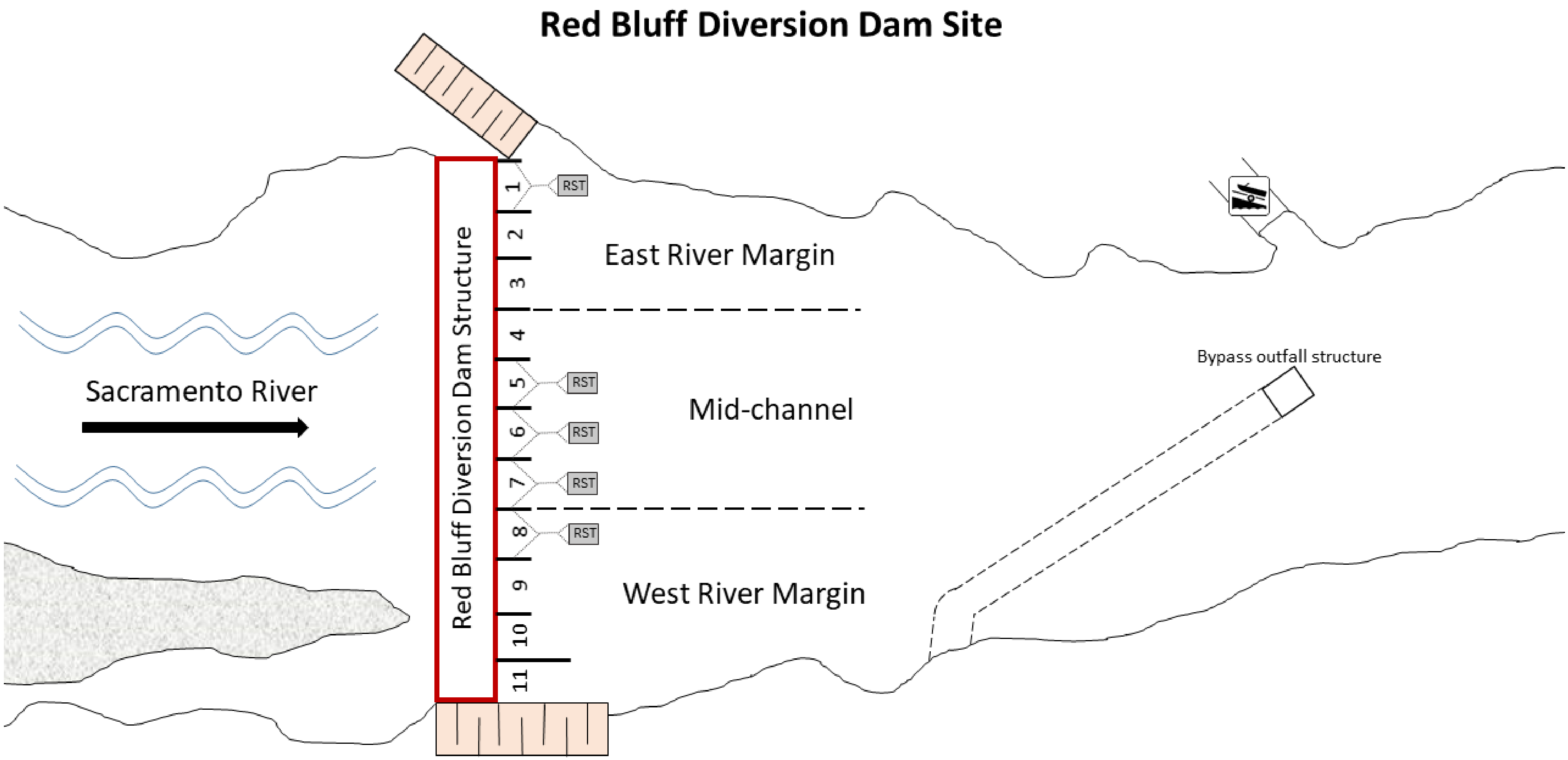

Figure 2. Rotary-screw trap sampling transect schematic of Red Bluff Diversion Dam site (RKM 391) on the Sacramento River, CA.

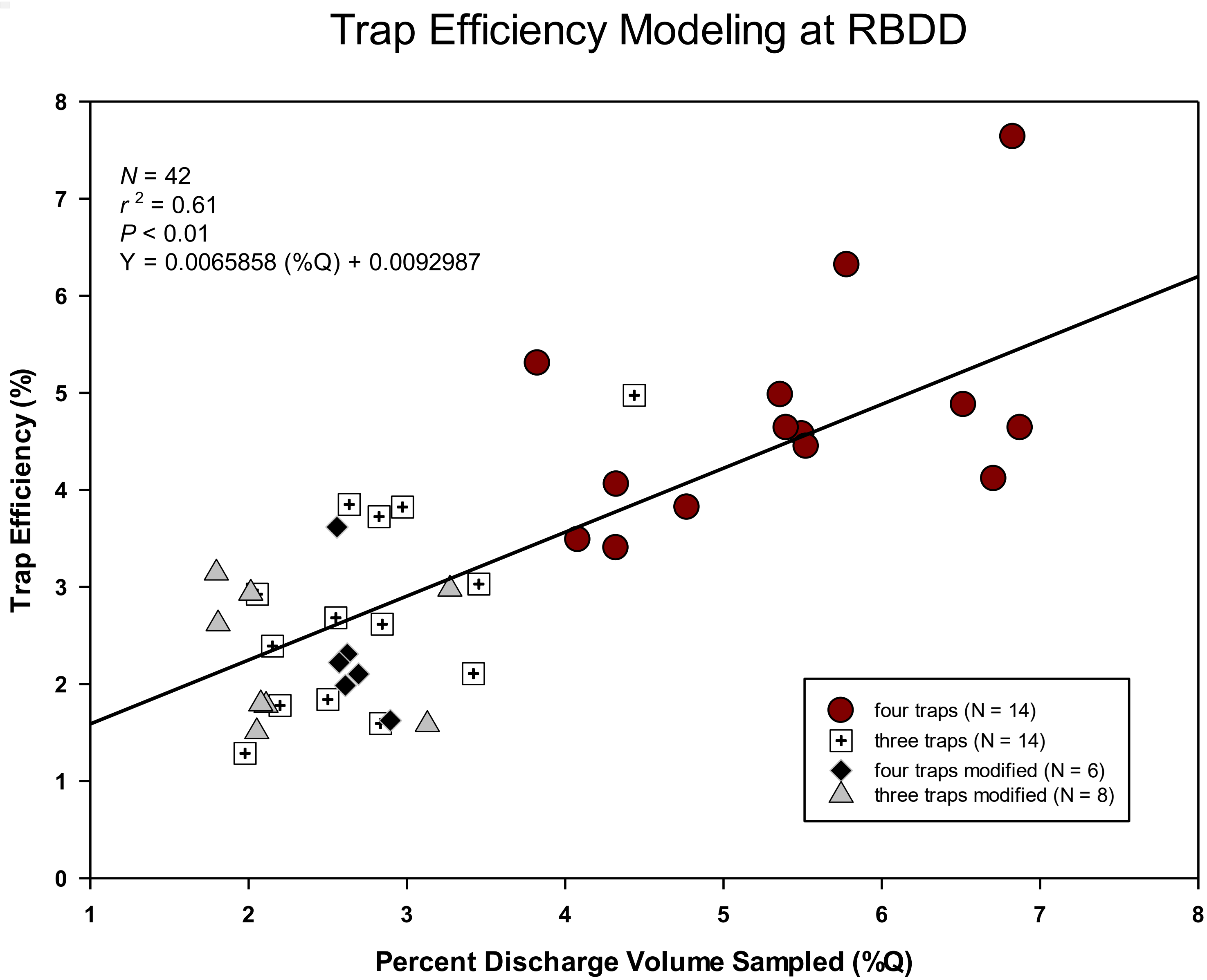

Figure 3. Trap Efficiency model for combined 2.4 m diameter rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four traps (N=14), three traps (N=14), or with traps modified to sample one-half the normal volume of water (N=14).

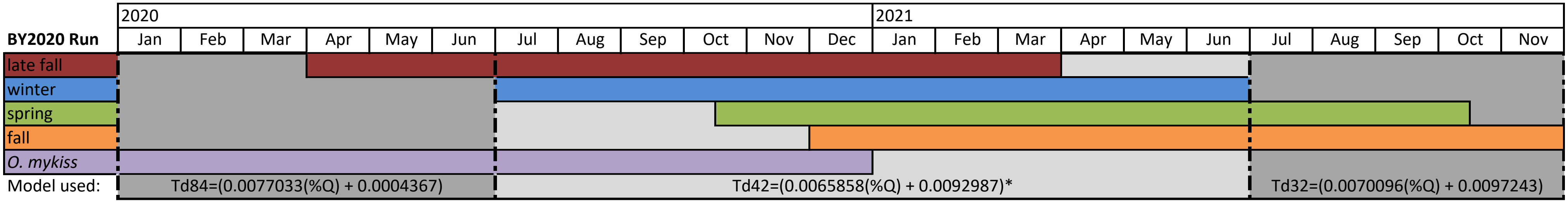

Figure 4.—Summary of trap efficiency models used for passage estimates during brood year 2020 for juvenile winter, spring, fall, late-fall Chinook Salmon and *O. mykiss* from 01/01/2020, the start of the *O. mykiss* 2020 brood year through 11/30/2021, the end of the 2020 fall Chinook brood year. *Model Td99 (Td99=(0.0073480(%Q) + 0.0025470)) was used to produce preliminary near real-time biweekly report estimates during BY2020; however, Td42 was used to produce passage estimates reported within this document.

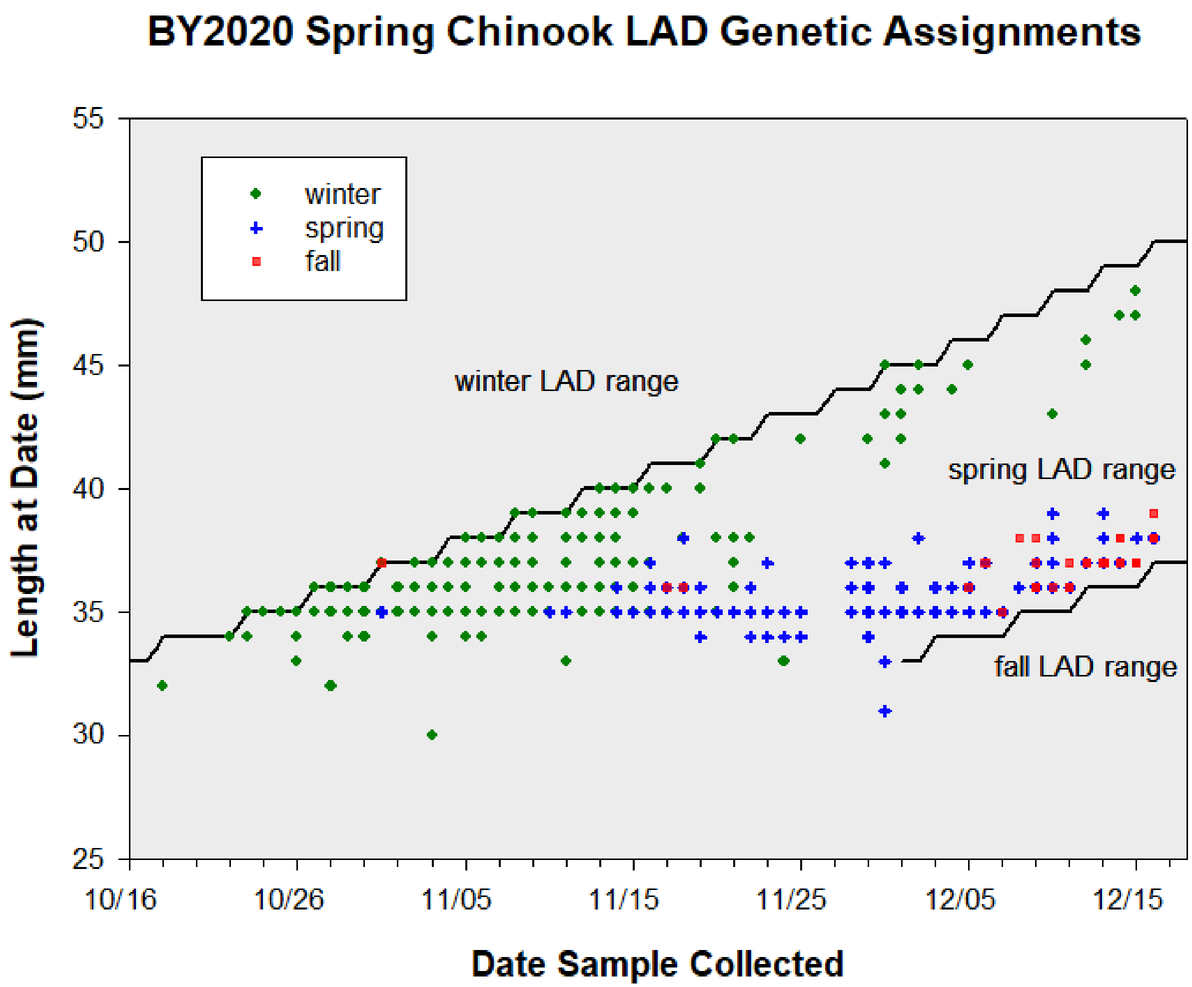

Figure 5. Genetic assignment results from brood year 2020 spring Chinook length-at-date (LAD) samples collected from 10/16/2020 through 12/16/2020. Solid black line represents upper and lower LAD range by date and genetic assignments are displayed by color and symbol.

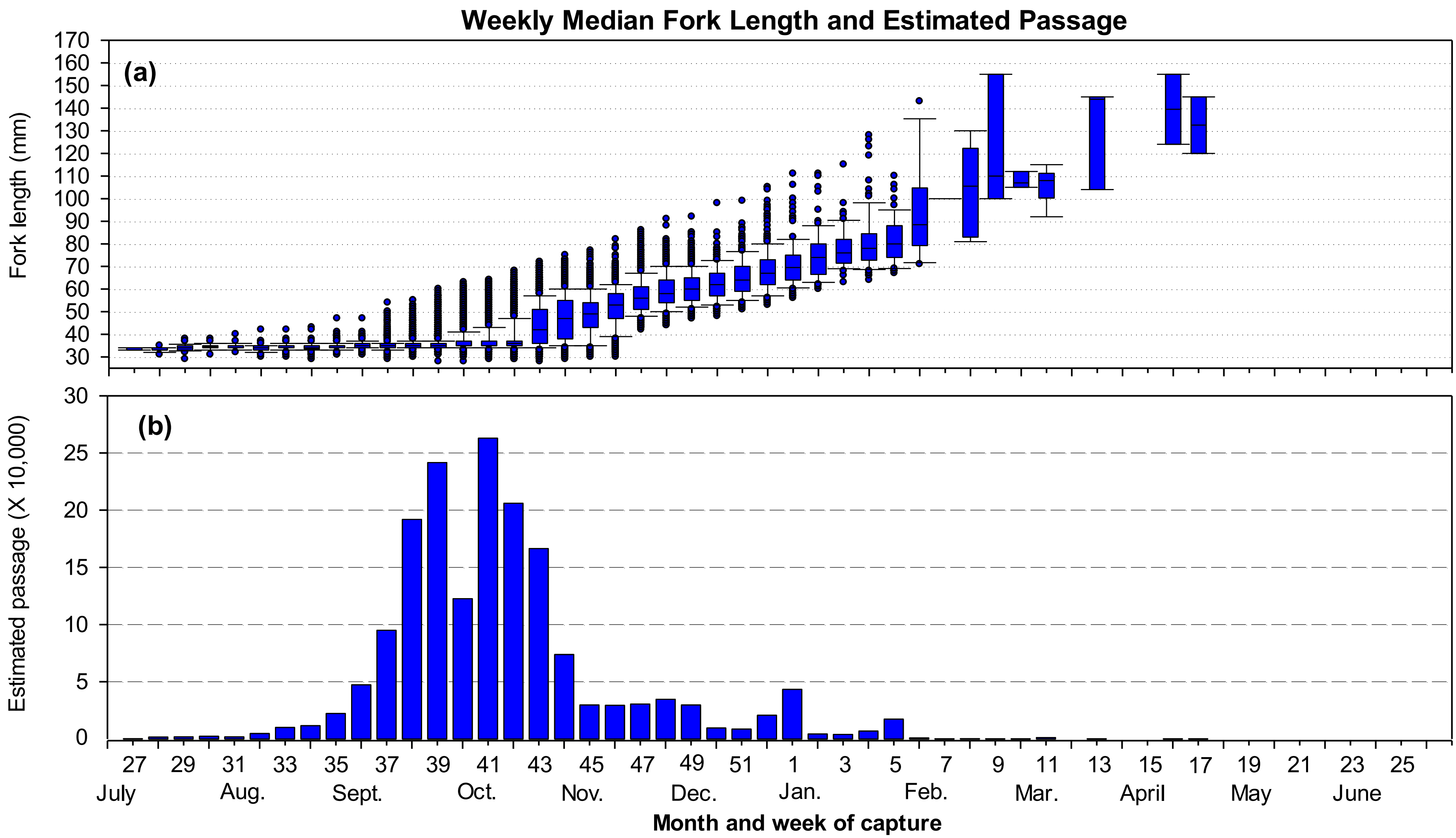

Figure 6. Weekly median fork length (a) and estimated passage (b) of brood year 2020 juvenile winter Chinook Salmon passing Red Bluff Diversion Dam (RKM 391), Sacramento River, California. Winter Chinook salmon were sampled by rotary-screw traps for the period 7/1/2020 through 6/30/2021. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

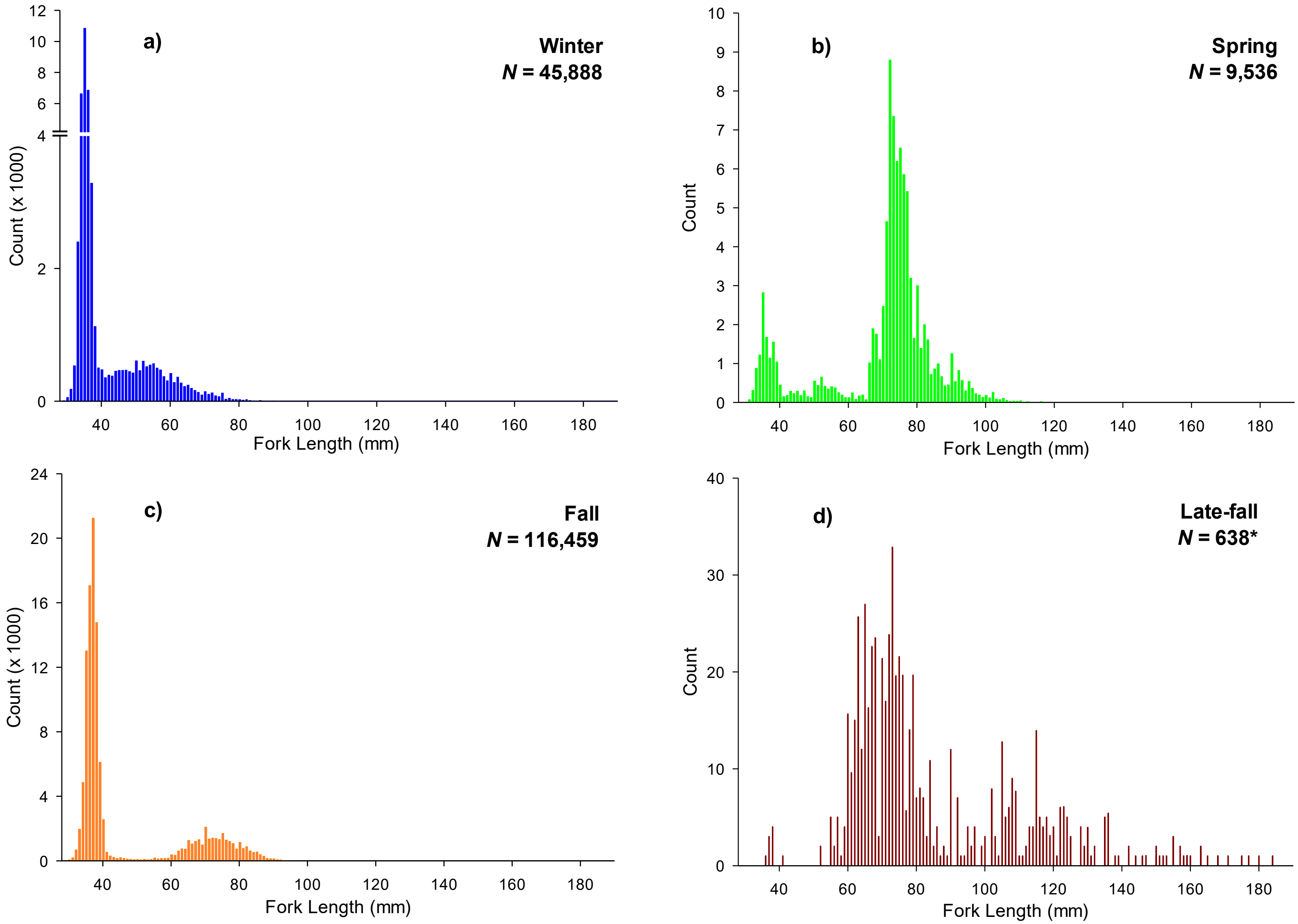

Figure 7. Fork length frequency distribution of brood year 2020 juvenile a) winter, b) spring, c) fall and d) late-fall Chinook Salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RKM 391), Sacramento River, California. Fork length data were expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from 7/1/2020 through 11/30/2021; *sampling ceased between 3/25/2020 and 6/30/2020 due to COVID-19.

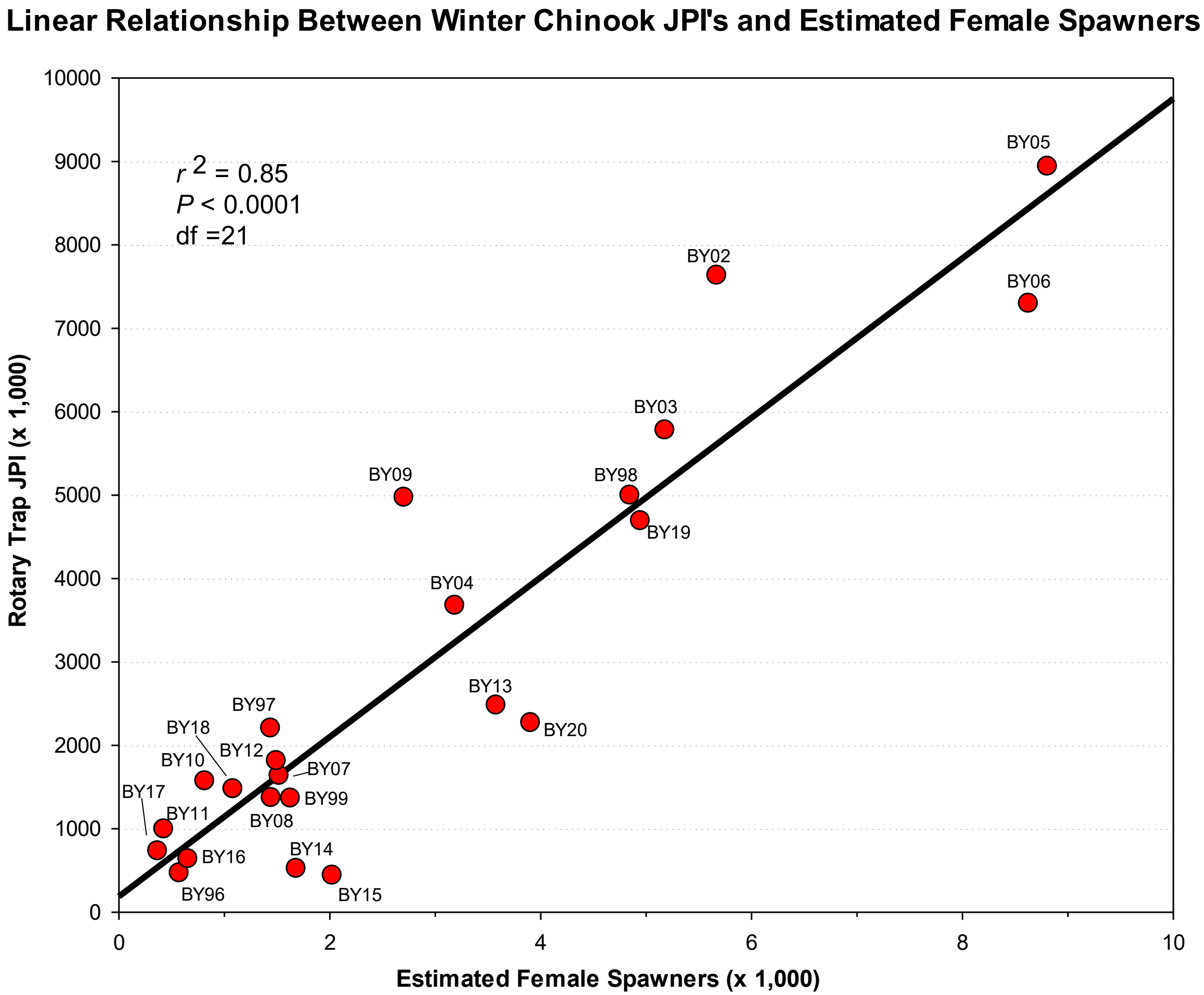

Figure 8. Linear relationship between rotary-screw trap juvenile winter Chinook fry-equivalent production indices (Rotary Trap JPI) and carcass survey derived estimated female spawners.

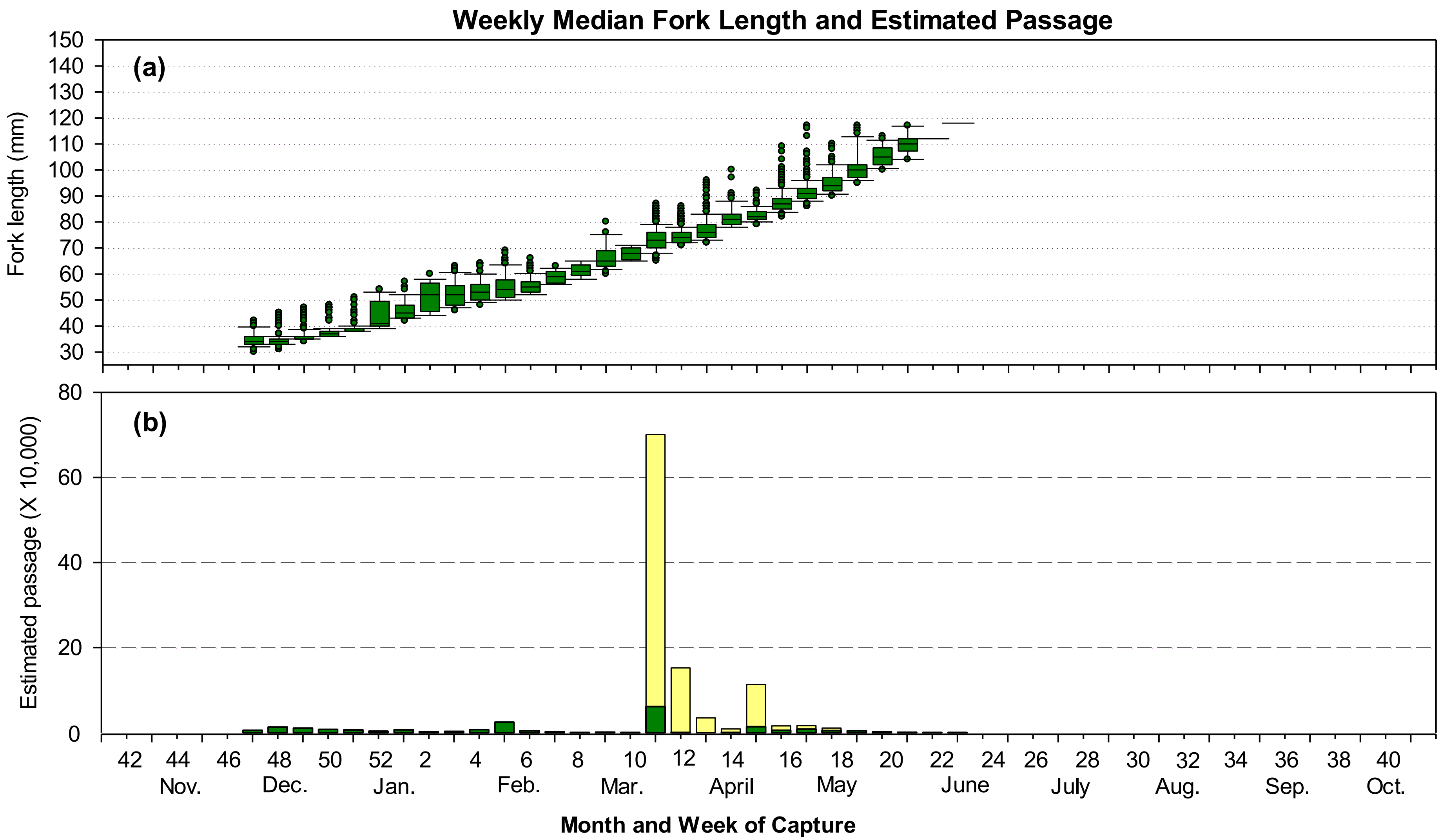

Figure 9. Weekly median fork length (a) and estimated passage (b) of brood year 2020 juvenile spring Chinook Salmon passing Red Bluff Diversion Dam (RKM 391), Sacramento River, California. Spring Chinook Salmon were sampled by rotary-screw traps for the period 10/16/2020 through 10/15/2021. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers. Yellow bars represent proportion of total passage of LAD spring Chinook that were estimated to be unmarked CNFH hatchery fall Chinook based on 75% unmarked ratio expansions.

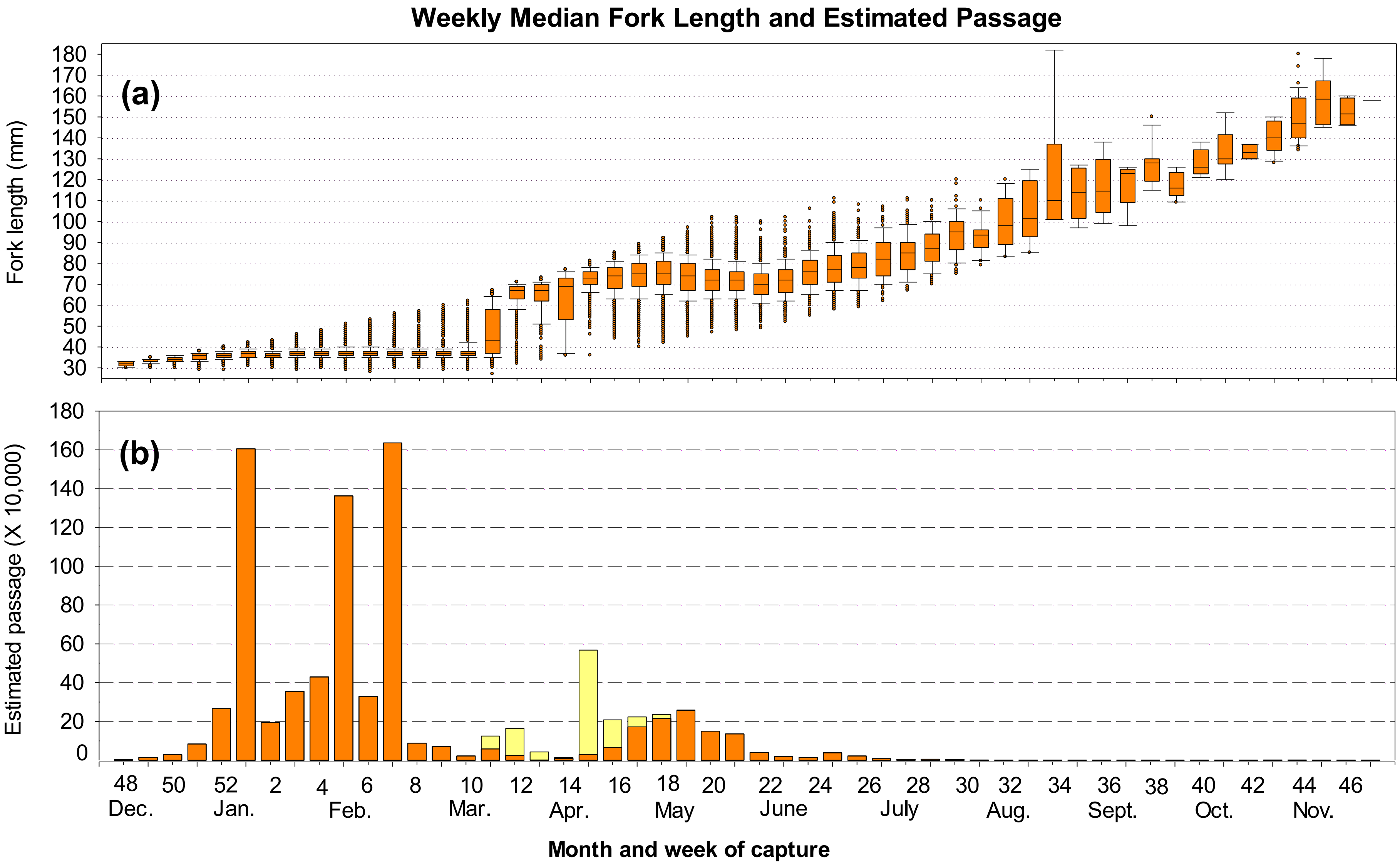

Figure 10. Weekly median fork length (a) and estimated passage (b) of brood year 2020 juvenile fall Chinook Salmon passing Red Bluff Diversion Dam (RKM 391), Sacramento River, California. Fall Chinook Salmon were sampled by rotary-screw traps for the period 12/1/2020 through 11/30/2021. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers. Yellow bars represent proportion of total passage of LAD spring Chinook that were estimated to be unmarked CNFH hatchery fall Chinook based on 75% unmarked ratio expansions.

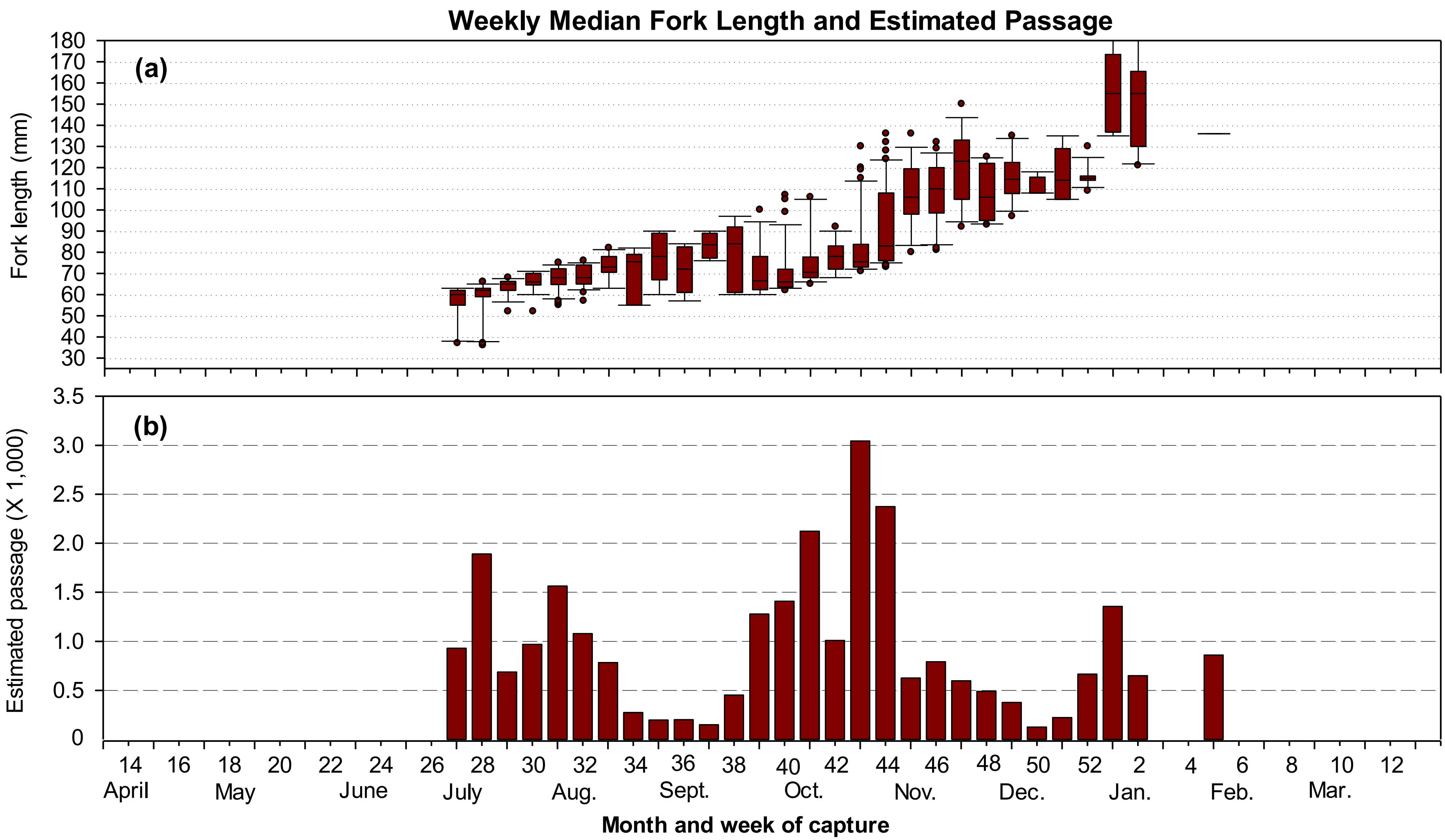

Figure 11. Weekly median fork length (a) and estimated passage (b) of brood year 2020 juvenile late-fall Chinook Salmon passing Red Bluff Diversion Dam (RKM 391), Sacramento River, California. Late-fall Chinook Salmon were sampled by rotary-screw traps for the period 7/1/2020 through 3/31/2021. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers. Shaded region represents sampling ceased due to COVID-19 pandemic (3/25/2020-6/30/2020).

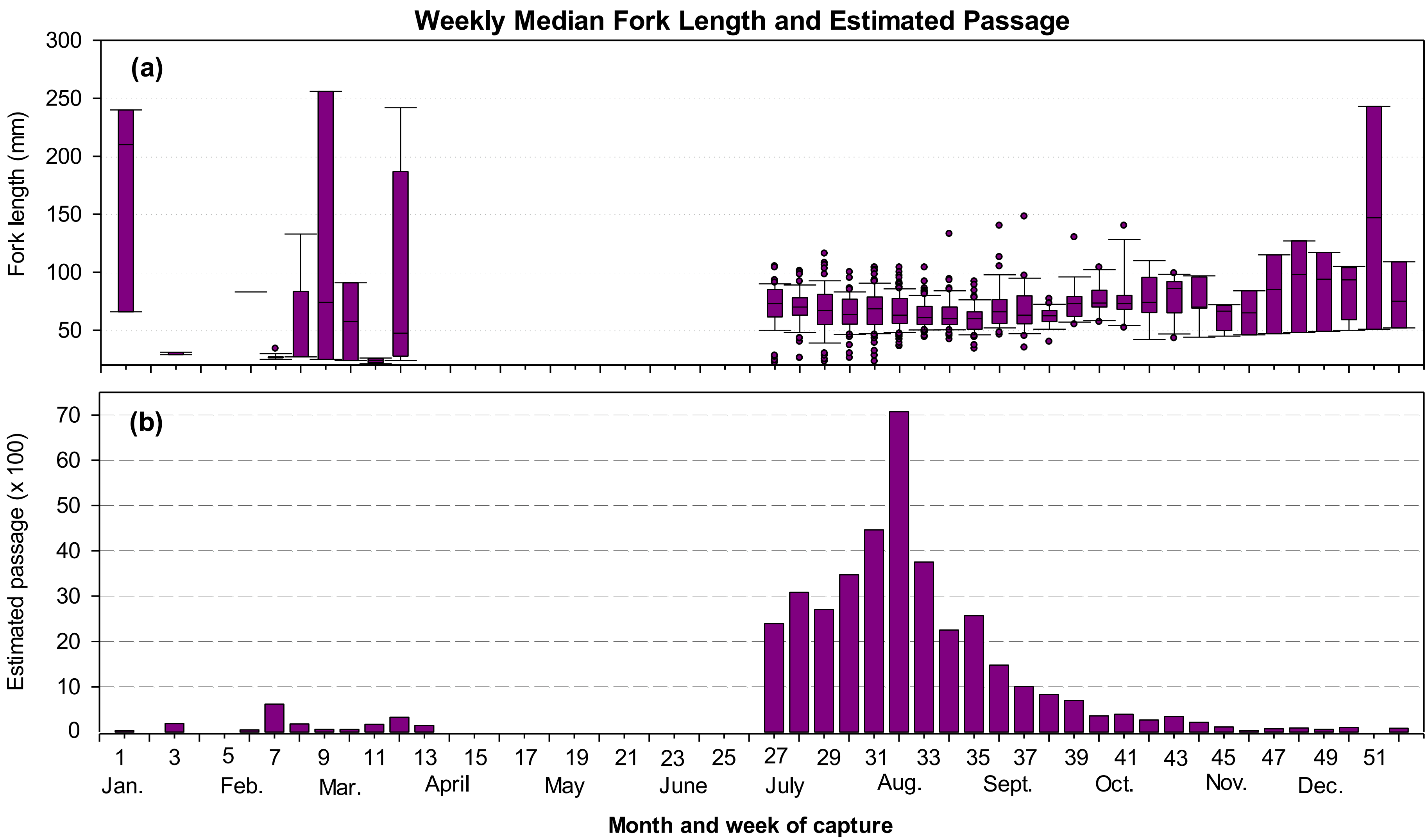

Figure 12. Weekly median fork length (a) and estimated passage (b) of brood year 2020 juvenile *O. mykiss* passing Red Bluff Diversion Dam (RKM 391), Sacramento River, California. *O. mykiss* were sampled by rotary-screw traps for the period 1/1/2020 through 12/31/2020. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers. Shaded region represents sampling ceased due to COVID-19 pandemic (3/25/2020-6/30/2020).

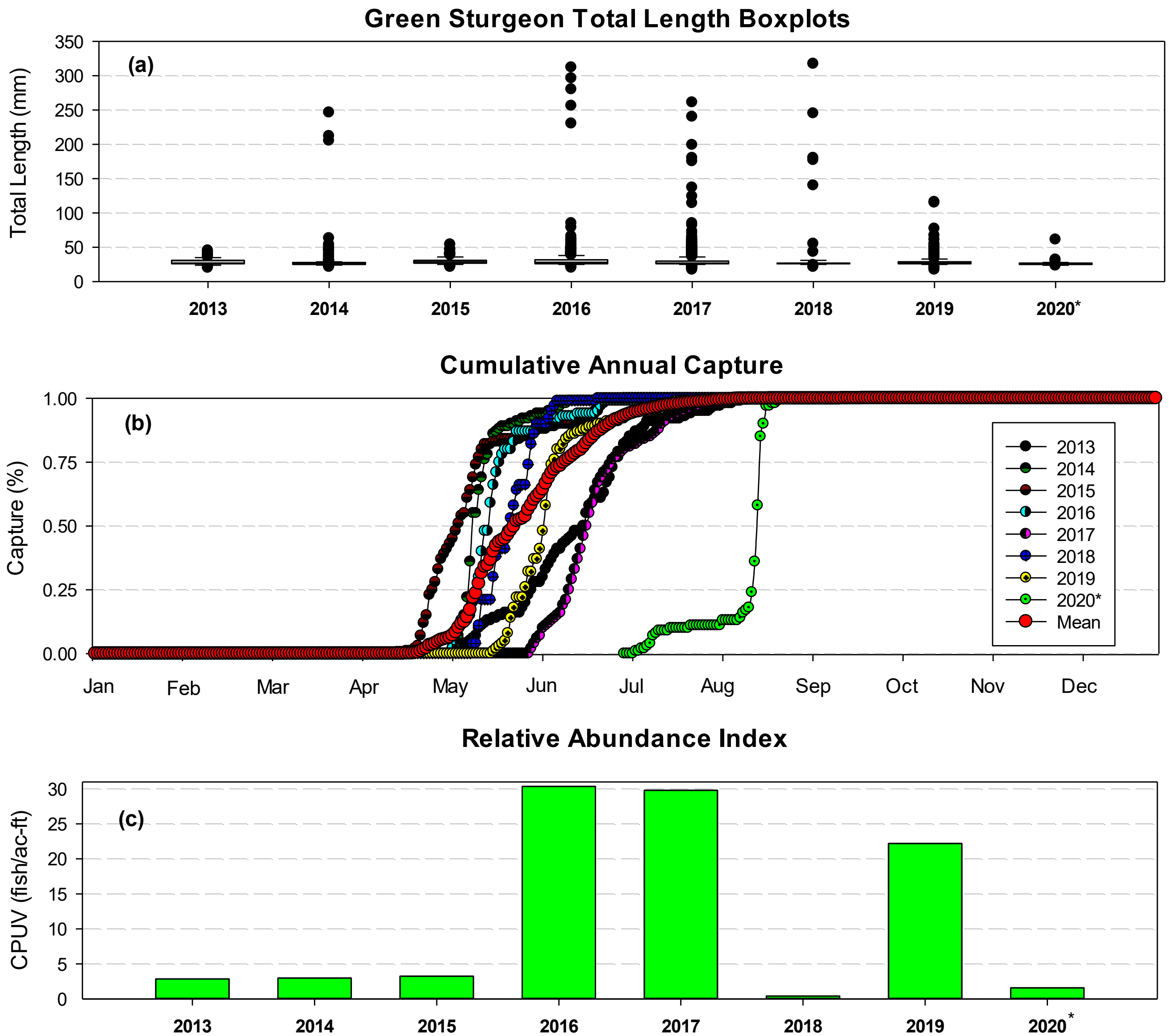

Figure 13. Green Sturgeon a) annual total length capture boxplots, b) annual cumulative capture trends with 17-year mean trend line, and c) relative abundance indices. All fish captured by rotary trap at RBDD (RKM 391) on the upper Sacramento River, CA between 2013 and 2020. *Calendar year 2020 included a period of no sampling due to COVID-19 pandemic from 3/25/2020-6/30/2020.

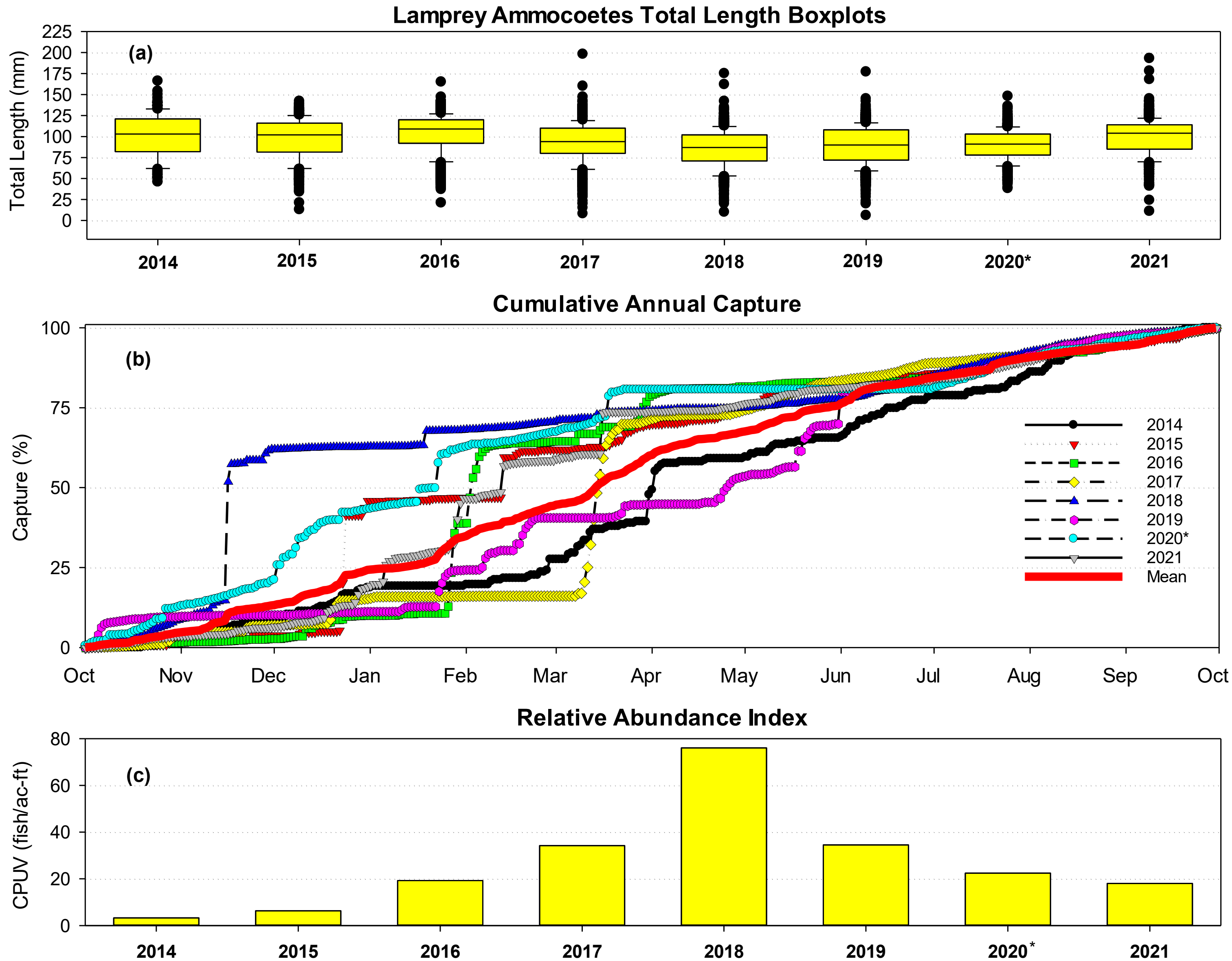

Figure 14. Unidentified lamprey ammocoetes a) total length distribution box plots, b) cumulative annual capture trends, and c) relative abundance indices from rotary traps collected between 10/1/2013 and 9/30/2020 by water year from the Sacramento River, CA at the RBDD (RKM 391). *Water year 2020 included a period of no sampling from 3/25/2020 to 6/30/2020 due to the COVID-19 global pandemic.

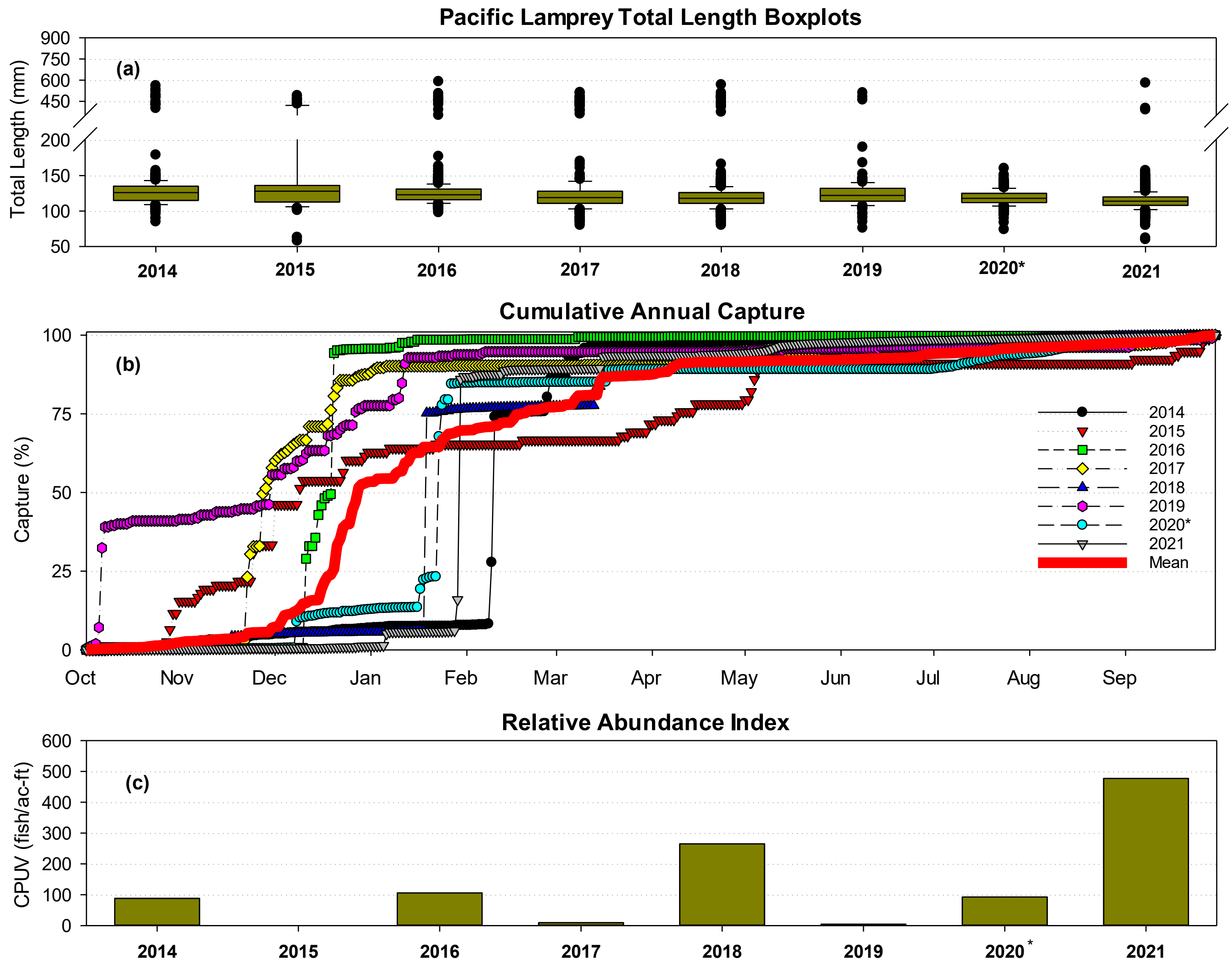

Figure 15. Pacific Lamprey (macropthalmia and adults) a) total length distribution box plots, b) cumulative annual capture trends, and c) relative abundance indices from rotary traps collected between 10/1/2013 and 9/30/2020 by water year from the Sacramento River, CA at the RBDD (RKM 391). *Water year 2020 included a period of no sampling from 3/25/2020 to 6/30/2020 due to the COVID-19 global pandemic.

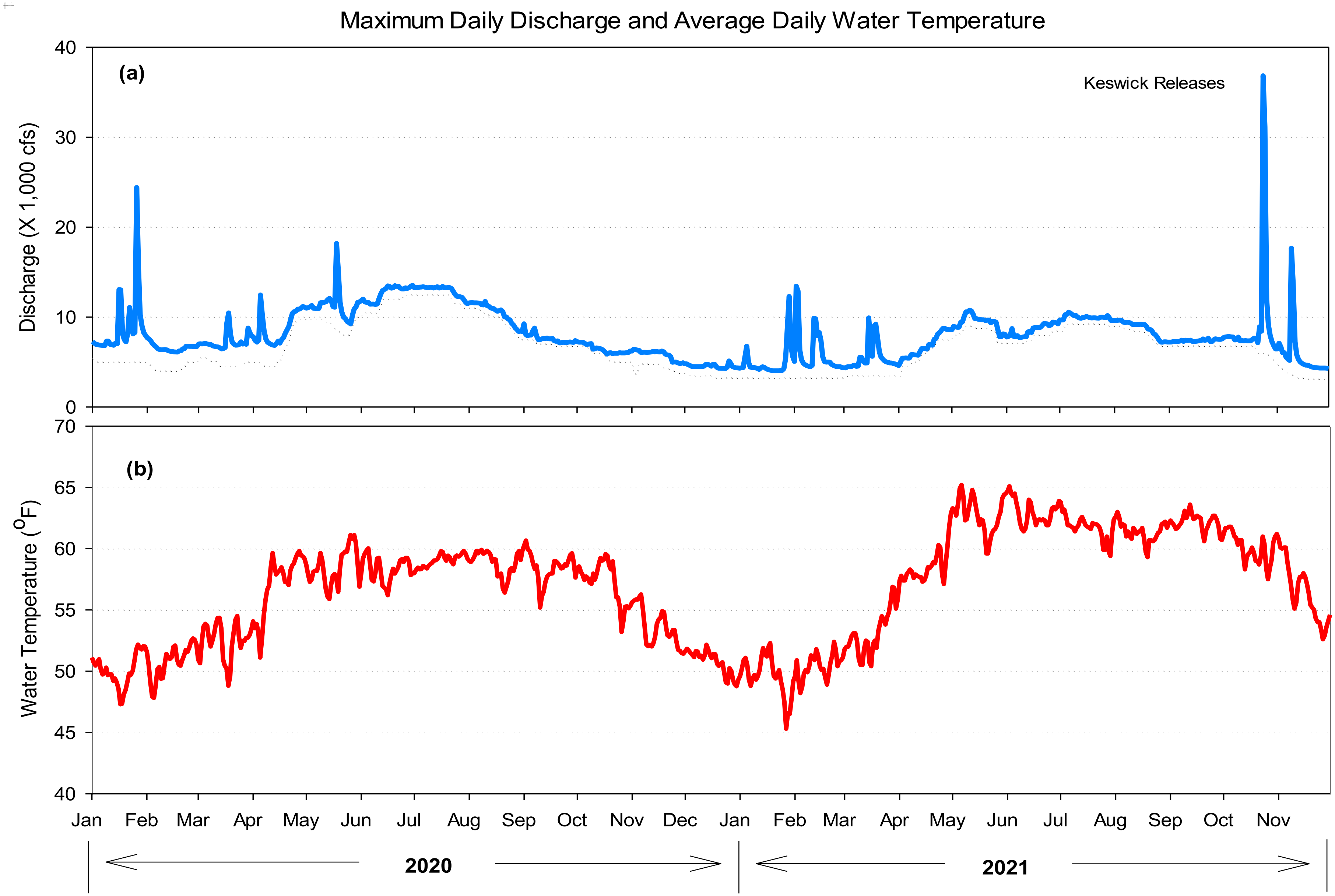

Figure 16. Sacramento River maximum daily discharge (a) observed at the California Data Exchange Center's Bend Bridge gaging station (blue line) showing water releases from Keswick Reservoir (cross-hatched gray shaded area) and average daily water temperatures (b) from rotary-screw traps at RBDD for the period 1/1/2020 through 11/30/2021. Shaded vertical region across both figures represents a period of no 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.

Table A1— 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 (RKM 391) for the period October 16, 2020 through October 15, 2021 (brood year 2020). 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
42	1.00	0	-	0	-	0	-	0
43	1.00	0	-	0	-	0	-	0
44 (Nov)	0.97	0	-	0	-	0	-	0
45	1.00	0	-	0	-	0	-	0
46	1.00	0	-	0	-	0	-	0
47	1.00	5,589	34	0	-	5,589	34	5,589
48 (Dec)	1.00	12,984	34	0	-	12,984	34	12,984
49	1.00	10,285	35	226	46	10,511	35	10,669
50	1.00	6,997	37	367	47	7,364	37	7,621
51	1.00	5,898	38	316	50	6,214	38	6,435
52	0.86	1,846	40	1,443	51	3,288	41	4,298
1 (Jan)	0.94	3,862	44	2,665	49	6,527	45	8,393
2	0.91	462	45	1,072	53	1,534	52	2,285
3	1.00	0	-	2,874	52	2,874	52	4,885
4	0.90	0	-	7,201	53	7,201	53	12,242
5 (Feb)	0.76	0	-	24,369	54	24,369	54	41,427
6	0.94	0	-	4,256	55	4,256	55	7,236
7	0.91	0	-	1,673	59	1,673	59	2,844
8	0.94	0	-	302	61	302	61	514
9 (Mar)	1.00	0	-	865	65	865	65	1,471
10	1.00	0	-	156	68	156	68	265
11	0.71	0	-	700,850	73	700,850	73	1,191,445
12	0.50	0	-	151,991	74	151,991	74	258,386
13	0.77	0	-	34,862	76	34,862	76	59,266
14 (Apr)	0.40	0	-	8,501	81	8,501	81	14,452
15	0.41	0	-	112,990	82	112,990	82	192,083

Table A1—(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	0.77	0	-	15,713	87	15,713	87	26,712
17	0.87	0	-	16,560	91	16,560	91	28,152
18 (May)	0.84	0	-	10,655	94	10,655	94	18,114
19	0.84	0	-	4,324	100	4,324	100	7,351
20	0.77	0	-	1,690	105	1,690	105	2,873
21	0.86	0	-	569	110	569	110	968
22 (Jun)	0.83	0	-	42	112	42	112	71
23	0.89	0	-	39	118	39	118	66
24	0.74	0	-	0	-	0	-	0
25	0.77	0	-	0	-	0	-	0
26	0.80	0	-	0	-	0	-	0
27 (Jul)	0.57	0	-	0	-	0	-	0
28	0.80	0	-	0	-	0	-	0
29	0.80	0	-	0	-	0	-	0
30	0.80	0	-	0	-	0	-	0
31 (Aug)	0.80	0	-	0	-	0	-	0
32	0.83	0	-	0	-	0	-	0
33	0.89	0	-	0	-	0	-	0
34	0.86	0	-	0	-	0	-	0
35 (Sep)	0.89	0	-	0	-	0	-	0
36	1.00	0	-	0	-	0	-	0
37	1.00	0	-	0	-	0	-	0
38	1.00	0	-	0	-	0	-	0
39	1.00	0	-	0	-	0	-	0
40 (Oct)	0.94	0	-	0	-	0	-	0
41	0.91	0	-	0	-	0	-	0
BY total		47,922		1,106,572		1,154,494		1,929,094
90% CI (low : high)		(29,968 : 65,876)		(345,424 : 1,867,720)		(376,327 : 1,932,660)		(620,807 : 3,237,381)

Table A2— 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 (RKM 391) for the period October 16, 2020 through October 15, 2021 (brood year 2020). 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
48 (Dec)	1.00	3,860	32	0	-	3,860	32	3,860
49	1.00	14,557	34	0	-	14,557	34	14,557
50	1.00	28,883	34	0	-	28,883	34	28,883
51	1.00	83,981	36	0	-	83,981	36	83,981
52	0.86	266,048	36	0	-	266,048	36	266,048
1 (Jan)	0.94	1,605,306	37	0	-	1,605,306	37	1,605,306
2	0.91	194,359	36	0	-	194,359	36	194,359
3	1.00	355,114	37	61	46	355,175	37	355,217
4	0.90	422,738	37	6,415	47	429,153	37	433,643
5 (Feb)	0.76	1,337,460	37	25,520	47	1,362,979	37	1,380,843
6	0.94	322,171	37	6,677	48	328,847	37	333,521
7	0.91	1,630,404	37	5,624	50	1,636,027	37	1,639,964
8	0.94	86,732	37	1,421	50	88,153	37	89,148
9 (Mar)	1.00	69,713	37	1,801	52	71,514	37	72,774
10	1.00	20,536	37	1,509	52	22,044	37	23,100
11	0.71	35,960	37	89,089	61	125,050	43	187,412
12	0.50	6,518	37	157,791	67	164,309	67	274,763
13	0.77	1,136	38	41,505	67	42,640	67	71,694
14 (Apr)	0.40	2,310	37	11,561	71	13,871	69	21,964
15	0.41	318	36	567,452	73	567,771	73	964,987
16	0.77	179	45	208,324	74	208,504	74	354,331
17	0.87	750	43	222,023	75	222,773	75	378,190
18 (May)	0.84	461	44.5	235,480	75	235,941	75	400,777
19	0.84	124	45	258,170	74	258,293	74	439,012
20	0.77	0	-	149,616	72	149,616	72	254,347
21	0.86	0	-	135,800	72	135,800	72	230,860

Table A2—(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)	0.83	0	-	40,316	70	40,316	70	68,538
23	0.89	0	-	19,636	72	19,636	72	33,381
24	0.74	0	-	14,069	76	14,069	76	23,917
25	0.77	0	-	37,953	77	37,953	77	64,520
26	0.80	0	-	21,592	78	21,592	78	36,707
27 (Jul)	0.57	0	-	7,803	82	7,803	82	13,264
28	0.80	0	-	4,813	85	4,813	85	8,183
29	0.80	0	-	5,423	87	5,423	87	9,219
30	0.80	0	-	3,770	95	3,770	95	6,408
31 (Aug)	0.80	0	-	985	93.5	985	93.5	1,674
32	0.83	0	-	472	98	472	98	803
33	0.89	0	-	495	101.5	495	101.5	841
34	0.86	0	-	289	110	289	110	491
35 (Sep)	0.89	0	-	191	114	191	114	325
36	1.00	0	-	292	114.5	292	114.5	497
37	1.00	0	-	177	123	177	123	302
38	1.00	0	-	428	128	428	128	728
39	1.00	0	-	422	116	422	116	717
40 (Oct)	0.94	0	-	307	126	307	126	522
41	0.91	0	-	310	130	310	130	528
42	0.89	0	-	181	136	181	136	308
43	0.71	0	-	1,480	140	1,480	140	2,517
44 (Nov)	0.89	0	-	1,442	147	1,442	147	2,452
45	0.87	0	-	421	158.5	421	158.5	716
46	0.89	0	-	127	151.5	127	151.5	215
47	0.83	0	-	36	158	36	158	61
BY total		6,489,617		2,289,271		8,778,888		10,381,378
90% CI (low : high)		(3,567,567 : 9,411,668)		(1,054,171 : 3,524,371)		(4,637,682 : 12,920,094)		(5,383,414 : 15,379,341)

Table A3.— 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 2021. *BY2019 has incomplete data collection due to COVID-19 and is excluded from Average and Standard Deviation calculations.

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	20,276,322	8,670,090	32,604,760	42,730	5,407	475	8.8	(3.8 : 14.1)
2007	13,907,856	7,041,759	20,838,463	16,996	5,407	818	15.1	(7.7 : 22.7)
2008	10,817,397	5,117,059	16,517,847	16,644	5,362	650	12.1	(5.7 : 18.5)
2009	9,674,829	3,678,373	15,723,368	6,531	5,318	1,481	27.9	(10.6 : 45.3)
2010	10,620,144	5,637,617	15,895,197	7,008	5,167	1,515	29.3	(15.6 : 43.9)
2011	7,554,574	4,171,332	10,960,125	9,260	5,945	816	13.7	(7.6 : 19.9)
2012	26,567,379	17,219,525	36,197,837	32,635	5,242	814	15.5	(10.1 : 21.2)
2013	34,163,943	6,247,962	62,079,924	39,422	5,390	867	16.1	(2.9 : 29.2)
2014	4,387,348	2,407,113	6,367,583	35,345	5,453	124	2.3	(1.2 : 3.3)
2015	30,728,228	-533,520	61,973,977	23,302	4,971	1,319	26.5	(-0.5 : 53.5)
2016[3]	25,812,410	-22,447,165	74,071,986	5,240	4,778	4,926	103.1	(-89.7 : 295.9)
2017	3,482,430	1,927,884	5,036,976	4,437	4,455	785	17.6	(9.8 : 25.5)
2018	13,178,718	-724,690	27,082,125	11,631	5,442	1,133	20.8	(-1.1 : 42.8)
2019*	7,575,182	2,718,701	12,431,662	24,421	4,815	310	6.4	(2.3 : 10.6)
2020	10,381,378	5,383,414	15,379,341	20,802	5,166	499	9.7	(5.0 : 14.3)
					Average	994	19.4	(-0.2 : 39.5)
					Standard Deviation	1,061	22.3	(22.1 : 64.0)

[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 2016.

[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]2016 values prior to CNFH fall Chinook releases: Fry Equivalent JPI: 8,471,017 (-3,521,433 : 20,463,466); Estimated Recruits/Female: 1,617; ETF Survival Rate (%): 33.8% (-14.1 : 81.7).