2021 RED BLUFF DIVERSION DAM ROTARY TRAP JUVENILE ANADROMOUS FISH ABUNDANCE ESTIMATES

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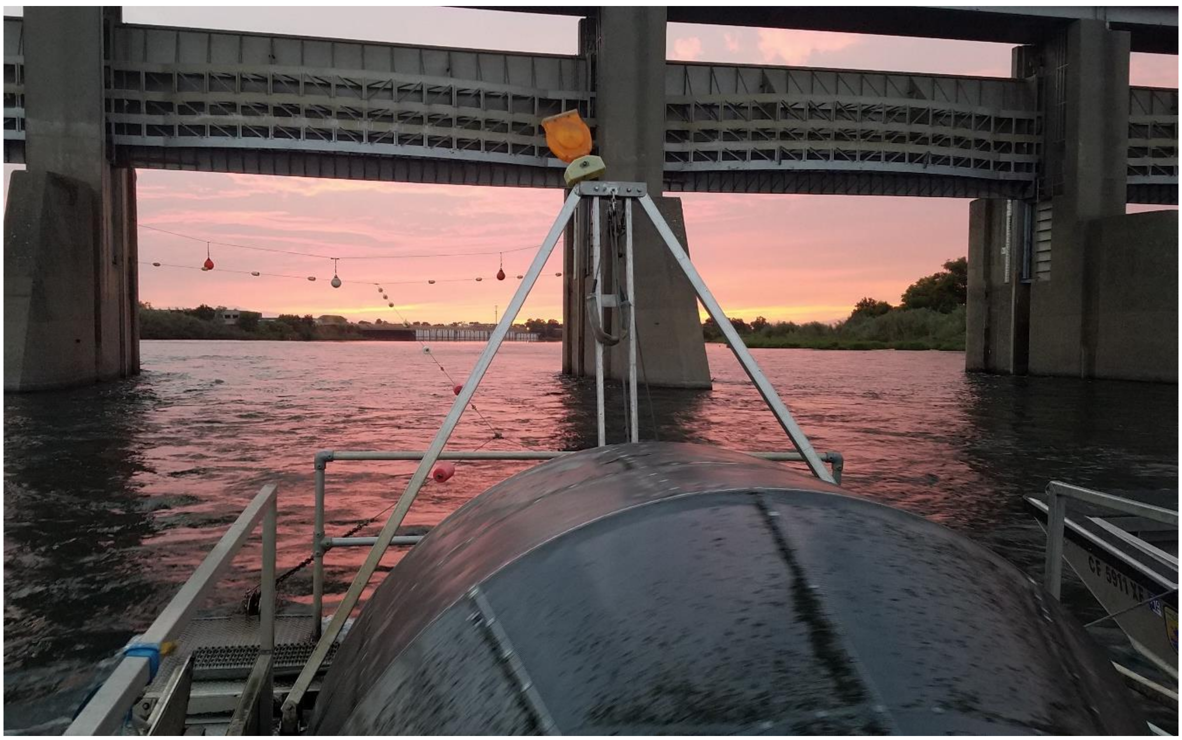

Prepared by:
Scott D. Voss and William R. Poytress

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

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Scott D. Voss and William R. Poytress

U.S. Fish and Wildlife Service
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***Abstract*.** Water year 2021 was designated as critically dry for the Sacramento Valley. Shasta Reservoir cold-water pool storage conditions did not allow for maintaining a daily average temperature of 56˚F or lower at the Clear Creek River (CCR) gauge for the duration of the temperature management season. After input from various agencies and stakeholders, a temperature control strategy using the Highway 44 Bridge (SAC) gauge compliance point was developed with life stage related temperature criteria to minimize modeled temperature dependent mortality utilizing the limited cold water pool.

Brood year 2021 (BY2021) juvenile winter Chinook salmon estimated passage at Red Bluff Diversion Dam (RBDD) was 572,664 for fry and pre-smolt/smolts combined. The fry-equivalent rotary trap juvenile production index (JPI) was estimated at 779,427 with the lower and upper 90% confidence intervals (CI) extending from 497,328 to 1,061,526 juveniles, respectively. The estimated egg-to-fry (ETF) survival rate, based on the BY2021 winter Chinook fry-equivalent JPI was 2.5%, a 20-year low. The range of ETF survival rates based on the 90% CI was 1.6% to 3.4%.

BY2021 juvenile spring Chinook salmon estimated passage was 189,576 fry and pre-smolt/smolts combined. The fry-equivalent JPI for 2021 spring Chinook was 248,842 with the lower and upper 90% CI extending from 123,936 to 373,748 juveniles, respectively. BY2021 fall Chinook juvenile estimated passage at RBDD was 5,361,012 fry and pre-smolt/smolts combined. The fry-equivalent JPI for 2021 fall Chinook was 5,900,643 with the lower and upper 90% CI extending from 3,766,576 to 8,034,709 juveniles, respectively. The estimated ETF survival rate was 5.1%, based on the BY2021 fall Chinook fry-equivalent JPI, estimated number of female spawners and eggs deposited in-river. BY2021 juvenile late-fall Chinook estimated passage at RBDD was 59,169 fry and pre-smolt/smolts combined. The fry-equivalent JPI for BY2021 late-fall was 97,255 with the lower and upper 90% CI extending from 45,695 to 148,815 juveniles, respectively.

A total of 1,043 sturgeon were captured during calendar year 2021 and ranged in total length from 21 to 331 mm. Green Sturgeon larval captures began in late April and continued through mid-August of 2021. Age-0 juvenile Green Sturgeon captures occurred in June (N=1) and July (N=3) and a single age-1 Green Sturgeon was captured in January. Annual Green Sturgeon catch per unit volume (CPUV) for 2021 was 12.3 fish/ac-ft.

Lamprey species sampled during water year 2022 (WY2022) included Pacific Lamprey (*Entosphenus tridentata*), Western Brook Lamprey (*Lampetra richardsoni*) and River Lamprey (*Lampetra ayresi*). Unidentified lamprey ammocoetes and Pacific Lamprey comprised 90.0% of all captures, 7.2% and 82.7% respectively. Lamprey CPUV for WY2022 was 24.3 fish/ac-ft for unidentified lamprey ammocoetes and 703.2 fish/ac-ft for Pacific lamprey. Both values are above the 19-year averages of 15.3 ± 17.7 fish/ac-ft for unidentified lamprey ammocoetes and 110.8 ± 183.9 fish/ac-ft for Pacific lamprey.

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Introduction

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

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

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

Martin et al. (2001) stated that RBDD was an ideal location to monitor juvenile winter Chinook production because (1) the spawning grounds occur 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-run Chinook salmon as threatened under the emergency listing procedures for the ESA (16 U.S.C.R. 1531-1543) on August 4, 1989 (54 FR 32085). A proposed rule to add winter Chinook salmon to the list of threatened species beyond expiration of the emergency rule was published by the NMFS on March 20, 1990 (55 FR 10260). Winter Chinook salmon were formally added to the list of federally threatened species by final rule on November 5, 1990 (55 FR 46515), and they were listed as a federally endangered species on January 4, 1994 (59 FR 440).

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 spp.*) 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) 2021, (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.

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[2] Real-time passage estimates located on SacPAS: Central Valley Prediction & Assessment of Salmon: https://www.cbr.washington.edu/sacramento/data/juv_monitoring.html

This annual progress report addresses, in detail, our juvenile anadromous fish monitoring activities at RBDD for the period January 1, 2021 through November 30, 2022. This report includes JPI's for the 2021 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 reaches the Pacific Ocean via San Francisco Bay (Figure 1). Shasta Dam and its associated downstream flow regulating structure, Keswick Dam, have formed a complete barrier to upstream anadromous fish passage since 1943 (Moffett 1949). The 95 River Kilometer (RK) reach between Keswick Dam (RK 486) and RBDD (RK 391) supports areas of intact riparian vegetation and largely remains unobstructed. Within this reach, several major tributaries to the Sacramento River upstream of RBDD support various Chinook salmon spawning populations. These include Clear Creek and Cottonwood Creek (including Beegum Creek) on the west side of the Sacramento River and Cow Creek, Bear Creek, Battle Creek and Payne's Creek on the east side (Figure 1). Below RBDD, the river encounters greater anthropogenic impacts as it flows south to the Sacramento-San Joaquin Delta. Impacts include, but are not limited to, channelization, water diversion, agricultural and municipal run-off, and loss of associated riparian vegetation.

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

Methods

Sampling Gear. 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 rotary traps across the transect varied throughout the study period but generally sampled in the river-margins (east and west) and mid-channel habitats simultaneously (Figure 2). RSTs were positioned within these spatial zones unless sampling equipment failed, river depths were insufficient (< 1.2 m), or river hydrology restricted our ability to sample with all traps (water velocity < 0.6 m/s).

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

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

[3] Sampling of (4) 1.5 m and (1) 2.4 m RST is equivalent to sampling 87.5% volume of (4) 2.4 m RST's.
[4] 24-hr sample periods were defined as beginning at 07:00 on day 1 and ending at 06:59 on day 2.

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 juveniles was possible based on meristic traits for individuals > 46 mm TL and larva were identified to genus for 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. Adults 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 gauging station at RK 415 (USGS site no. 11377100, http://waterdata.usgs.gov/usa/nwis/uv?site_no=11377100). Daily river volume at RBDD was adjusted from Bend Bridge river flows by subtracting daily TCCA diversions, when diversions occurred.

Sampling Effort. Weekly rotary trap sampling effort was quantified by assigning a value of 1.00 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 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

[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.

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; $\widehat{T}$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).

During BY2020, further refinement of the model occurred whereby trials conducted prior to the cease in RBDD gate operations in 2011 were removed (Voss and Poytress 2022) resulting in a 42-trial model. Changes in river morphology since the winter of 2016 led to shallower conditions and increased trap efficiencies across the transect that were observed beginning in 2018. The BY2021 passage and production estimates employ a 32-trial hybrid configuration trap efficiency model incorporating 12 trials 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 (r^2 = 0.40, P = < 0.016, df = 31; Figure 3).

Daily Passage Estimates ($\widehat{\mathbf{P}}_d$). 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.

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

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 2021 as the best available science. This survival estimate was employed, as recommended by the Interagency Ecological Program's Winter-Run Project Work Team, to produce a winter run juvenile production estimate to guide incidental take at the Sacramento-San Joaquin Delta pumping facilities in 2020 (NMFS 2022). O'Farrell's method incorporates summation of fry JPI and a weighted (2.258:1) pre-smolt/smolt JPI (inverse value of 44.29% fry-to-pre-smolt/smolt survival) for estimation of BY2021 winter Chinook fry-equivalents. All BY2021 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 2022) 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 smolts from CNFH in the late winter to early spring months can impart positive bias to naturally produced spring and fall run Chinook passage and production estimates (Voss and Poytress 2019). In most years, CNFH fall Chinook smolts are released at lengths that overlap with the spring Chinook LAD size category. Therefore, unmarked hatchery fish captures 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 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 for fall and spring Chinook herein are reported with the removal of hatchery fish in Tables 2, 3 and 8 and without in Appendix Tables A1-A3.

Results

Sampling effort. Weekly sampling effort throughout the BY2021 winter Chinook salmon emigration period ranged from 0.47 to 1.00 ($\bar{x}$ = 0.85; *N* = 52 weeks; Table 1). Weekly sampling effort ranged from 0.57 to 1.00 ($\bar{x}$ = 0.85; *N* = 26 weeks) between July and the end of December, the period of greatest juvenile winter Chinook emigration, and 0.47 to 1.00 ($\bar{x}$ = 0.85; *N* = 26 weeks) during the latter half of the emigration period (Table 1).

Weekly sampling effort throughout the BY2021 spring Chinook emigration period ranged from 0.47 to 1.00 ($\bar{x}$ = 0.86; *N* = 52 weeks; Table 2). Weekly sampling effort ranged from 0.47 to 1.00 ($\bar{x}$ = 0.84; *N* = 26 weeks) between mid-October and mid-April, the period of greatest juvenile spring Chinook emigration, and 0.61 to 1.00 ($\bar{x}$ = 0.89; *N* = 26 weeks) during the latter half of the emigration period (Table 2).

Weekly sampling effort throughout the BY2021 fall Chinook emigration period ranged from 0.47 to 1.00 ($\bar{x}$ = 0.87; *N* = 52 weeks; Table 3). Weekly sampling effort ranged from 0.47 to 1.00 ($\bar{x}$ = 0.86; *N* = 26 weeks) between December and the end of May, the first half of the juvenile fall Chinook 2021 brood year, and 0.57 to 0.97 ($\bar{x}$ = 0.87; *N* = 26 weeks) during the latter half of the emigration period (Table 3).

Weekly sampling effort throughout the BY2021 late-fall Chinook emigration period ranged from 0.40 to 1.00 ($\bar{x}$ = 0.84; *N* = 52 weeks; Table 4). Weekly sampling effort ranged from 0.40 to 1.00 ($\bar{x}$ = 0.81; *N* = 26 weeks) between April and the end of September, the first half of the juvenile late-fall Chinook 2021 brood year, and 0.47 to 1.00 ($\bar{x}$ = 0.86; *N* = 26 weeks) during the latter half of the emigration period (Table 4).

Weekly sampling effort throughout the BY2021 *O. mykiss* emigration period ranged from 0.40 to 1.00 ($\bar{x}$ = 0.83; *N* = 52 weeks; Table 5). Weekly sampling effort ranged from 0.40 to 1.00 ($\bar{x}$ = 0.81; *N* = 26 weeks) between January and the end of June, the first half of the juvenile *O. mykiss* 2021 brood year, and 0.58 to 1.00 ($\bar{x}$ = 0.87; *N* = 26 weeks) during the latter half of the emigration period (Table 5).

Variance in sampling effort throughout the reporting period was attributed to several sources. Intentional reductions in effort resulting from sampling < 5 traps, cone modification(s), staffing limitations, and unintentional reductions in effort resulting from high flows and debris loads influenced sample effort variance.

Mark-recapture trials. Seven mark-recapture trials were conducted during this report period to estimate and validate RST efficiency using four 1.5 m and one 2.4 m RST's (Table 6). One trial was conducted during the fall of 2021 using naturally produced winter Chinook. Six trials using naturally produced fall Chinook were conducted from mid-January through mid-February 2022. Sacramento River discharge sampled during the seven trials ranged from 4,352 to 7,325 cubic feet per second (cfs). Estimated *%Q* during trap efficiency trials ranged from 2.42% to 3.78% ($\bar{x}$ = 2.93%).

Trials (*N* =7) were conducted using four 1.5 m and one 2.4 m RSTs sampling with unmodified cones in four of the seven trials. All trials were conducted using Chinook sampled from rotary traps, and trap efficiencies ranged from 3.14% to 4.94% ($\bar{x}$ = 3.86%). The number of marked fish released per trial ranged from 687 to 1,597 ($\bar{x}$ = 1,325) and the number of marked fish recaptured ranged from 22 to 69 ($\bar{x}$ = 52). All fish were released after sunset and 98.3% 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 60 mm ($\bar{x}$ = 37.1 mm). Fork lengths of recaptured marked fish ranged from 31 to 58 mm ($\bar{x}$ = 37.0 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 (98.8% fry, 1.2% pre-smolts).

Fish collected and used for all trials were obtained from traps in all three spatial zones (east-margin, mid-channel and west-margin). 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 seven trials.

Trap efficiency modeling. Twelve trials conducted during BY2020 using naturally produced winter Chinook (N=7) and fall Chinook (N=5) were included into the BY2021 model (Figure 3). A 32-trial model (r^2 = 0.40, P < 0.01, df = 31) was employed for passage estimation for the purpose of near real-time biweekly report production during BY2021 (Figure 4). All passage estimates reported herein used the 32-trial trap efficiency model (Figure 4).

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 to spring Chinook using LAD criteria for a period of 20 days during BY2021, from mid-October thru early November (Figure 5).

Based upon genetic data, LAD spring Chinook captured between October 16 and November 4, 2021 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 BY2021. These re-assignments are reflected in the estimates reported herein.

Winter Chinook fork length evaluations. BY2021 winter Chinook fork lengths ranged between 27 and 178 mm (Figure 7a). Winter Chinook were weighted (77.5%) to the fry size-class category (<46mm) with 95.6% of those measuring less than 40 mm (Figure 6a). The remaining 22.5% were attributed to the pre-smolt/smolt category (>45 mm) with 99.1% of the fish sampled between 46 and 100 mm.

Winter Chinook passage. BY2021 winter Chinook juvenile estimated passage at RBDD was 572,664 fry and pre-smolt/smolts combined (Table 1). Fry sized juveniles (<46 mm FL) comprised 71.3% of total estimated winter Chinook passage (Table 1). Fry passage occurred from July through the end of November (weeks 27 thru 47; Figure 6a). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 28.7% 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 May (week 21; Figure 6b).

Winter Chinook JPI to adult comparisons. The BY2021 winter Chinook fry-equivalent JPI was 779,427 with the lower and upper 90% CI extending from 497,328 to 1,061,526 juveniles, respectively (Table 7). Adult females contributing to in-river spawning of BY2021 winter Chinook were estimated to have been 5,860 individuals (D. Killam, CDFW, pers. comm.). The estimated ETF survival rate was 2.5%, based on the BY2021 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 1.6% to 3.4% (Table 7).

Adult female spawner estimates derived from winter Chinook carcass surveys and rotary-screw trap data from brood years 1996-2021 were used to evaluate the linear relationship between the estimates. Twenty-three 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 = 0.84, P < 0.0001, df = 22; Figure 8); however, BY2021's data point fell well outside the prediction intervals of the regression model.

Spring Chinook fork length evaluations*.* BY2021 spring Chinook fork lengths ranged between 29 and 126 mm (Figure 7b). Spring Chinook were weighted to the pre-smolt/smolt size-class category (>45mm) with 38.0% spring Chinook designated as fry with 92.8% measuring less than 40 mm FL (Figure 9a). Nearly two thirds of the catch (62.0%) was attributed to the pre-smolt/smolt category (>45 mm) with fish between 46 and 95 mm comprising 91.9% of this size class.

Spring Chinook passage*.* Including genetic corrections and removal of unmarked hatchery smolts, BY2021 spring Chinook juvenile estimated passage at RBDD was 189,576 fry and pre-smolt/smolts combined (Table 2). Fry sized juveniles (<46 mm FL) comprised 55.3% of total estimated spring Chinook passage (Table 2). Fry passage occurred from early November through early January (weeks 45 thru 2; Table 2). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 44.7% of total passage and the first observed emigration past RBDD occurred in mid-December (week 50; Table 2). Detection of pre-smolt/smolt passage for the brood year ended in June (week 23; Figure 9b).

The fry-equivalent rotary trap JPI for BY2021 was 248,842 with the lower and upper 90% CI extending from 123,936 to 373,748 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*.* BY2021 fall Chinook fork lengths ranged between 27 and 190 mm (Figure 7c). BY2021 fall Chinook were composed of 80.1% in the fry size-class category (<46 mm) with 96.5% of individuals measuring less than 40 mm FL (Figure 10a). The remaining 19.9% were attributed to the pre-smolt/smolt category (>45 mm) with fish between 50 and 100 mm comprising 99.2% of the size group.

Fall Chinook passage*.* After removal of an estimated number of unmarked hatchery smolts, BY2021 fall Chinook juvenile estimated passage at RBDD was 5,361,012 fry and pre-smolt/smolts combined (Table 3). However, CNFH released 1,859,029 unmarked fall Chinook fry into the Sacramento River between December 17, 2021 and January 11, 2022 and no attempts were made to remove these fish from fall Chinook fry, total or fry equivalent estimates. Fry sized juveniles (<46 mm FL) comprised 85.6% of total estimated fall Chinook passage (Table 3). Fry passage began in December and was detected through early April (weeks 48 thru 15; Figure 10b). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 14.4% of total passage. The first observed pre-smolt/smolt passage occurred in early February and continued through late November (weeks 5 thru 46; Table 3).

Fall Chinook JPI to adult comparisons*.* The fry-equivalent rotary trap JPI for BY2021 was 5,900,643 with the lower and upper 90% CI extending from 3,766,576 to 8,034,709 juveniles, respectively (Table 3). The total number of adult BY2021 fall Chinook females contributing to in-river spawning upstream of RBDD was estimated to be 22,987 individuals. The estimated ETF survival rate was 5.1%, based on the BY2021 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 3.3% to 7.0% (Table 8).

Late-Fall Chinook fork length evaluations. BY2021 late-fall Chinook were sampled between 33 and 184 mm (Figure 7d). BY2021 late-fall Chinook sampled were heavily weighted to the pre-smolt/smolt size-class category (>45 mm). Only 6.6% of all fish sampled as late-fall were designated fry (<46 mm; Figure 11a). The remaining 93.4% of juveniles were attributed to the pre-smolt/smolt category, with fish between 50 and 130 mm comprising 85.9% of that value.

Late-fall Chinook passage. BY2021 late-fall Chinook juvenile estimated passage at RBDD was 59,169 fry and pre-smolt/smolts combined (Table 4). Fry sized juveniles (<46 mm FL) comprised only 8.0% of total estimated late-fall Chinook passage (Table 4). Fry passage was only detected from April through mid-July (weeks 14 thru 28; Figure 11b). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 92.0% of total passage and the first observed emigration past RBDD also occurred in late May (week 21; Table 4). Weekly pre-smolt/smolt passage for the brood year ended in early February (week 5; Figure 11b). The fry-equivalent rotary trap JPI for BY2021 was 97,255 with the lower and upper 90% CI extending from 45,695 to 148,815 juveniles, respectively (Table 4). Late-fall Chinook ETF survival rates were not estimated due to inaccuracies in adult count data as noted in Poytress et al. (2014).

O. mykiss fork length evaluations. BY2021 juvenile *O. mykiss* were sampled between 22 and 260 mm (Figure 12a). Sub-yearling (41-138mm) and yearling (139-280 mm) *O. mykiss* were amongst the first sampled at the beginning of calendar year 2021 (Table 5). *O. mykiss* fry (<41mm) captures were steady, with the first several fry of the year captured in mid-February (Figure 11a). The last fry capture occurred in week 25 (late June). Sub-yearling captures began in January (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. BY2021 *O. mykiss* juvenile total estimated passage at RBDD was 64,319 fry, sub-yearling and yearlings combined (Table 5). Fry sized juveniles (<41 mm) comprised only 4.3% of total *O. mykiss* passage. Fry passage occurred from mid-February through late June (weeks 7 thru 25; Figure 12b). Sub-yearling/yearling sized juveniles (≥41 mm) comprised 93.7% 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 51 (late December).

Green Sturgeon data. Similar to observations in prior years (Poytress et al. 2014), sturgeon catch in the rotary traps was primarily composed of recently emerged, exogenous feeding larvae with a mean total length of 27.5 mm and median of 26.0 mm (Table 9). A total of 1,043 sturgeon were captured during calendar year 2021 ranging in length from 21 to 331 mm (Figure 13a). Green Sturgeon larval captures began in late April and continued through mid-August of 2021 (Figure 13b). Annual Green Sturgeon CPUV for 2021 was 12.3 fish/ac-ft (Table 9; Figure 13c). Juvenile age-0 Green Sturgeon captures occurred in June (N=1) and July (N=3) as larval sturgeon began to develop morphometric features that could positively identify them as Green Sturgeon in the field. A single juvenile age-1 Green Sturgeon was captured in January of 2022 with a total length of 331 mm (Figure 13a).

Lamprey species data. Capture of multiple lamprey species occurred in water year 2022 (WY2022; October 1, 2021 – September 30, 2022). Lamprey species sampled during WY2022 included Pacific Lamprey (*Entosphenus tridentata*), Western Brook Lamprey (*Lampetra Richardsoni*) and River Lamprey (*Lampetra ayresi*). Unidentified lamprey ammocoetes and Pacific Lamprey composed 90.0% of all captures, 7.2% and 82.7% respectively. Fifty-one individual River Lamprey and one Western Brook Lamprey were captured in the rotary traps during WY2022.

Annual catch of unidentified lamprey ammocoetes during WY2022 was 759 (Table 10) and ranged from 40 mm to 175 mm in total length ($\bar{x}$ = 114 mm; Figure 14a). Annual catch of Pacific Lamprey was 8,694 (Table 11) and ranged from 41 mm to 580 mm in total length ($\bar{x}$ = 121 mm, Figure 14a).

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 WY2022 was 24.3 fish/ac-ft (Table 10, Figure 14c) for unidentified lamprey ammocoetes and 703.2 fish/ac-ft (Table 11, Figure 15c) for Pacific Lamprey. Both of these abundance values are above the 19-year averages of 15.3 ± 17.7 fish/ac-ft for unidentified lamprey ammocoetes and 110.8 ± 183.9 fish/ac-ft for Pacific Lamprey.

Discussion

Sampling effort. The program was able to put forth moderately high sampling effort for the reporting period of January 1, 2021 through November 30, 2022 ($\bar{x}$ = 0.85). Mean sampling effort for BY2021 winter, spring, fall, late-fall Chinook and *O. mykiss* was 0.85, 0.86, 0.87, 0.84 and 0.83, respectively (Tables 1-5). During the primary juvenile winter Chinook salmon capture and passage period of July through December of 2021, mean sampling effort was moderately high (0.85), and the latter half of the brood year was more variable, yet still moderately high and averaged 0.86.

Decreased sampling effort during the latter half of the winter Chinook brood year was due to hatchery releases as well as staffing restrictions due to COVID-19 exposures. Releases of CNFH *O. mykiss* into Battle Creek in mid-December 2021 resulted in sampling some traps with 50% modifications. This action to reduce effort reduces total catch, which reduces handling stress on hatchery origin salmonids as they moved through our sampling transect. Hatchery releases of approximately 11.8 million fall Chinook from mid-March through mid-April of 2022 resulted in a total of 10 non-sample days. The number of consecutive days was dependent on the number of salmon released during each event and resultant catch associated with random sub-sampling of periods after releases. Traps were not sampled for five days in April 2021 due to a COVID-19 exposure affecting multiple field staff. High flows resulted in a loss of two sample days during the reporting period.

Genetic-based run corrections. Genetic sub-sampling results indicated that field-assigned LAD BY2021 spring Chinook prior to November 4, 2021 were genetically winter Chinook. Subsequently, when incorporating genetic revisions into passage estimates, 4,755 LAD spring Chinook were estimated to be winter Chinook based on genetic identification during the period of October 16 thru November 4, 2021. For BY2021 winter Chinook, the addition of LAD spring Chinook genetic reassignments (October 16 thru November 4) resulted in a net increase of only 0.83% of the BY2021 passage estimate, and thus did not substantially affect the accuracy of the brood year total.

Trap efficiency model adjustments. The BY2022 passage and production estimates will employ a 39-trial hybrid configuration trap efficiency model incorporating 7 trials from this reporting period using four 1.5 m RSTs and one 2.4 m RST (Table 6), the 12 from the previous reporting period (Voss and Poytress 2022) as well as 20 trials conducted during 2018 and 2019 using 2.4 m RSTs. This 39-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.

Patterns of abundance. Juvenile winter Chinook began to emerge in early July in low numbers. Catch and subsequent passage generally increased, peaking in late September (Table 1; Figure 6b). Fry passage declined thereafter and ceased in late November.

Winter Chinook fry out-migrants represented 71.3% of total winter Chinook passage, with pre-smolt/smolts representing the remaining 28.7%. Through the end of December 2021, 99.5% of the total annual passage estimate for BY2021 winter Chinook was collected. Due to mild winter conditions and relatively high sampling effort ($\bar{x}$ = 0.86) during the second half of the brood year, passage interpolation was minimal. Overall, interpolation for missed days of sampling accounted for 2.6% of the total BY2021 estimate of 572,664 winter Chinook passing the RBDD.

Capture of BY2021 juvenile spring Chinook began on October 16, 2021 according to LAD criteria; however, genetic assignment results from tissue samples collected between mid-October and mid-December of 2021 indicated spring Chinook passage began in early November of 2021. Sampling effort was moderately high throughout the fry passage period of weeks 45 thru 2 ($\bar{x}$ = 0.84, Table 2). Sampling effort during the remainder of the brood year was more variable yet slightly higher overall ($\bar{x}$ = 0.87; Table 2) which included weeks of very low effort, primarily due to hatchery releases. Overall, interpolation for missed days of sampling accounted for 15.3% of the total BY2021 estimate of 189,576 spring Chinook passing the RBDD.

Fall Chinook fry passage accounted for 85.6% of the total passage for brood year 2021. 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 moderately high, averaging 0.84 and was largely influenced by a number of runoff events throughout the passage period of weeks 50 to 2, with a peak in fry passage during week 2 (Table 3; Figures 10b & 16).

Fall Chinook passage in the pre-smolt/smolt size category, which comprised 14.4% of total brood year passage, began in early February. Sampling effort during the smolt passage period remained relatively high at 0.88 with periods of reduced effort due to hatchery releases. Overall, interpolation for missed samples accounted for 4.0% of the brood year total, the 2nd lowest amount for any fall Chinook brood year in the last 19 years of sampling at RBDD.

Late-fall Chinook fry passage began in early April and continued through mid-July (Table 4; Figure 11b). Late-fall Chinook passage in the pre-smolt/smolt size category, which comprised 92.0% of total brood year passage, began in late May and continued in a variable fashion ending in early February. Sampling effort during the brood year was moderately high ($\bar{x}$ = 0.84), with interpolation accounting for 8.3% of the total estimate.

O. mykiss passage began the first week in January (Table 5), with the first fry observed in mid-February 2021. Passage remained variable for all size classes throughout the rest of the calendar year with a peak occurring in mid-May. Total passage for the brood year was 64,319 and interpolation accounted for only 2.5% of the brood year estimate.

Bias associated with unmarked CNFH fall Chinook. A total of 1,859,029 fry were released at Balls Ferry boat ramp between December 17, 2021 and January 11, 2022 (weeks 50-2) as part of an experimental unfed fry release program at CNFH. These fry were produced in addition to standard CNFH fall Chinook production targets (USFWS 2022). No attempts were made to remove these unmarked fish from BY2021 passage and production estimates as they were indistinguishable from naturally produced fall Chinook. The result is positive bias and uncertainty around the fry proportion of the BY2021 fall Chinook estimate of 4,590,110 (Table 3; Figure 10b) which also affects total passage and fry equivalent JPI estimates. Uncertainty and bias of naturally produced fall Chinook fry-equivalent JPIs extends further to resultant ETF estimates. The fall Chinook ETF survival estimate for naturally produced fish is likely closer to the lower CI value of 3.3% for BY2021 because of the addition of unmarked fry released upstream of the RBDD sampling transect.

Releases of 25% marked (adipose fin clipped) brood year 2021 fall Chinook into Battle Creek (Figure 1) began in mid-March and continued through mid-April of 2022 (weeks 11 thru 15; 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 four weeks immediately following (weeks 11-19; Table 12), 29.9% of the marked CNFH fall Chinook captured fell into the spring LAD size category. Without the removal of unmarked hatchery fish, spring Chinook smolt passage estimates for the brood year were 203,734 with smolts accounting for 66.0% of the total brood year estimate

(Table A1). Had unmarked hatchery fish not been removed, resultant total BY2021 spring Chinook estimates would have been nearly 2.5 times higher.

During the release period, and including four weeks immediately following (weeks 11-19; Table 12), 70.1% 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 1,405,987 with smolts accounting for 23.5% of the total brood year estimate (Table A2). Also, the increased number of smolts estimated results in a higher fry equivalent JPI value of 6,963,059 and a slightly higher egg to fry survival rate of 6.0% (Table A3) in contrast to the value of 5.1% (Table 8) which incorporated removal of unmarked CNFH production smolts.

Egg to fry survival for many salmon runs during BY2021 was likely negatively impacted by Thiamine Deficiency Complex (TDC; NMFS 2021), including fall run. Additionally, under sustained drought conditions with lower flows and warmer water temperatures, there can be a higher potential for parasitic infection to impact survival of juvenile salmonids. Prior to any releases of fractionally marked CNFH BY2021 fall Chinook, USFWS California Nevada Fish Health Center (CANVFHC) sampled 42 fall Chinook fry from the RBDD RSTs from 2/28/2022 to 3/14/2022 to evaluate parasitic infection via histological analyses. Results showed prevalence of infection for *Ceratonova shasta* was 17% (7/42) with four of the seven infected fry categorized as "diseased". Prevalence of infection for *Parvicapsula minibicornis* within these fish was 11% with no fry categorized as "diseased". There was one fish sample with a gill infestation of *Ichthyoboda sp.* (Foott 2022). While the results of these analyses don't indicate an alarming impact due to parasitic infection, it may have contributed to lower than average ETF survival of BY2021 fall Chinook (Table 8).

Winter Chinook JPI and ETF survival estimate. The BY2021 winter Chinook fry-equivalent JPI value of 779,427 was the fifth lowest value in the last twenty years. Adult escapement for BY2021 was estimated at 9,956 in-river adults (NMFS 2021) which is the third highest in the same twenty years. However, the fry-equivalent based ETF survival rate for BY2021 was estimated at 2.5% (Table 7), the lowest value since monitoring began in 1995 and well below the 19-year average ETF survival rate of 23.4% (Voss and Poytress 2022).

Water year 2021 was designated as critically dry for the Sacramento Valley. Shasta Reservoir cold-water pool storage conditions were described as Tier 4; meaning there was insufficient cold water to maintain a daily average temperature of 56˚F or lower at the Clear Creek River (CCR) gauge for the duration of the entire temperature management season (USBR 2021). Temperature dependent mortality (TDM) models were largely developed from Tier 2 and Tier 3 year-types and were unable to accurately predict for Tier 4 conditions with initial TDM estimates ranging from 90-99% for BY2021 winter Chinook (USBR 2021). After input from various agencies and stakeholders, a temperature control strategy using the Highway 44 Bridge (SAC) gauge compliance point was developed with numerous criteria and approaches to minimize modeled TDM utilizing the limited cold water pool. The final Temperature Management Plan for 2021 established criteria to maintain temperatures near 57 ˚F for holding adults, time cold water (54.5˚F) deliveries during critical egg incubation periods to preserve redds down to the Highway 44 Bridge (in hopes of delaying loss of temperature control as late into the fall as possible), and provide some ability to respond to heat waves or extreme meteorological conditions. Despite all the efforts described in the 2021 Temperature Management Plan, winter Chinook salmon spawned during the 2nd warmest and driest spring (Apr-June) period on record within a final modeled TDM estimate of 75% (USBR 2021).

Just as increased water temperatures played a large role in low winter Chinook ETF survival for BY2021, TDC also continued to hinder ETF survival of BY2021 winter Chinook. Egg mortality due to TDC was modeled to be 44% for BY2021 winter Chinook salmon which compounded the 75% TDM estimates of mortality (M. Daniels, NMFS, unpublished data).

From mid-September to late October 2021, the RBDD RSTs were sampled for wild winter Chinook to determine the prevalence and severity of infection of internal and external parasites. USFWS CANVFHC performed histological analyses on 20 fish samples with a focus on the internal parasites *Ceratonova shasta* and *Parvicapsula minibicornis*. *C. Shasta* was observed within the intestine of 35% of the sample group (7/20 fish; 5 categorized as “early stage” and 2 as “diseased”) and *P. minibicornis* was observed in the kidney of 68% of the sample group (13/19 fish categorized as “early stage”; Foott 2021). 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* (10%) and *P. minibicornis* (0%) is not as alarming but certainly could have contributed to additional losses of natural production fry and smolts within the Sacramento River.

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Literature Cited

Azat, J. 2022. GrandTab 2022.07.20. California Central Valley Chinook Population Database Report. California Department of Fish and Wildlife. http://www.dfg.ca.gov/fish/Resources/Chinook/CValleyAssessment.asp

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

Foott, J.S. 2022. Histological evaluation for parasites of Sacramento River Fall-run Chinook fry. U.S. Fish and Wildlife Service, California-Nevada Health Center, Anderson, CA. March 2022. Technical Report.

Foott, J.S. 2022. Histological evaluation of Sacramento River Winter-run Chinook fry, Red Bluff Diversion Dam trap September and October 2021. U.S. Fish and Wildlife Service, California-Nevada Health Center, Anderson, CA. March 2022. Technical Report.

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

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

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

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

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

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

Johnson, R. R. and C. D Martin. 1997. Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing Red Bluff Diversion Dam, Sacramento River, July 1994 - June 1995. Red Bluff Research Pumping Plant Report Series, Volume 2. U. S. Fish and Wildlife Service, Red Bluff, CA.

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

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

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

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

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

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

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

National Marine Fisheries Service (NMFS). 2021. Letter from Cathy Marcinkevage (NMFS) to Ms. Kristin White (USBR) dated 1/25/2021. National Marine Fisheries Service signed 2020 Juvenile Production Estimate letter.

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

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

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

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

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

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

United States Bureau of Reclamation (USBR). 2020. LTO Shasta Cold Water Pool Seasonal Report 12302020. Central Valley Project, California-Great Basin Region.

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

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

United States Fish and Wildlife Service (USFWS). 2001. Final Restoration Plan for the Anadromous Fish Restoration Program. A plan to increase natural production of anadromous fish in the Central Valley of California. Prepared for the Secretary of the Interior by the United States Fish and Wildlife Service with the assistance from the Anadromous Fish and Restoration Program Core Group under authority of the Central Valley Project Improvement Act.

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

United States Fish and Wildlife Service (USFWS). 2022. Hatchery Evaluation Program Annual Report Fiscal Year 2022. USFWS, Red Bluff Fish and Wildlife Office, Red Bluff, California. Hatchery Evaluation Program.

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

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

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

Tables

Table 1.— Sampling effort, weekly passage estimates, median fork length (Med FL) and juvenile production indices (JPI's) for winter Chinook salmon passing Red Bluff Diversion Dam (RK 391) for the period 7/1/2021 through 6/30/2022 (brood year 2021). 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 (44.29% or approximately 2.259:1; O'Farrell 2018).

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
27 (Jul)	0.57	329	33	0	-	329	33	329
28	0.80	260	34	0	-	260	34	260
29	0.80	617	34	0	-	617	34	617
30	0.80	2,635	34	0	-	2,635	34	2,635
31 (Aug)	0.80	3,528	35	0	-	3,528	35	3,528
32	0.83	6,501	36	0	-	6,501	36	6,501
33	0.89	7,047	35	0	-	7,047	35	7,047
34	0.86	7,048	35	0	-	7,048	35	7,048
35 (Sep)	0.89	14,393	36	37	49	14,430	36	14,476
36	1.00	41,703	35	69	47	41,772	35	41,858
37	1.00	57,724	35	492	48	58,217	35	58,836
38	1.00	55,361	35	1,360	49.5	56,721	35	58,431
39	1.00	93,762	35	7,328	53	101,091	35	110,310
40 (Oct)	0.94	74,055	35	12,252	53	86,307	35	101,719
41	0.91	25,105	35	10,800	55	35,905	35	49,490
42	0.89	5,378	35	7,011	56	12,389	50	21,209
43	0.71	8,325	41.5	34,637	56	42,961	54	86,534
44 (Nov)	0.89	3,068	39	27,027	58	30,095	57	64,095
45	0.87	1,205	44	32,828	58	34,033	58	75,329
46	0.89	155	44	7,353	62	7,509	61	16,759
47	0.83	103	44	5,326	66	5,429	66	12,129
48 (Dec)	0.86	0	-	2,848	68	2,848	68	6,431
49	1.00	0	-	969	65	969	65	2,189
50	0.76	0	-	6,016	73	6,016	73	13,583
51	0.84	0	-	3,168	73	3,168	73	7,154
52	0.58	0	-	2,195	79	2,195	79	4,957

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)	0.84	0	-	994	77.5	994	77.5	2,244
2	0.93	0	-	309	85	309	85	697
3	0.91	0	-	103	95	103	95	232
4	0.90	0	-	336	77.5	336	77.5	758
5 (Feb)	0.91	0	-	79	125	79	125	179
6	1.00	0	-	78	135	78	135	177
7	0.97	0	-	195	96.5	195	96.5	440
8	1.00	0	-	28	110	28	110	64
9 (Mar)	0.99	0	-	0	-	0	-	0
10	0.90	0	-	146	135	146	135	330
11	0.69	0	-	46	110	46	110	103
12	0.47	0	-	61	101	61	101	137
13	0.97	0	-	0	-	0	-	0
14 (Apr)	0.49	0	-	0	-	0	-	0
15	0.80	0	-	96	145.5	96	145.5	216
16	0.61	0	-	0	-	0	-	0
17	1.00	0	-	145	161	145	161	328
18 (May)	1.00	0	-	0	-	0	-	0
19	1.00	0	-	0	-	0	-	0
20	1.00	0	-	0	-	0	-	0
21	1.00	0	-	30	147	30	147	68
22 (Jun)	0.66	0	-	0	-	0	-	0
23	0.80	0	-	0	-	0	-	0
24	0.80	0	-	0	-	0	-	0
25	0.80	0	-	0	-	0	-	0
26	0.80	0	-	0	-	0	-	0
BY total		408,303		164,361		572,664		779,427
90% CI (low : high)		(273,897 : 542,708)		(95,519 : 233,204)		(372,041 : 773,288)		(497,328 : 1,061,526)

Table 2— Sampling effort, weekly passage estimates, median fork length (Med FL) and juvenile production indices (JPI's) for spring Chinook salmon passing Red Bluff Diversion Dam (RK 391) for the period 10/16/2021 through 10/15/2022 (brood year 2021). 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 smolts removed and genetic corrections*. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry to pre-smolt/smolt survival rate (59% or approximately 1.7:1; Hallock undated).

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
42	0.89	0	-	0	-	0	-	0
43	0.71	0	-	0	-	0	-	0
44 (Nov)	0.89	0	-	0	-	0	-	0
45	0.87	7,278	33	0	-	7,278	33	7,278
46	0.89	5,861	33	0	-	5,861	33	5,861
47	0.83	10,880	33	0	-	10,880	33	10,880
48 (Dec)	0.86	25,036	34	0	-	25,036	34	25,036
49	1.00	8,064	35	0	-	8,064	35	8,064
50	0.76	23,361	37	251	46	23,612	37	23,788
51	0.84	15,923	39	444	47	16,367	39	16,677
52	0.58	4,577	42	779	47	5,356	42	5,901
1 (Jan)	0.84	1,666	43	1,600	47.5	3,266	45	4,387
2	0.93	2,265	44	2,279	48.5	4,545	47	6,140
3	0.91	0	-	103	47	103	47	175
4	0.90	0	-	78	63	78	63	132
5 (Feb)	0.91	0	-	28	53	28	53	48
6	1.00	0	-	0	-	0	-	0
7	0.97	0	-	61	61	61	61	104
8	1.00	0	-	120	63	120	63	204
9 (Mar)	0.99	0	-	126	63.5	126	63.5	214
10	0.90	0	-	247	67	247	67	420
11	0.69	0	-	166	70	166	70	283
12	0.47	0	-	13,166	73	13,166	73	22,382
13	0.97	0	-	4,953	75	4,953	75	8,420
14 (Apr)	0.49	0	-	11,435	79	11,435	79	19,439
15	0.80	0	-	3,779	83	3,779	83	6,424

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	0.61	0	-	31,364	88.5	31,364	88.5	53,318
17	1.00	0	-	7,940	91	7,940	91	13,498
18 (May)	1.00	0	-	2,604	95	2,604	95	4,427
19	1.00	0	-	2,596	102	2,596	102	4,413
20	1.00	0	-	325	105	325	105	553
21	1.00	0	-	123	106.5	123	106.5	208
22 (Jun)	0.66	0	-	0	-	0	-	0
23	0.80	0	-	99	121	99	121	168
24	0.80	0	-	0	-	0	-	0
25	0.80	0	-	0	-	0	-	0
26	0.80	0	-	0	-	0	-	0
27 (Jul)	0.97	0	-	0	-	0	-	0
28	0.91	0	-	0	-	0	-	0
29	0.91	0	-	0	-	0	-	0
30	0.91	0	-	0	-	0	-	0
31 (Aug)	0.91	0	-	0	-	0	-	0
32	0.77	0	-	0	-	0	-	0
33	0.89	0	-	0	-	0	-	0
34	0.91	0	-	0	-	0	-	0
35 (Sep)	0.91	0	-	0	-	0	-	0
36	0.91	0	-	0	-	0	-	0
37	0.91	0	-	0	-	0	-	0
38	0.89	0	-	0	-	0	-	0
39	0.91	0	-	0	-	0	-	0
40 (Oct)	0.94	0	-	0	-	0	-	0
41	0.91	0	-	0	-	0	-	0
BY total		104,912		84,665		189,576		248,842
90% CI (low : high)		(56,688 : 153,135)		(37,782 : 131,548)		(95,524 : 283,629)		(123,936 : 373,748)

Table 3. — Sampling effort, weekly passage estimates, median fork length (Med FL) and juvenile production indices (JPI's) for fall Chinook salmon passing Red Bluff Diversion Dam (RK 391) for the period 12/1/2021 through 11/30/2022 (brood year 2021). 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 smolts removed**. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry to pre-smolt/smolt survival rate (59% or approximately 1.7:1; Hallock undated).

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
48 (Dec)	0.86	24,122	32	0	-	24,122	32	24,122
49	1.00	21,172	33	0	-	21,172	33	21,172
50	0.76	126,485	34	0	-	126,485	34	126,485
51	0.84	247,977	35	0	-	247,977	35	247,977
52	0.58	284,044	36	0	-	284,044	36	284,044
1 (Jan)	0.84	907,099	36	0	-	907,099	36	907,099
2	0.93	975,065	37	0	-	975,065	37	975,065
3	0.91	660,509	37	0	-	660,509	37	660,509
4	0.90	462,023	37	0	-	462,023	37	462,023
5 (Feb)	0.91	330,083	37	279	48	330,362	37	330,557
6	1.00	350,341	37	757	48	351,097	37	351,627
7	0.97	145,340	37	85	50	145,425	37	145,484
8	1.00	37,087	37	396	50	37,483	37	37,760
9 (Mar)	0.99	10,994	37	776	50	11,770	37	12,313
10	0.90	4,020	36	1,291	52.5	5,310	37	6,214
11	0.69	1,225	35.5	414	64	1,640	63	1,930
12	0.47	1,663	37.5	32,980	65	34,643	65	57,729
13	0.97	437	37	12,516	68	12,953	68	21,714
14 (Apr)	0.49	274	36	100,026	70	100,299	70	170,317
15	0.80	121	42	48,612	71	48,734	71	82,762
16	0.61	0	-	147,358	73	147,358	73	250,509
17	1.00	0	43	99,119	75	99,149	75	168,532
18 (May)	1.00	0	-	90,066	76	90,066	76	153,113
19	1.00	0	-	113,496	76	113,496	76	192,944
20	1.00	0	-	45,356	76	45,356	76	77,105
21	1.00	0	-	23,661	75	23,661	75	40,223

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)	0.66	0	-	11,744	77	11,744	77	19,966
23	0.80	0	-	18,833	76	18,833	76	32,016
24	0.80	0	-	9,604	74.5	9,604	74.5	16,327
25	0.80	0	-	7,448	74.5	7,448	74.5	12,662
26	0.80	0	-	1,559	84	1,559	84	2,650
27 (Jul)	0.97	0	-	529	81.5	529	81.5	900
28	0.91	0	-	923	82.5	923	82.5	1,569
29	0.91	0	-	513	88	513	88	872
30	0.91	0	-	232	90.5	232	90.5	395
31 (Aug)	0.91	0	-	147	97	147	97	251
32	0.77	0	-	242	109	242	109	412
33	0.89	0	-	242	102	242	102	411
34	0.91	0	-	118	121	118	121	200
35 (Sep)	0.91	0	-	29	115	29	115	49
36	0.91	0	-	31	99	31	99	53
37	0.91	0	-	27	108	27	108	47
38	0.89	0	-	1,126	128	1,126	128	1,915
39	0.91	0	-	113	122	113	122	191
40 (Oct)	0.94	0	-	0	-	0	-	0
41	0.91	0	-	28	131	28	131	47
42	0.91	0	-	29	134	29	134	50
43	0.94	0	-	27	151	27	151	46
44 (Nov)	0.91	0	-	56	157.5	56	157.5	95
45	0.89	0	-	29	167	29	167	50
46	0.91	0	-	84	154	84	154	142
47	0.57	0	-	0	-	0	-	0
BY total*		4,590,110		770,901		5,361,012		5,900,643
90% CI (low : high)		(2,899,752 : 6,280,468)		(506,811 : 1,034,992)		(3,408,337 : 7,313,687)		(3,766,576 : 8,034,709)

*no attempt was made to remove 1,859,029 BY2021 unmarked CNFH unfed fry release fish from any category of passage estimates within the table above.

Table 4. — Sampling effort, weekly passage estimates, median fork length (Med FL) and juvenile production indices (JPI's) for late-fall Chinook salmon passing Red Bluff Diversion Dam (RK 391) for the period 4/1/2021 through 3/31/2022 (brood year 2021). 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)	0.40	642	35	0	-	642	-	642
15	0.41	0	-	0	-	0	-	0
16	0.77	347	35	0	-	347	35	347
17	0.87	710	35	0	-	710	35	710
18 (May)	0.84	776	37	0	-	776	37	776
19	0.84	1,097	36	0	-	1,097	36	1,097
20	0.77	319	37	0	-	319	37	319
21	0.86	62	37	175	47	237	47	360
22 (Jun)	0.83	200	36.5	87	48	287	41	348
23	0.89	0	-	148	46	148	46	251
24	0.74	0	-	169	54	169	54	287
25	0.77	0	-	559	55	559	55	951
26	0.80	59	33	182	58	241	56.5	368
27 (Jul)	0.57	242	37	314	61	556	57	775
28	0.80	306	37	127	64	433	38	522
29	0.80	0	-	362	63.5	362	63.5	616
30	0.80	0	-	179	62.5	179	62.5	304
31 (Aug)	0.80	0	-	0	-	0	-	0
32	0.83	0	-	0	-	0	-	0
33	0.89	0	-	131	80	131	80	222
34	0.86	0	-	0	-	0	-	0
35 (Sep)	0.89	0	-	149	71.5	149	71.5	253
36	1.00	0	-	284	74.5	284	74.5	482
37	1.00	0	-	394	67	394	67	670
38	1.00	0	-	684	67	684	67	1,163
39	1.00	0	-	2,352	66	2,352	66	3,998

Table 4—(continued)

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
40 (Oct)	0.94	0	-	2,295	66	2,295	66	3,902
41	0.91	0	-	2,013	72.5	2,013	72.5	3,423
42	0.89	0	-	1,280	74.5	1,280	74.5	2,176
43	0.71	0	-	6,247	80	6,247	80	10,620
44 (Nov)	0.89	0	-	6,967	117	6,967	117	11,844
45	0.87	0	-	6,145	115	6,145	115	10,446
46	0.89	0	-	2,248	121	2,248	121	3,821
47	0.83	0	-	2,029	118	2,029	118	3,449
48 (Dec)	0.86	0	-	960	120	960	120	1,632
49	1.00	0	-	379	116	379	116	645
50	0.76	0	-	13,662	140	13,662	140	23,225
51	0.84	0	-	1,773	115.5	1,773	115.5	3,013
52	0.58	0	-	661	118	661	118	1,124
1 (Jan)	0.84	0	-	652	129.5	652	129.5	1,108
2	0.93	0	-	588	130.5	588	130.5	1,000
3	0.91	0	-	103	136	103	136	175
4	0.90	0	-	0	-	0	-	0
5 (Feb)	0.91	0	-	112	149	112	149	190
6	1.00	0	-	0	-	0	-	0
7	0.97	0	-	0	-	0	-	0
8	1.00	0	-	0	-	0	-	0
9 (Mar)	0.99	0	-	0	-	0	-	0
10	0.90	0	-	0	-	0	-	0
11	0.69	0	-	0	-	0	-	0
12	0.47	0	-	0	-	0	-	0
13	0.97	0	-	0	-	0	-	0
BY total		4,760		54,409		59,169		97,255
90% CI (low : high)		(-405 : 9,924)		(25,156 : 83,663)		(25,241 : 93,096)		(45,695 : 148,815)

Table 5.— Sampling effort, weekly passage estimates and median fork length (Med FL) for *O. mykiss* passing Red Bluff Diversion Dam (RK 391) for the period 1/1/2021 through 12/31/2021 (brood year 2021). 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).

Week	Sampling Effort	Total Est. passage	Total Med FL	Week (cont.)	Sampling Effort (cont.)	Total Est. passage (cont.)	Total Med FL (cont.)
1 (Jan)	0.94	184	78	27 (Jul)	0.57	1,665	70.5
2	0.91	35	204	28	0.80	1,130	62
3	1.00	58	91.5	29	0.80	827	66.5
4	0.90	35	85	30	0.80	1,094	73
5 (Feb)	0.76	253	165.5	31 (Aug)	0.80	1,363	69.5
6	0.94	79	154	32	0.83	996	66
7	0.91	119	29.5	33	0.89	590	59
8	0.94	464	26	34	0.86	710	60.5
9 (Mar)	1.00	180	54	35 (Sep)	0.89	828	65
10	1.00	221	24	36	1.00	495	71.5
11	0.71	318	84	37	1.00	493	71
12	0.50	67	26	38	1.00	440	78
13	0.77	84	64.5	39	1.00	876	68.5
14 (Apr)	0.40	188	23.5	40 (Oct)	0.94	367	66
15	0.41	1,103	54	41	0.91	238	73
16	0.77	901	52	42	0.89	192	79
17	0.87	2,947	56	43	0.71	240	90.5
18 (May)	0.84	4,451	59	44 (Nov)	0.89	135	77.5
19	0.84	10,151	61	45	0.87	159	69
20	0.77	8,435	64	46	0.89	62	169
21	0.86	6,423	68	47	0.83	32	96
22 (Jun)	0.83	5,797	65	48 (Dec)	0.86	65	99
23	0.89	2,196	70.5	49	1.00	31	86
24	0.74	1,868	66	50	0.76	229	184
25	0.77	2,137	72	51	0.84	227	105
26	0.80	1879	70	52	0.58	262	116
				BY total		64,319	
				90% CI (low : high)		(29,438 : 99,200)	

Table 6.—Summary of results from mark-recapture trials conducted in 2021 (N = 1) and 2022 (N = 6) to evaluate rotary-screw trap efficiency at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Results include the run of Chinook salmon, 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	2021	winter	687	37.5	22	37.2	3.20	2.49	5	No
2	2022	fall	1,520	36.1	57	36.3	3.75	3.78	5	No
3	2022	fall	1,497	36.8	56	37.3	3.74	2.53	5	Yes
4	2022	fall	1,434	37.1	45	36.0	3.14	2.55	5	Yes
5	2022	fall	1,304	37.1	51	37.2	3.91	2.42	5	Yes
6	2022	fall	1,597	37.2	69	37.5	4.32	3.39	5	No
7	2022	fall	1,234	36.8	61	37.0	4.94	3.33	5	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 2012 and June 2022.

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
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)
2021	779,427	497,328	1,061,526	5,860	5,312	133	2.5	(1.6 : 3.4)
					Average	847	18.3	(11.5 : 25.2)
					Standard Deviation	583	13.9	(9.0 : 19.0)

[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 2012 and November 2022. Brood years 2012 through 2021 include estimates *with unmarked hatchery smolts removed to reduce bias to JPI estimates*.

BY	Fry Equivalent JPI	Lower 90% CI	Upper 90% CI	Estimated Females[1]	Fecundity	Estimated Recruits/Female	ETF Survival Rate (%)	L90 CI : U90 CI
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[2]	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)
2021[3]	5,900,643	3,766,576	8,034,709	22,987	5,029	257	5.1	(3.3 : 7.0)
					Average	677	13.5	(1.9 : 25.0)
					Standard Deviation	520	10.9	(5.5 : 26.1)

[1]Estimated females derived from carcass survey; sex ratios used to determine female spawners based on CNFH data between 2008 and 2021.

[2] BY2019 has incomplete data collection due to COVID-19 and is excluded from Average and Standard Deviation calculations.

[3] No attempt was made to remove 1,859,029 BY2021 unmarked CNFH unfed fall Chinook fry release fish from any passage estimates within the table above.

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 2021. *2020 has incomplete data collection due to 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
2021	1043	12.3	21	331	27.5	26
Mean	1812.5	13.3	19.8	210.3	30.3	27.1
SD	1942.4	12.8	1.8	120.0	3.6	1.0
CV	107.2%	96.2%	8.9%	57.1%	11.8%	3.7%

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 2022. *WY2020 has incomplete data collection due to 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
2022	759	24.3	40	175	114	114
Mean	1871.6	27.0	21.0	173.9	97.6	100.3
SD	1625.8	22.8	15.0	17.4	8.9	9.3
CV	86.9%	84.6%	71.4%	10.0%	9.1%	9.3%

Table 11.— Pacific Lamprey macrophthalmia and adult annual capture, catch per unit volume (CPUV; fish /acre-ft) and total length (mm) summaries for macrophthalmia captured by RBDD rotary traps between water year (WY) 2014 and 2022. *WY2020 has incomplete data collection due to 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
2022	8694	703.2	41	580	121	119
Mean	3084.8	206.8	70.3	548.8	133.2	121.5
SD	3234.4	259.0	20.9	38.4	14.9	4.0
CV	104.8%	125.3%	29.7%	7.0%	11.2%	3.3%

Table 12.— Summary of Coleman National Fish Hatchery brood year 2021 fall Chinook released as unmarked fry or fractionally marked smolts into the Sacramento River upstream of the RBDD transect from December 17, 2021 through April 14, 2022. 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. "NA" indicates no marked Chinook captures for associated release date. *Release on April 5, 2022 included 100% marked fall Chinook smolts; all other smolt 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
50	12/17/2021	615,426	30 - 35	0 - 37	NA	--	--
52	12/30/2021	635,998	30 - 35	0 - 40	NA	--	--
2	1/11/2022	607,605	30 - 35	0 - 43	NA	--	--
11	3/15/2022	2,865,384	75	0 - 66	NA	67 - 89	NA
11	3/18/2022	2,982,466	75	0 - 67	61.2%	68 - 91	38.8%
12	--	--	--	0 - 71	77.8%	72 - 95	22.2%
13	3/31/2022	4,218,454	75	0 - 73	57.5%	74 - 99	42.5%
14	4/5/2022	171,324*	72	35 - 76	71.9%	77 - 103	28.1%
15	4/14/2022	1,779,461	75	37 - 80	64.0%	81 - 109	36.0%
16	--	--	--	39 - 83	89.8%	84 - 112	10.2%
17	--	--	--	40 - 87	87.1%	88 - 119	12.9%
18	--	--	--	42 - 91	91.9%	92 - 123	8.1%
19	--	--	--	44 - 95	100.0%	96 - 129	0.0%
	Total:	**13,704,794**			**72.8%**		**27.2%**

Figures

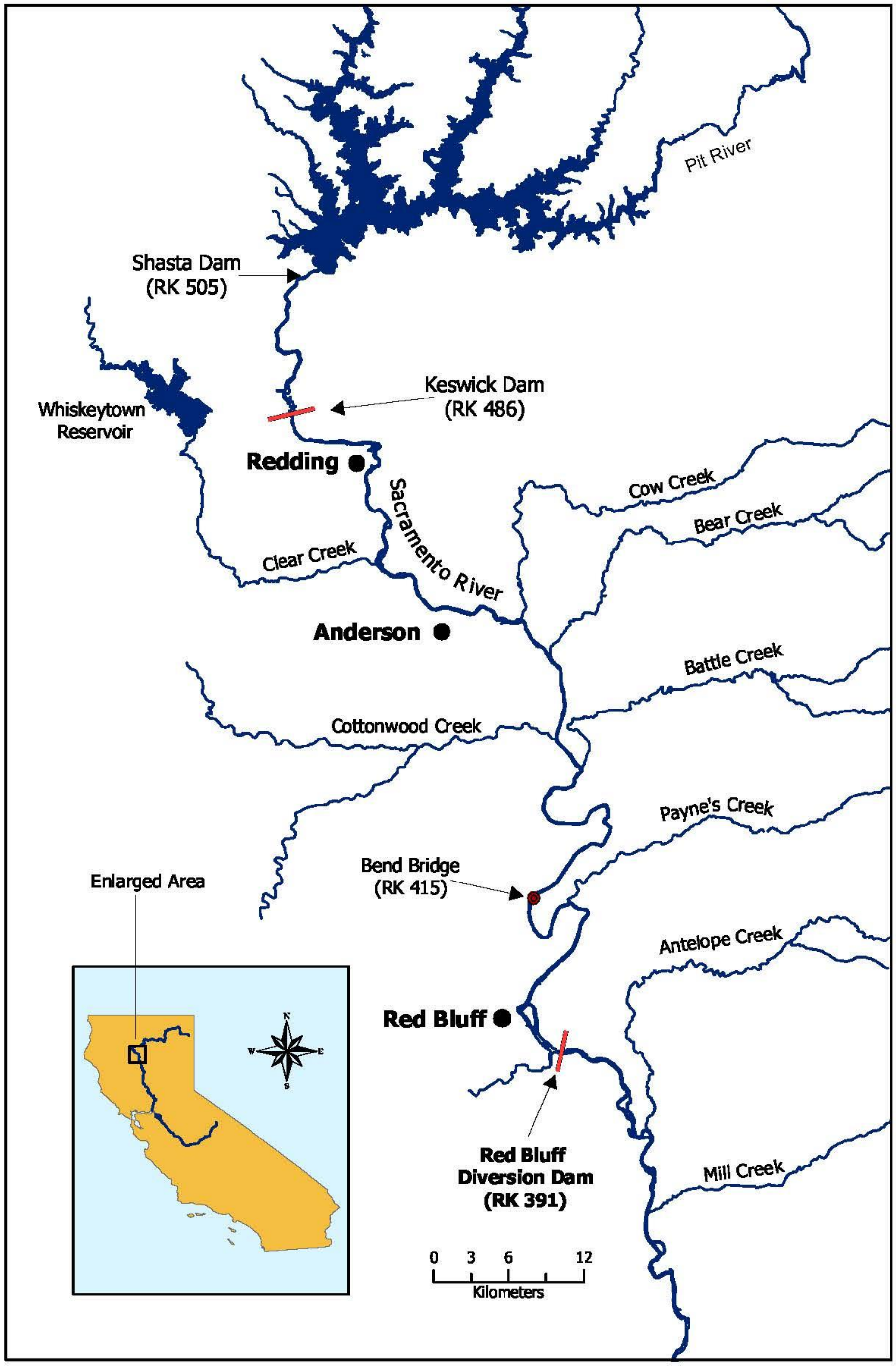

Figure 1. Location of Red Bluff Diversion Dam sample site on the Sacramento River, California, at river kilometer 391 (RK 391).

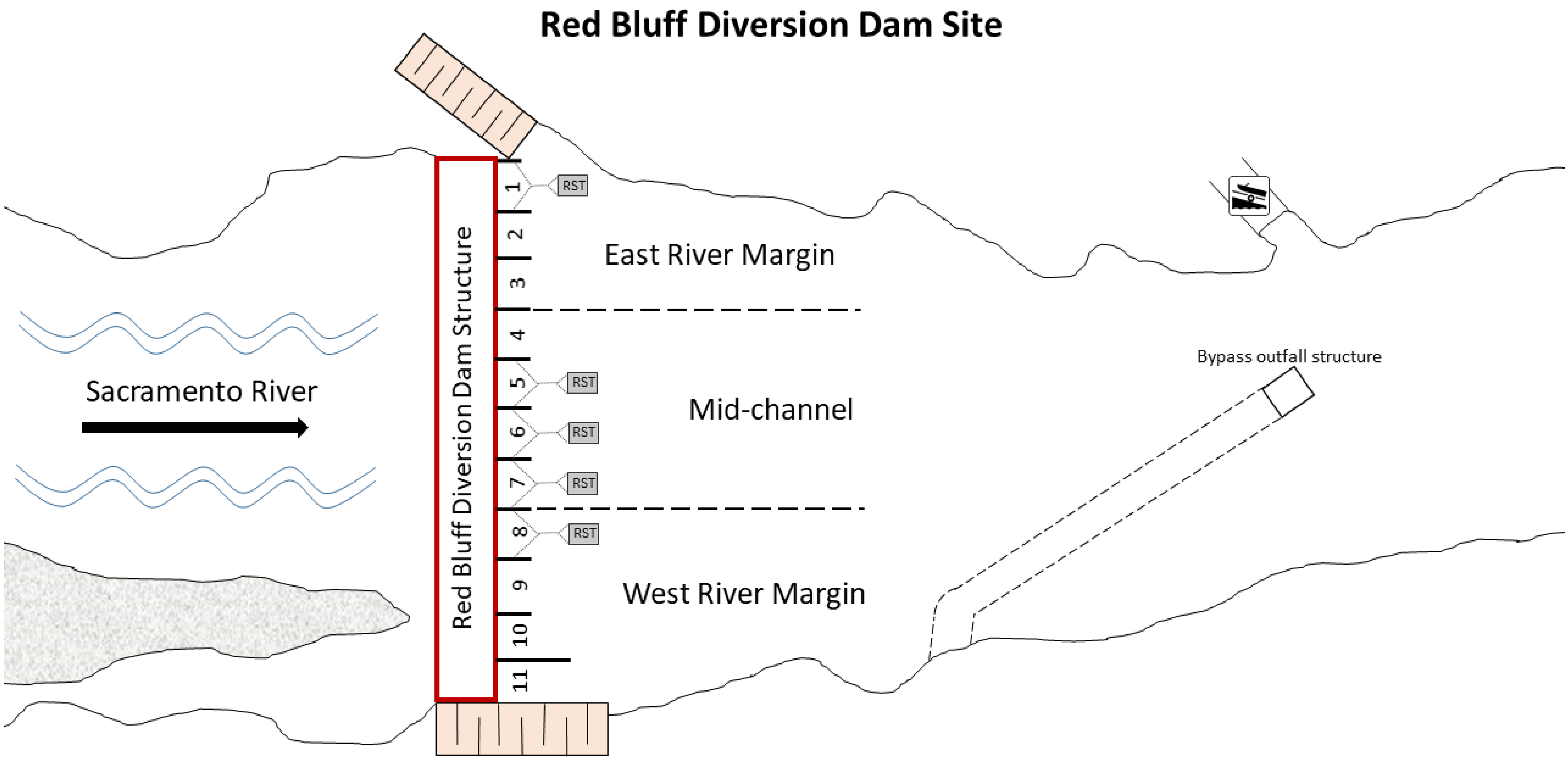

Figure 2. Rotary-screw trap sampling transect schematic of Red Bluff Diversion Dam site (RK 391) on the Sacramento River, CA.

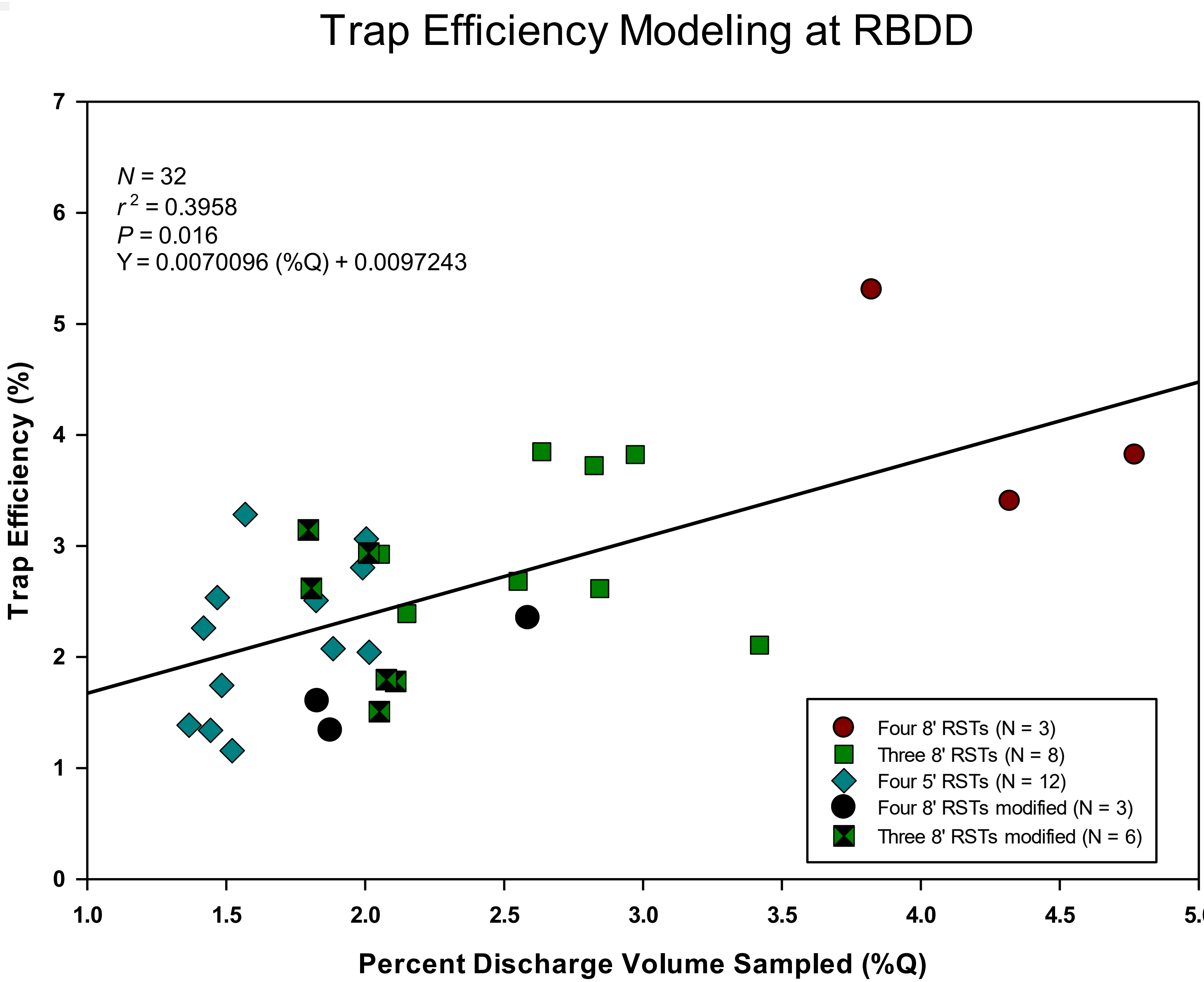

Figure 3. Hybrid trap efficiency model for 1.5 m and 2.4 m diameter rotary-screw trap arrays at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four 2.4 m traps (N=6), three 2.4 m traps (N=14), or four 1.5 m traps (N=12).

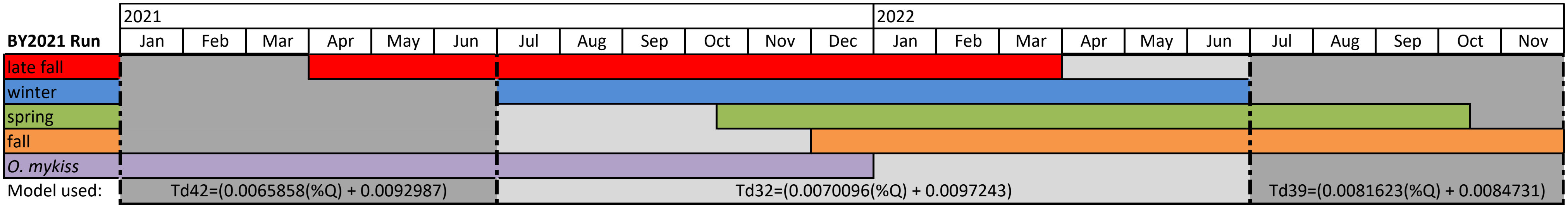

Figure 4. Summary of trap efficiency models used for passage estimates during brood year 2021 for juvenile winter, spring, fall, late-fall Chinook salmon and *O. mykiss* from 01/01/2021, the start of the *O. mykiss* 2021 brood year through 11/30/2022, the end of the 2021 fall Chinook brood year.

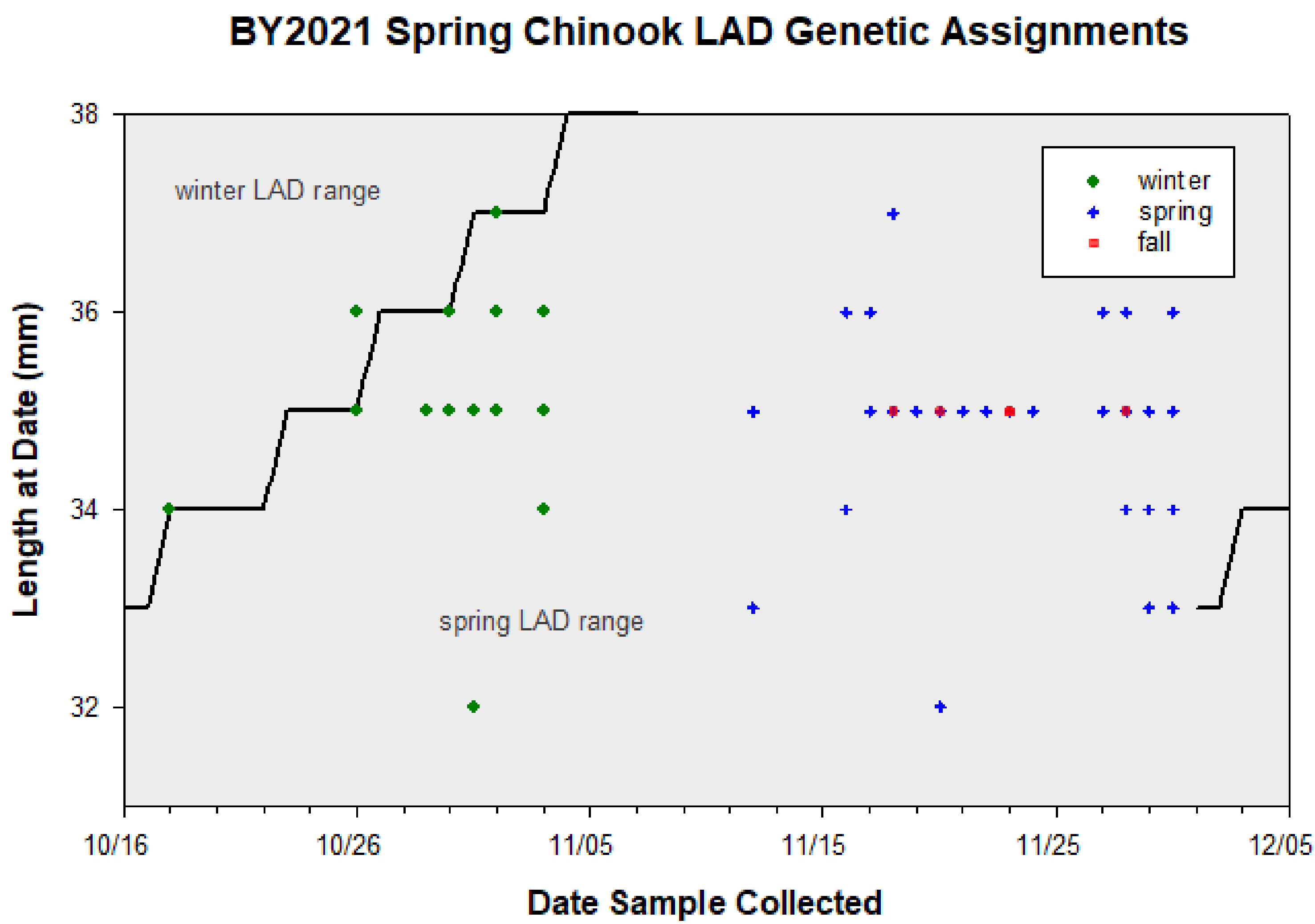

Figure 5. Genetic assignment results from brood year 2021 spring Chinook length-at-date (LAD) samples collected from 10/18/2021 through 11/30/2021. Solid black line represents upper and lower LAD range by date and genetic assignments are displayed by color and symbol.

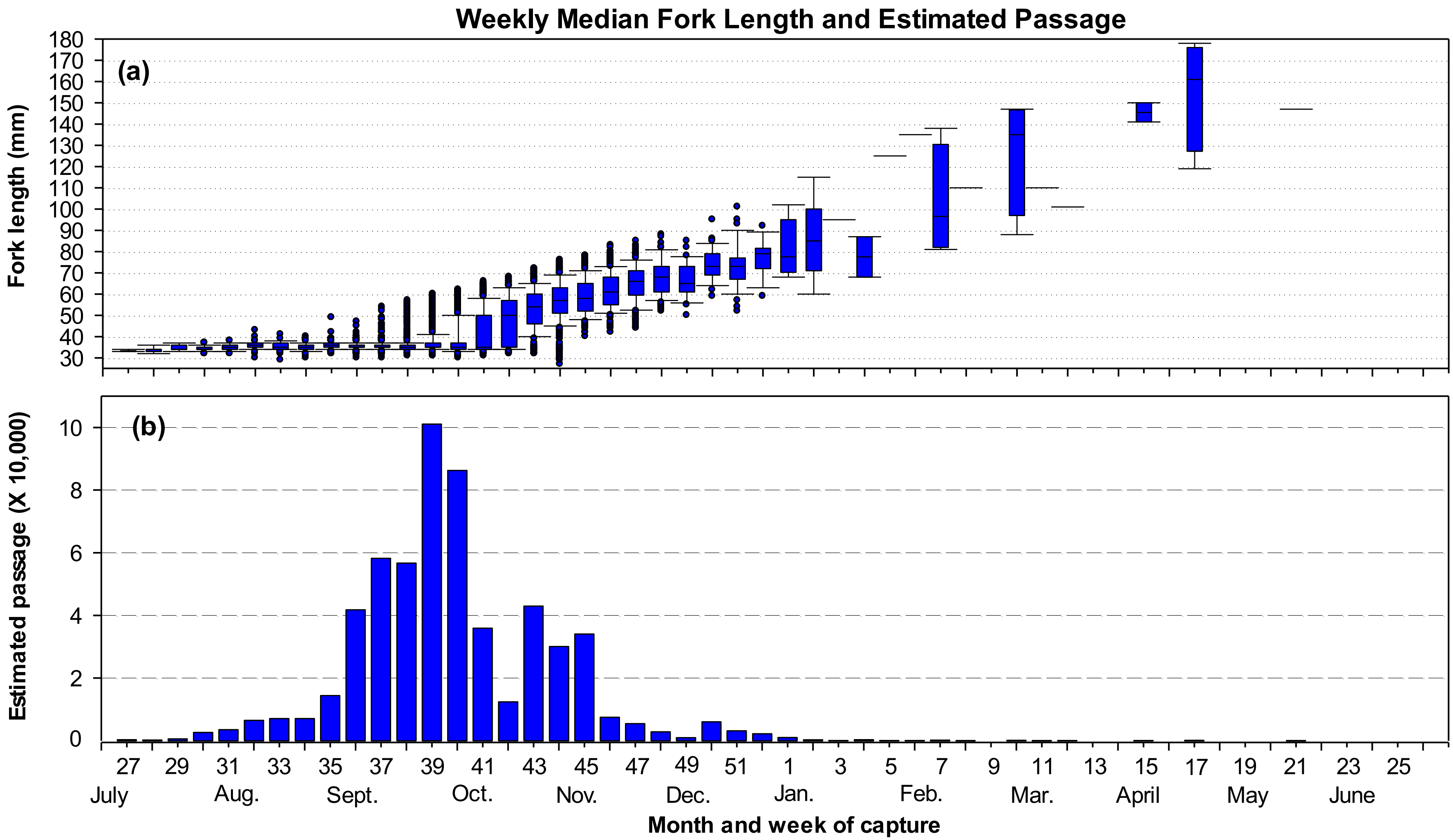

Figure 6. Weekly median fork length (a) and estimated passage (b) of brood year 2021 juvenile winter Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Winter Chinook salmon were sampled by rotary-screw traps for the period 7/1/2021 through 6/30/2022. Box plots display weekly median fork length, 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles and outliers.

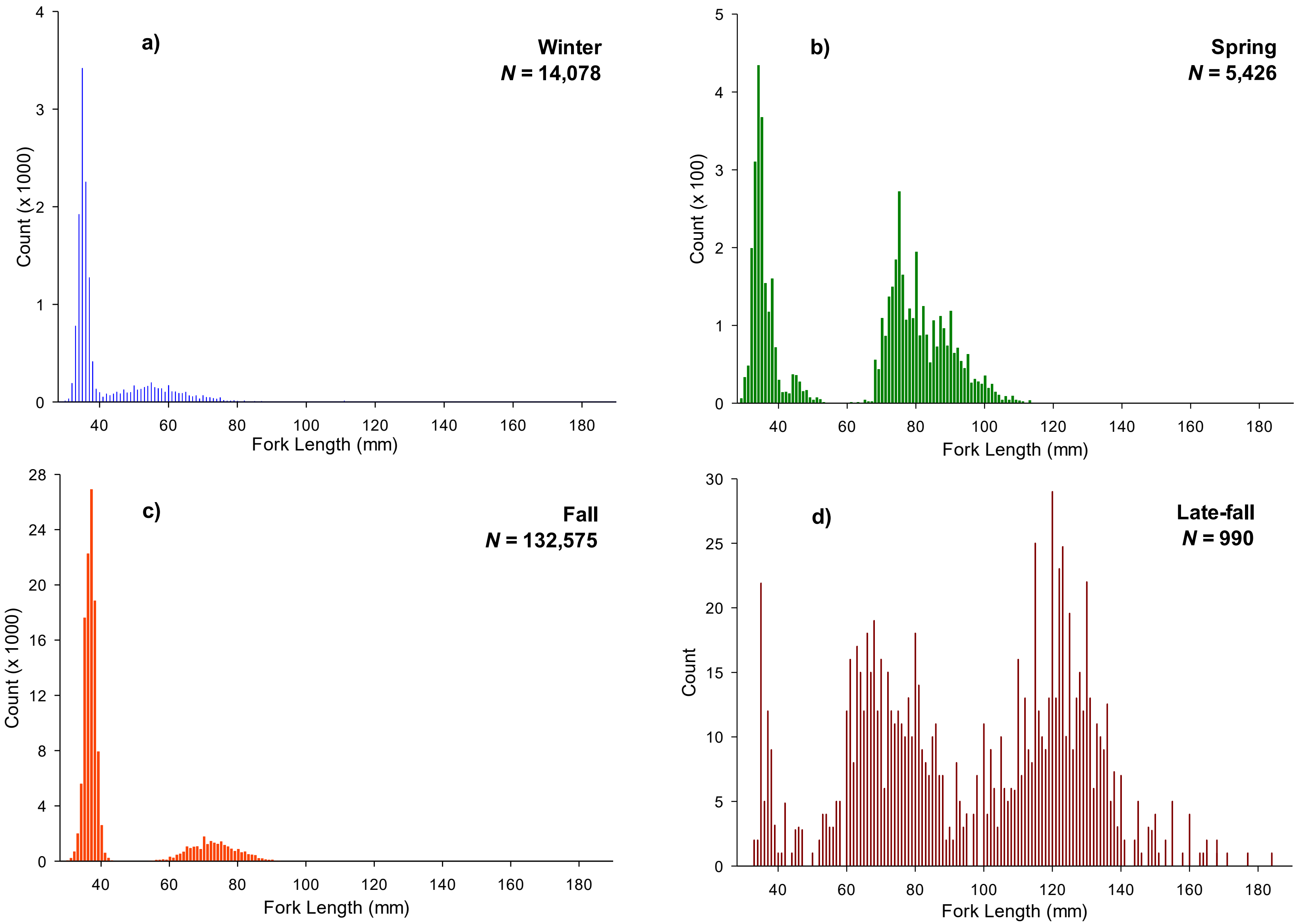

Figure 7. Fork length frequency distribution of brood year 2021 juvenile a) winter, b) spring, c) fall and d) late-fall Chinook salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fork length data were expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from 4/1/2021 through 11/30/2022.

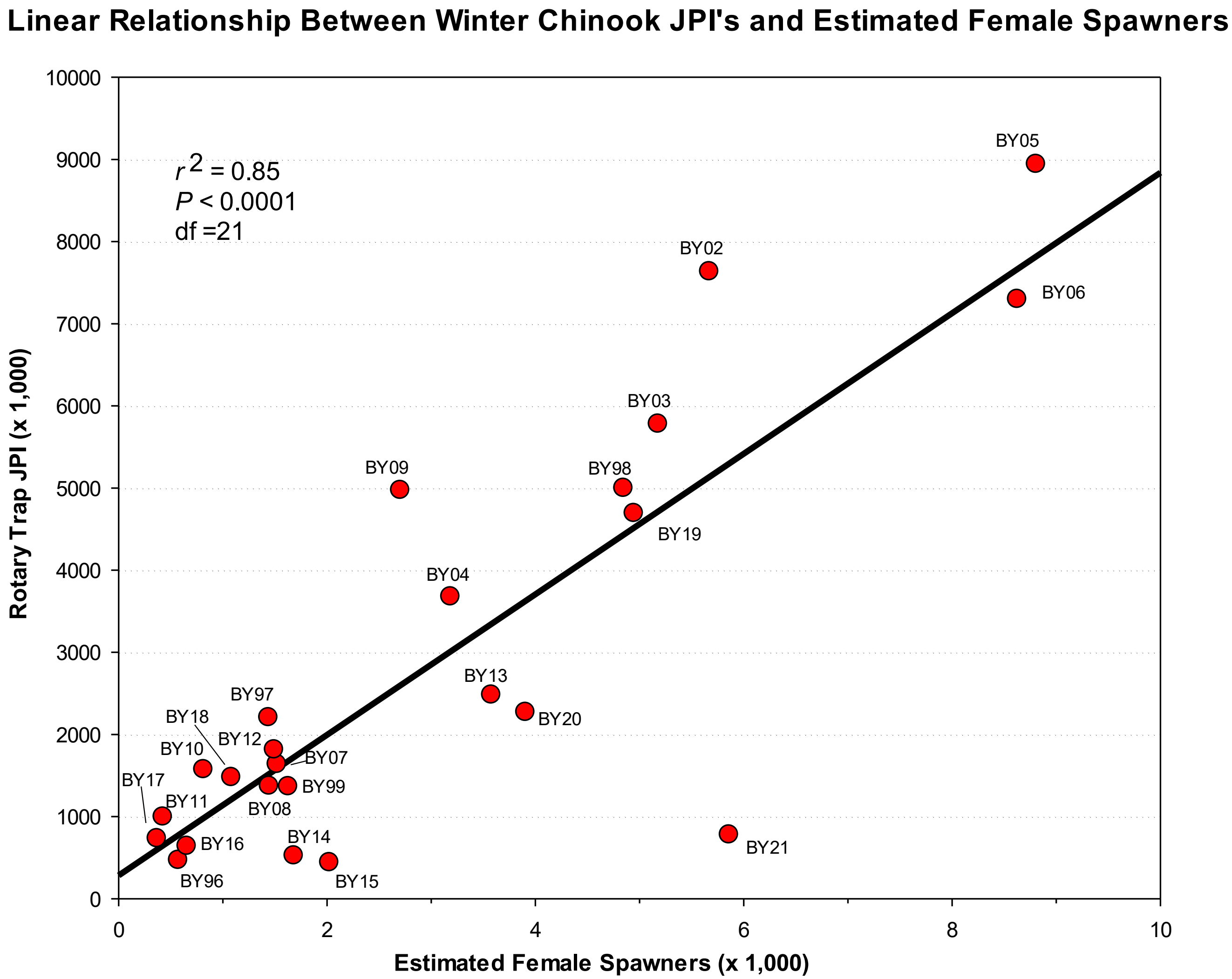

Figure 8. Linear relationship between rotary-screw trap juvenile winter Chinook fry-equivalent production indices (Rotary Trap JPI) and carcass survey derived estimated female spawners.

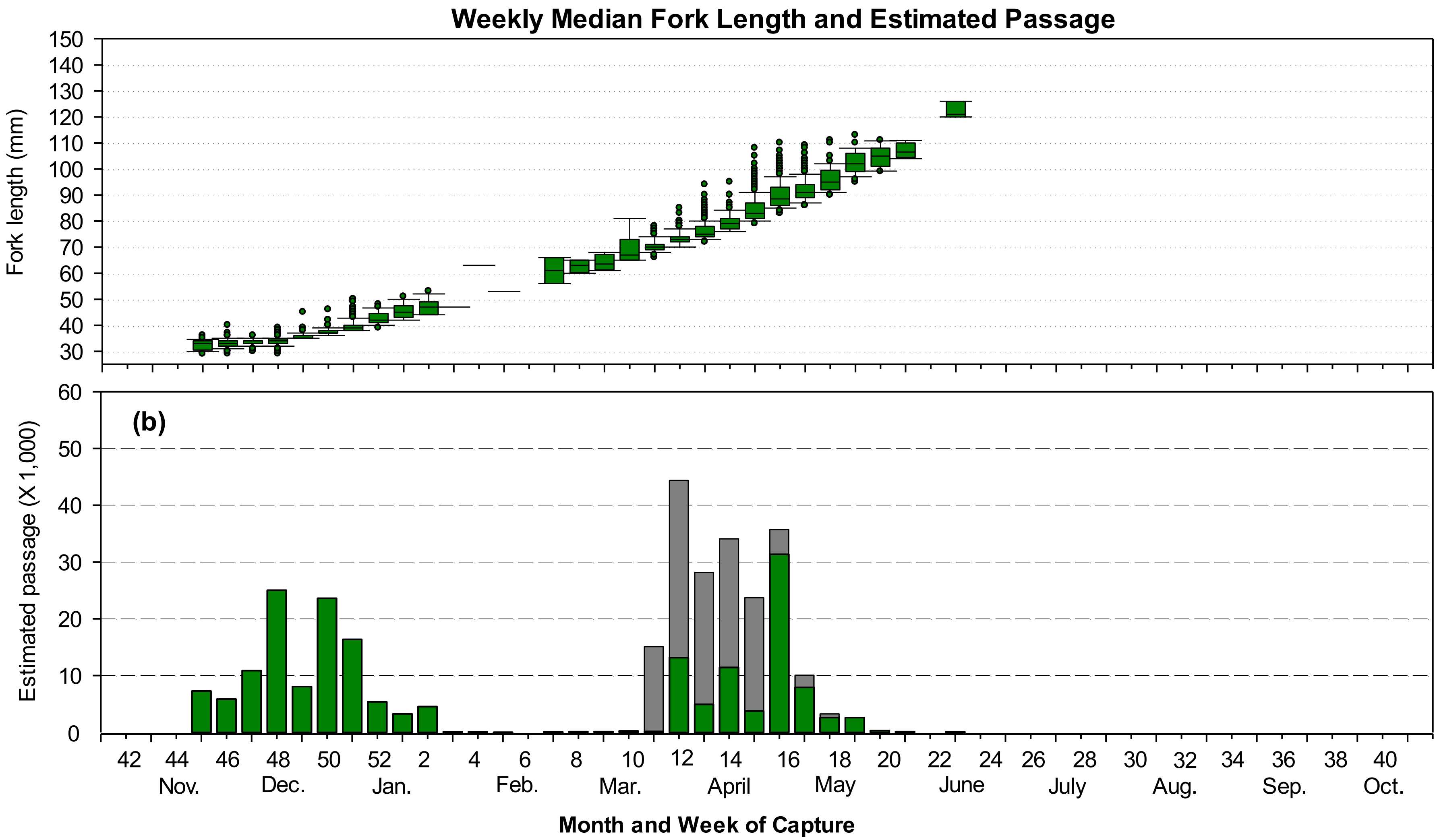

Figure 9. Weekly median fork length (a) and estimated passage (b) of brood year 2021 juvenile spring Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Spring Chinook salmon were sampled by rotary-screw traps for the period 10/16/2021 through 10/15/2022. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers. Dark grey 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.

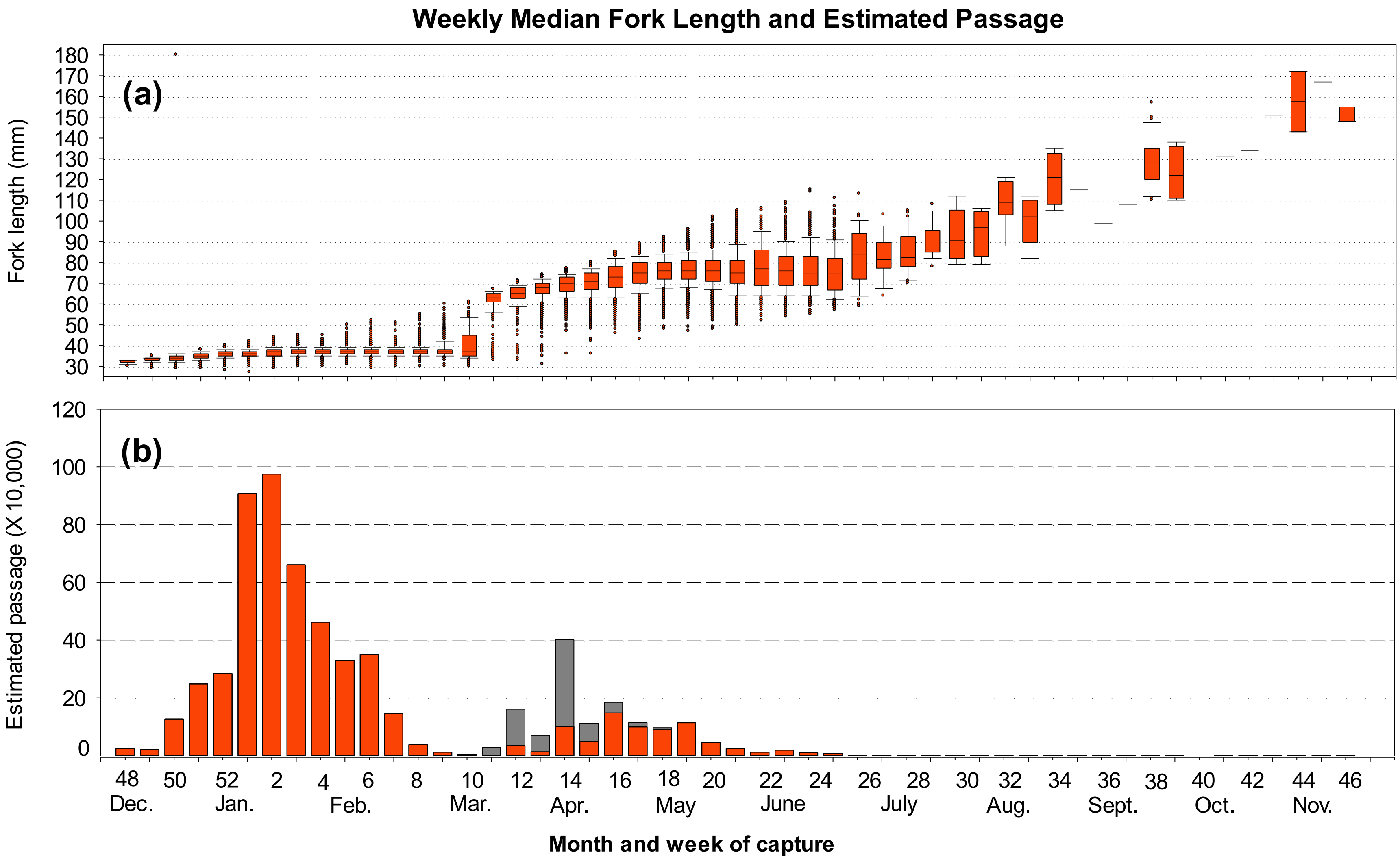

Figure 10. Weekly median fork length (a) and estimated passage (b) of brood year 2021 juvenile fall Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fall Chinook salmon were sampled by rotary-screw traps for the period 12/1/2021 through 11/30/2022. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers. Dark grey 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. *Unmarked* CNFH unfed fry released from 12/17/2021-1/11/2022 (weeks 50-2) at Balls Ferry boat ramp.

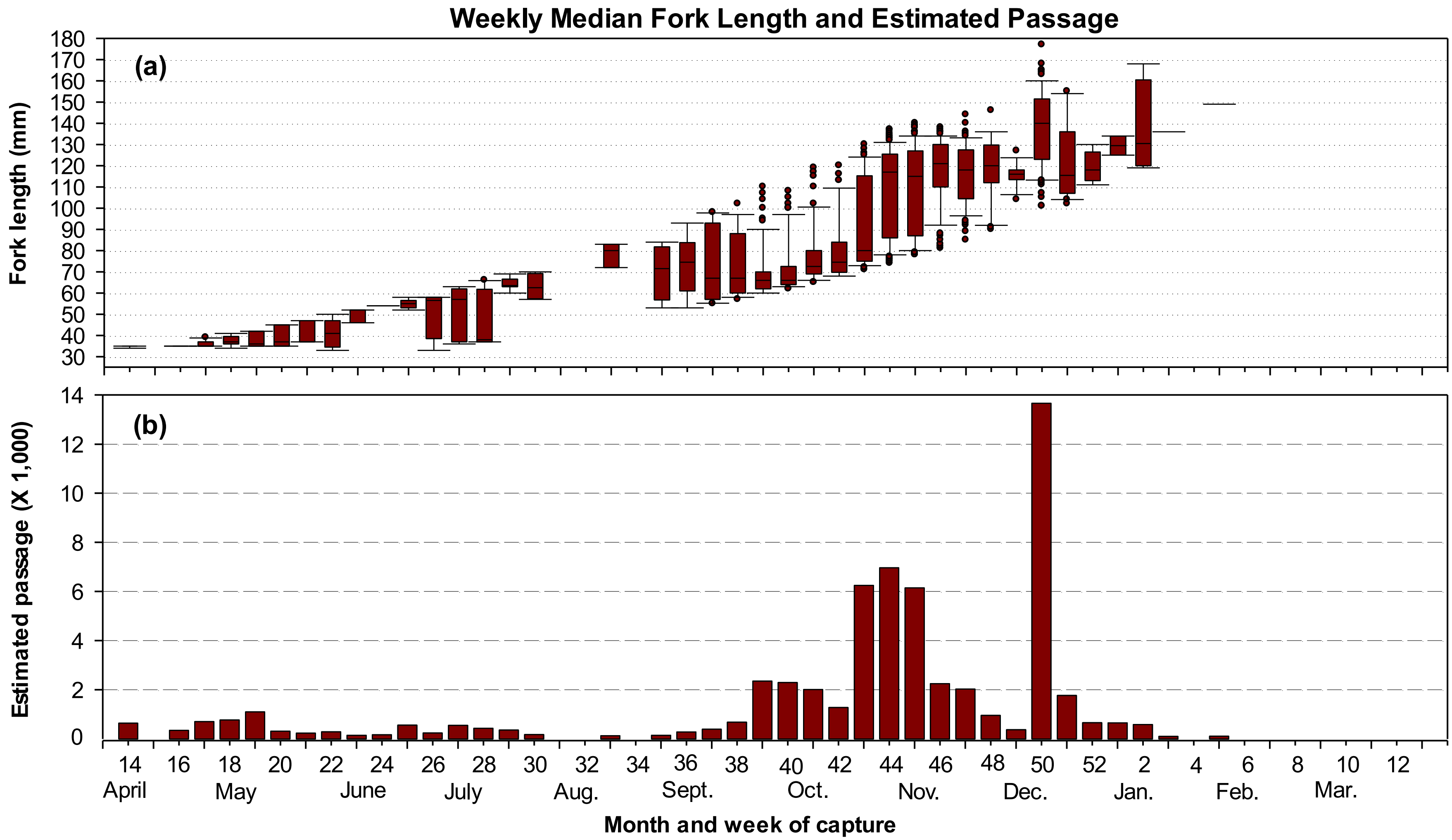

Figure 11. Weekly median fork length (a) and estimated passage (b) of brood year 2021 juvenile late-fall Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Late-fall Chinook salmon were sampled by rotary-screw traps for the period 4/1/2021 through 3/31/2022. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

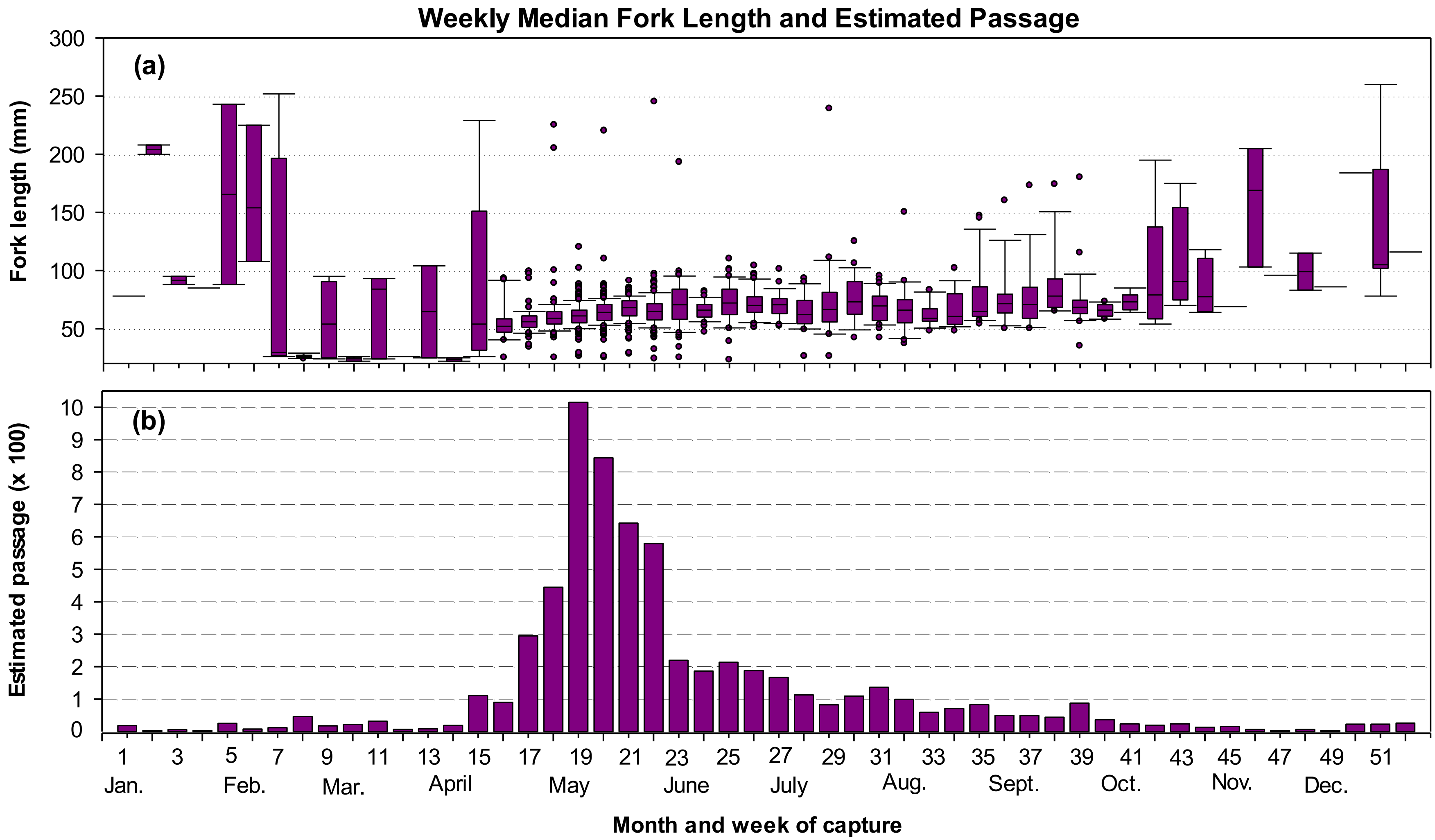

Figure 12. Weekly median fork length (a) and estimated passage (b) of brood year 2021 juvenile *O. mykiss* passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. *O. mykiss* were sampled by rotary-screw traps for the period 1/1/2021 through 12/31/2021. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

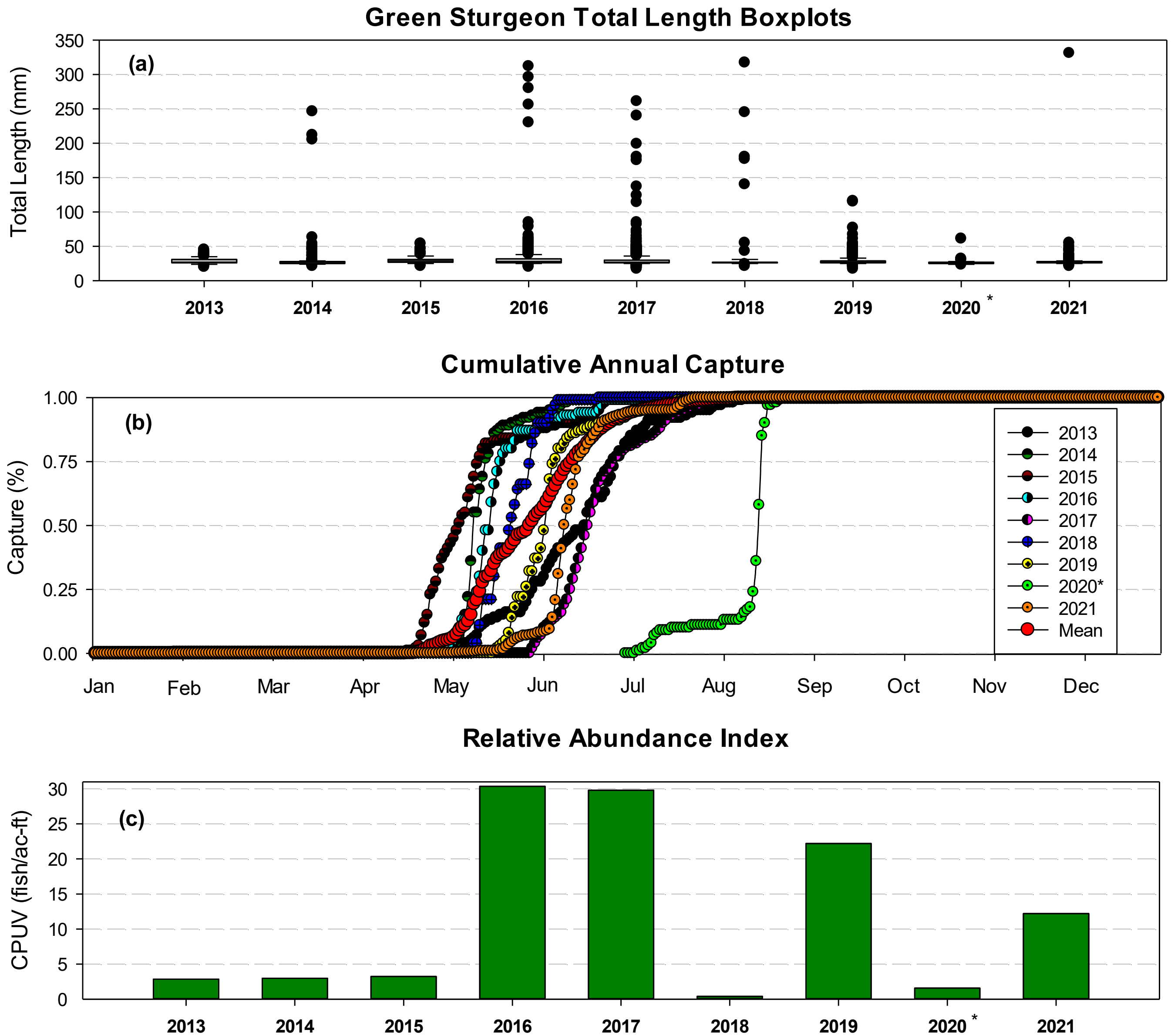

Figure 13. Green Sturgeon a) annual total length capture boxplots, b) annual cumulative capture trends with 18-year mean trend line, and c) relative abundance indices. All fish captured by rotary trap at RBDD (RK 391) on the upper Sacramento River, CA between 2013 and 2021. *Calendar year 2020 included a period of no sampling due to COVID-19 pandemic from 3/25/2020-6/30/2020.

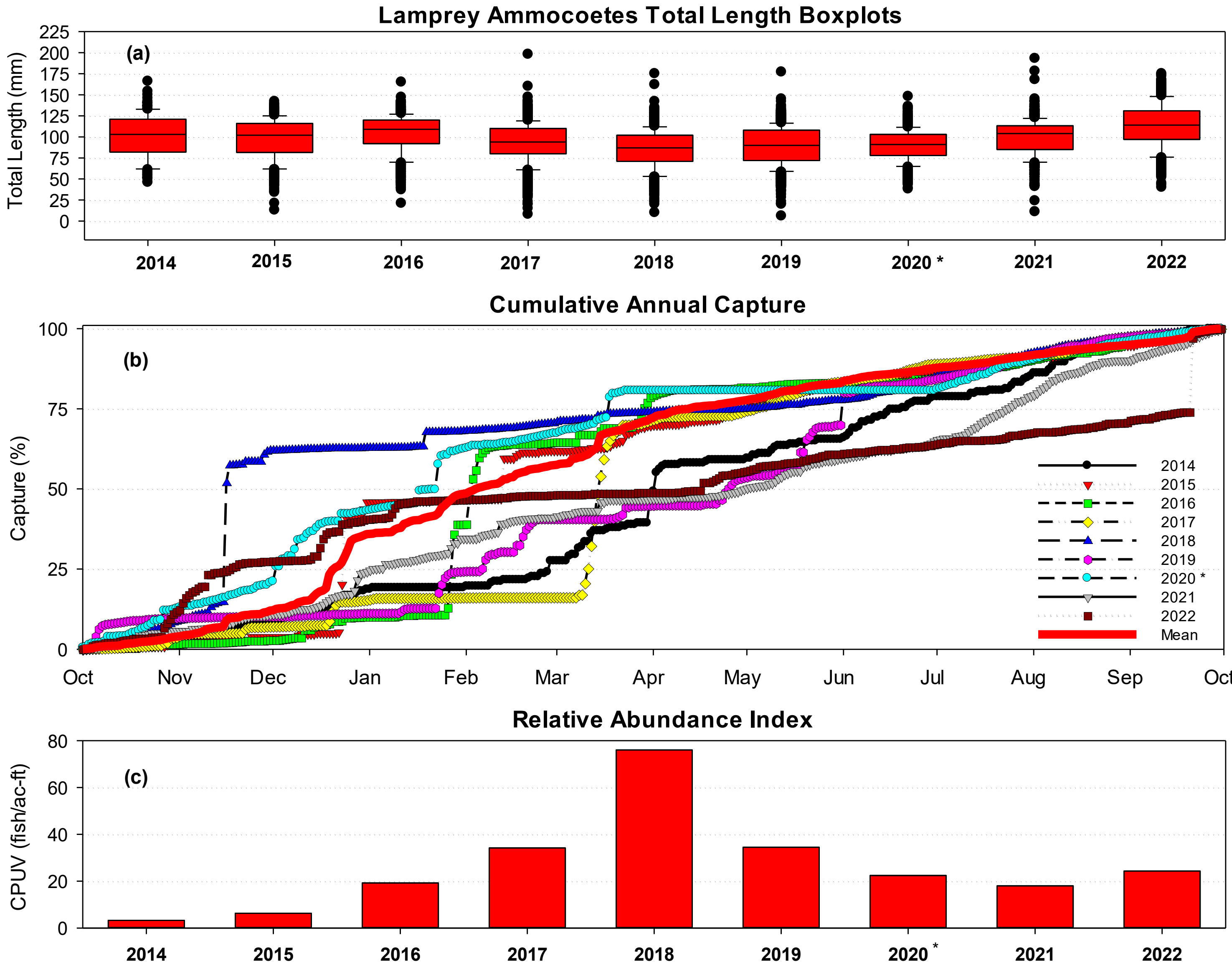

Figure 14. Unidentified lamprey ammocoetes a) total length distribution box plots, b) cumulative annual capture trends, and c) relative abundance indices from rotary traps collected between 10/1/2013 and 9/30/2022 by water year from the Sacramento River, CA at the RBDD (RK 391). *Water year 2020 included a period of no sampling from 3/25/2020 to 6/30/2020 due to the COVID-19 global pandemic.

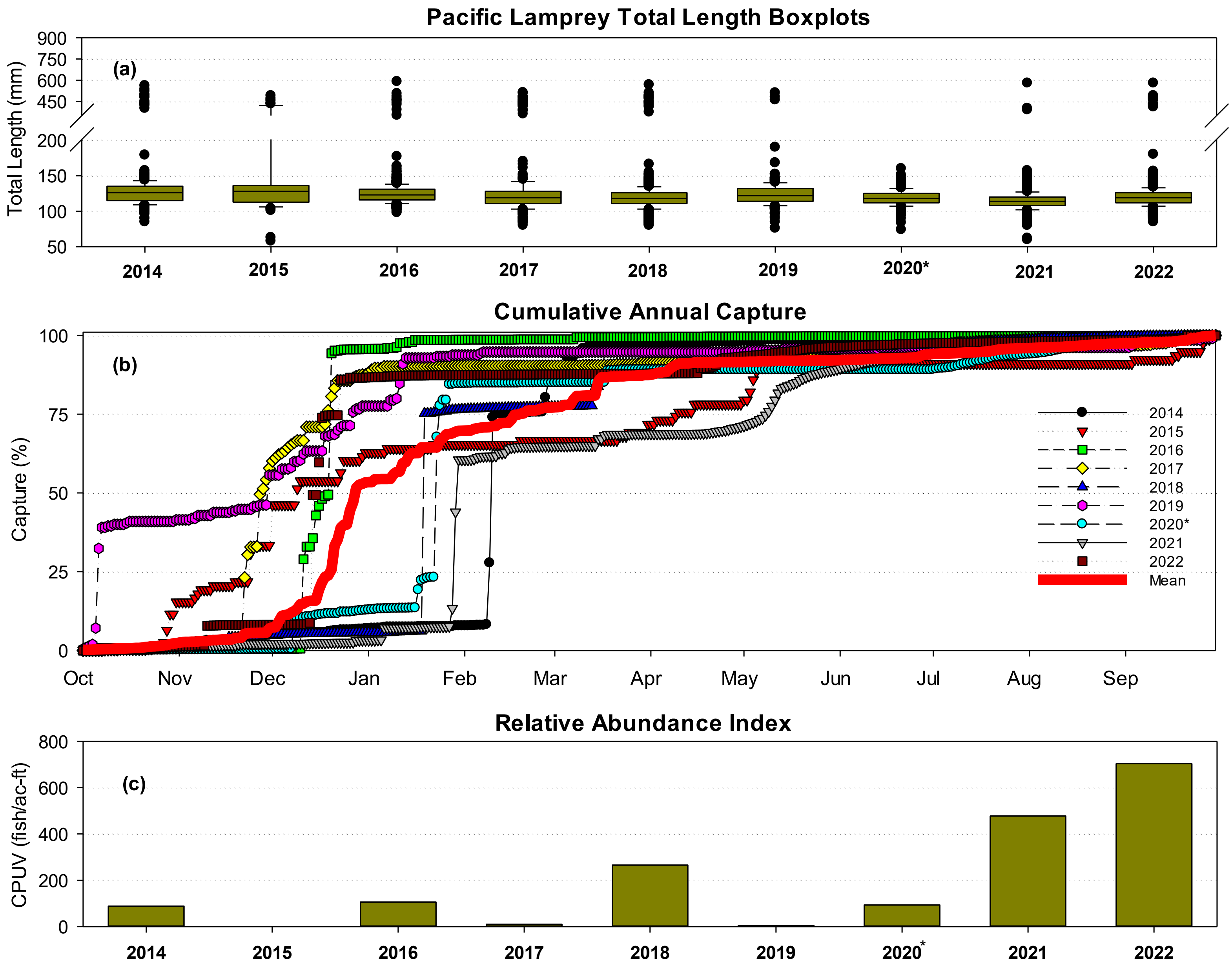

Figure 15. Pacific Lamprey (macrophthalmia and adults) a) total length distribution box plots, b) cumulative annual capture trends, and c) relative abundance indices from rotary traps collected between 10/1/2013 and 9/30/2022 by water year from the Sacramento River, CA at the RBDD (RK 391). *Water year 2020 included a period of no sampling from 3/25/2020 to 6/30/2020 due to the COVID-19 global pandemic.

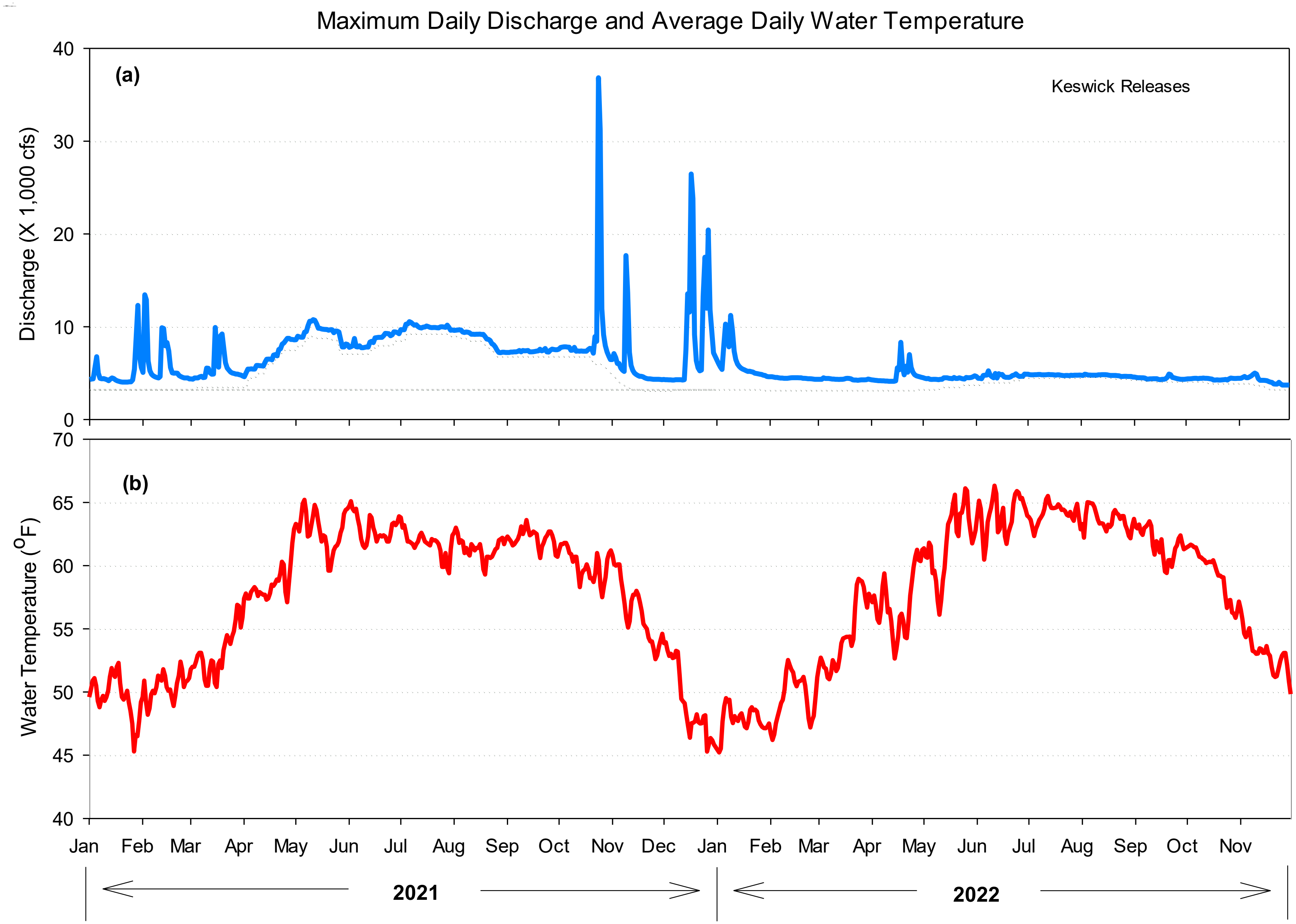

Figure 16. Sacramento River maximum daily discharge (a) observed at the California Data Exchange Center's Bend Bridge gauging station (blue line) showing water releases from Keswick Reservoir (cross-hatched gray shaded area) and average daily water temperatures (b) from rotary-screw traps at RBDD for the period 1/1/2021 through 11/30/2022.

Appendix 1.

Appendix 1. 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 2.

Appendix 2: List of Tables

Table **Page**

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 (RK 391) for the period October 16, 2021 through October 15, 2022 (brood year 2021). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 1.5 m diameter 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).

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
42	0.89	0	-	0	-	0	-	0
43	0.71	0	-	0	-	0	-	0
44 (Nov)	0.89	0	-	0	-	0	-	0
45	0.87	7,278	33	0	-	7,278	33	7,278
46	0.89	5,861	33	0	-	5,861	33	5,861
47	0.83	10,880	33	0	-	10,880	33	10,880
48 (Dec)	0.86	25,036	34	0	-	25,036	34	25,036
49	1.00	8,064	35	0	-	8,064	35	8,064
50	0.76	23,361	37	251	46	23,612	37	23,788
51	0.84	15,923	39	444	47	16,367	39	16,677
52	0.58	4,577	42	779	47	5,356	42	5,901
1 (Jan)	0.84	1,666	43	1,600	47.5	3,266	45	4,387
2	0.93	2,265	44	2,279	48.5	4,545	47	6,140
3	0.91	0	-	103	47	103	47	175
4	0.90	0	-	78	63	78	63	132
5 (Feb)	0.91	0	-	28	53	28	53	48
6	1.00	0	-	0	-	0	-	0
7	0.97	0	-	61	61	61	61	104
8	1.00	0	-	120	63	120	63	204
9 (Mar)	0.99	0	-	126	63.5	126	63.5	214
10	0.90	0	-	247	67	247	67	420
11	0.69	0	-	15,101	70	15,101	70	25,672
12	0.47	0	-	44,370	73	44,370	73	75,429
13	0.97	0	-	28,157	75	28,157	75	47,868
14 (Apr)	0.49	0	-	34,098	79	34,098	79	57,967
15	0.80	0	-	23,697	83	23,697	83	40,285

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	0.61	0	-	35,737	88.5	35,737	88.5	60,754
17	1.00	0	-	10,050	91	10,050	91	17,085
18 (May)	1.00	0	-	3,264	95	3,264	95	5,549
19	1.00	0	-	2,596	102	2,596	102	4,413
20	1.00	0	-	325	105	325	105	553
21	1.00	0	-	123	106.5	123	106.5	208
22 (Jun)	0.66	0	-	0	-	0	-	0
23	0.80	0	-	99	121	99	121	168
24	0.80	0	-	0	-	0	-	0
25	0.80	0	-	0	-	0	-	0
26	0.80	0	-	0	-	0	-	0
27 (Jul)	0.97	0	-	0	-	0	-	0
28	0.91	0	-	0	-	0	-	0
29	0.91	0	-	0	-	0	-	0
30	0.91	0	-	0	-	0	-	0
31 (Aug)	0.91	0	-	0	-	0	-	0
32	0.77	0	-	0	-	0	-	0
33	0.89	0	-	0	-	0	-	0
34	0.91	0	-	0	-	0	-	0
35 (Sep)	0.91	0	-	0	-	0	-	0
36	0.91	0	-	0	-	0	-	0
37	0.91	0	-	0	-	0	-	0
38	0.89	0	-	0	-	0	-	0
39	0.91	0	-	0	-	0	-	0
40 (Oct)	0.94	0	-	0	-	0	-	0
41	0.91	0	-	0	-	0	-	0
BY total		104,912		203,734		308,646		451,260
90% CI (low : high)		(56,688 : 153,135)		(102,452 : 305,016)		(160,194 : 457,098)		(233,999 : 668,521)

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 (RK 391) for the period October 16, 2021 through October 15, 2022 (brood year 2021). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 1.5 m diameter 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).

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
48 (Dec)	0.86	6,892	32	0	-	6,892	32	6,892
49	1.00	21,172	33	0	-	21,172	33	21,172
50	0.76	126,485	34	0	-	126,485	34	126,485
51	0.84	247,977	35	0	-	247,977	35	247,977
52	0.58	284,044	36	0	-	284,044	36	284,044
1 (Jan)	0.84	907,099	36	0	-	907,099	36	907,099
2	0.93	975,065	37	0	-	975,065	37	975,065
3	0.91	660,509	37	0	-	660,509	37	660,509
4	0.90	462,023	37	0	-	462,023	37	462,023
5 (Feb)	0.91	330,083	37	279	48	330,362	37	330,557
6	1.00	350,341	37	757	48	351,097	37	351,627
7	0.97	145,340	37	85	50	145,425	37	145,484
8	1.00	37,087	37	396	50	37,483	37	37,760
9 (Mar)	0.99	10,994	37	776	50	11,770	37	12,313
10	0.90	4,020	36	1,291	52.5	5,310	37	6,214
11	0.69	1,225	35.5	27,357	64	28,582	63	47,731
12	0.47	1,663	37.5	159,245	65	160,908	65	272,379
13	0.97	437	37	69,579	68	70,016	68	118,721
14 (Apr)	0.49	274	36	400,594	70	400,868	70	681,283
15	0.80	121	42	111,542	71	111,664	71	189,743
16	0.61	0	-	184,649	73	184,649	73	313,904
17	1.00	29	43	114,016	75	114,045	75	193,856
18 (May)	1.00	0	-	96,631	76	96,631	76	164,273
19	1.00	0	-	115,712	76	115,712	76	196,710
20	1.00	0	-	45,705	76	45,705	76	77,699
21	1.00	0	-	23,661	75	23,661	75	40,223

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)	0.66	0	-	11,744	77	11,744	77	19,966
23	0.80	0	-	18,833	76	18,833	76	32,016
24	0.80	0	-	9,604	74.5	9,604	74.5	16,327
25	0.80	0	-	7,448	74.5	7,448	74.5	12,662
26	0.80	0	-	1,559	84	1,559	84	2,650
27 (Jul)	0.97	0	-	529	81.5	529	81.5	900
28	0.91	0	-	923	82.5	923	82.5	1,569
29	0.91	0	-	513	88	513	88	872
30	0.91	0	-	232	90.5	232	90.5	395
31 (Aug)	0.91	0	-	147	97	147	97	251
32	0.77	0	-	242	109	242	109	412
33	0.89	0	-	242	102	242	102	411
34	0.91	0	-	118	121	118	121	200
35 (Sep)	0.91	0	-	29	115	29	115	49
36	0.91	0	-	31	99	31	99	53
37	0.91	0	-	27	108	27	108	47
38	0.89	0	-	1,126	128	1,126	128	1,915
39	0.91	0	-	113	122	113	122	191
40 (Oct)	0.94	0	-	0	-	0	-	0
41	0.91	0	-	28	131	28	131	47
42	0.91	0	-	29	134	29	134	50
43	0.94	0	-	27	151	27	151	46
44 (Nov)	0.91	0	-	56	157.5	56	157.5	95
45	0.89	0	-	29	167	29	167	50
46	0.91	0	-	84	154	84	154	142
47	0.57	0	-	0	-	0	-	0
BY total		4,590,110		1,405,987		5,978,867		6,963,059
90% CI (low : high)		(2,899,752 : 6,280,468)		(792,298 : 2,019,677)		(3,688,737 : 8,268,998)		(4,246,779 : 9,679,338)

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 2012 and November 2022. *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	Estimated Recruits/Female	ETF Survival Rate (%)	L90 CI : U90 CI
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 [2]	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)
2021	6,963,059	4,246,779	9,679,338	22,987	5,029	303	6.0	(3.7 : 8.4)
					Average	1,197	24.2	(0 : 54.9)
					Standard Deviation	1,449	30.5	(31.4 : 91.8)

[1]Estimated females derived from carcass survey; sex ratios used to determine female spawners based on CNFH data between 2008 and 2021.

[2]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).