BROOD YEAR 2017 JUVENILE SALMONID PRODUCTION AND PASSAGE INDICES AT RED BLUFF DIVERSION DAM

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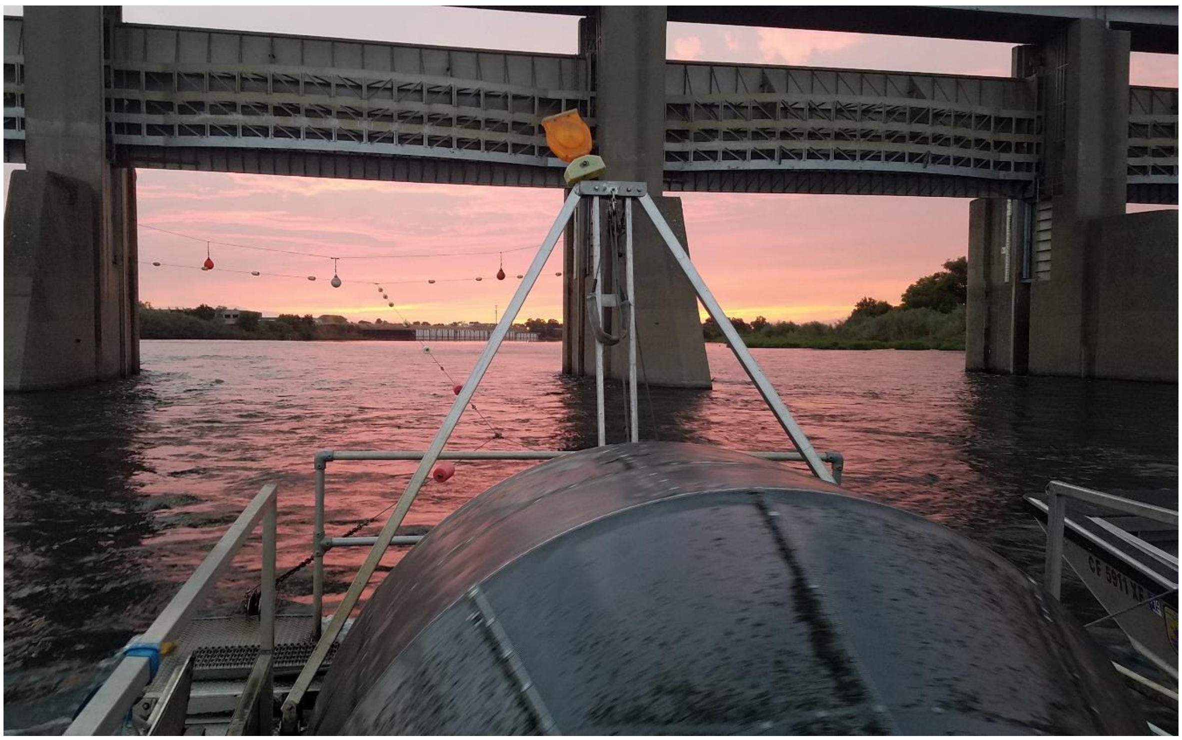

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Brood year 2017 juvenile salmonid production and passage indices at Red Bluff Diversion Dam.

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Abstract.— Brood year 2017 (BY2017) juvenile winter Chinook salmon estimated passage at Red Bluff Diversion Dam (RBDD) was 601,677 for fry and pre-smolt/smolts combined. The fry-equivalent rotary trap juvenile production index (JPI) was estimated at 734,432 with the lower and upper 90% confidence intervals (CI) extending from 471,292 to 997,572 juveniles, respectively. The estimated egg-to-fry (ETF) survival rate, based on the BY2017 winter Chinook fry-equivalent JPI was 48.7%, the highest value detected since monitoring began. The range of ETF survival rates based on the 90% CI were 31.3% to 66.2%.

A high BY2017 winter Chinook ETF survival rate was likely a result of adequate cold-water pool availability in Shasta Reservoir due to one of the wettest water years on record and efforts to follow the 2017 Sacramento River temperature management plan. This plan targeted a 53°F daily average temperature at the Sacramento River-Clear Creek gauging station and temperatures of 55°F within a seven-day average daily maximum at the most downstream winter Chinook redd. However, the winter Chinook ETF survival estimate for BY2017 was likely elevated due to uncertainty in the adult spawner estimates. The total escapement was estimated at 1,155 in-river adults, yet the 90%CI around the estimate ranged from a low of 109 to a high of 1,888. Difficulties in getting precise estimates was attributed to poor visibility on the carcass survey resultant from high water early in the survey season and prolonged turbidity throughout the survey season.

BY2017 juvenile spring Chinook salmon estimated passage was 311,973 fry and pre-smolt/smolts combined. The fry-equivalent JPI for 2016 spring Chinook was 524,627 with the lower and upper 90% CI extending from 270,106 to 779,149 juveniles, respectively. BY2017 fall Chinook juvenile estimated passage at RBDD was 2,170,361 fry and pre-smolt/smolts combined. The fry-equivalent JPI for 2017 fall Chinook was 3,482,430 with the lower and upper 90% CI extending from 1,927,884 to 5,036,976 juveniles, respectively. BY2017 late-fall Chinook juvenile estimated passage at RBDD was 77,885 fry and pre-smolt/smolts combined. The fry-equivalent JPI for BY2017 late-fall was 118,896 with the lower and upper 90% CI extending from 46,821 to 190,971 juveniles, respectively.

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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).

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

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

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

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

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

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

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) 2017, (2) define temporal patterns of abundance for all anadromous salmonids passing RBDD, (3) correlate juvenile salmon production with adult salmon escapement estimates (where appropriate), and (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. This annual progress report addresses, in detail, our juvenile salmonid monitoring activities at RBDD for the period January 1, 2017 through November 30, 2018. This report includes JPI's for the 2017 brood year emigration period for the four runs of Chinook salmon and passage estimates of *O. mykiss* 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-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

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

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, *Acipenser medirostris* (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.

Methods

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

Sampling Regimes.—In general, RSTs sampled continuously throughout 24-hour periods and samples were processed once daily. 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 were reduced from four to three. During storm events and associated elevated river discharge levels, each 24-hour sampling period was divided into four or six non-overlapping strata and one or two strata were randomly selected for sampling (Martin et al 2001). Estimates were extrapolated to un-sampled strata by dividing catch by the strata-selection probability (i.e., $P = 0.25$ or 0.17). If further reductions in effort were needed or river conditions were intolerable, sampling was discontinued or not conducted. When days or weeks were not sampled, mean daily passage estimates were imputed for missed days based on weekly or monthly interpolated mean daily estimates, respectively.

Data Collection.— All fish captured were anesthetized, identified to species, and enumerated with fork lengths (FL) measured to the nearest millimeter (mm). When capture of Chinook juveniles exceeded approximately 200 fish/trap, a random sub-sample of the catch was measured to include approximately 100 individuals, with all additional fish being enumerated and recorded. Chinook salmon race was field assigned using length-at-date (LAD) criteria developed by Greene (1992)[3]. 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 correction procedures.

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, 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 2.4-m diameter rotary-screw traps sampling 24 hours daily, 7 days per week. Weekly values <1.00 represented occasions when less than four traps were sampling, one or more traps were structurally modified to sample only one-half the normal volume of water or when less than 7 days per week were sampled.

Mark-Recapture Trials.—Chinook salmon collected as part of daily samples were marked with bismark brown staining solution (Mundie and Traber 1983) prepared at a concentration of 21.0 mg/L of water. Fish were stained for a period of 45-50 minutes, removed, and allowed to recover in fresh water. Marked fish were held for 6-24 hours before being released approximately 4-km upstream from RBDD after official sunset. Recapture of marked fish was recorded for up to five days after release. Trap efficiency was calculated based on the proportion of recaptures to total fish released (i.e., mark-recapture trials). Trials were

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[3] 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.

conducted as fish numbers and staffing levels allowed under a variety of river discharge levels and trap effort combinations.

Trap Efficiency Modeling.— To develop a trap efficiency model, mark-recapture trials were conducted as noted above. Estimated trap efficiency (i.e., the proportion of the juvenile population passing RBDD captured by traps; $\hat{T}_d$) was modeled with *%Q* to develop a simple least-squares regression equation (eq. 5). The equation (slope and intercept) was then used to estimate daily trap efficiencies based on daily proportion of river volume sampled. Each successive year of mark-recapture trials were added annually to the original trap efficiency model developed by Martin et al. (2001) on July 1 of each year. Since 2014, the trap efficiency model has been updated to include naturally produced fish sampled during monitoring activities without the RBDD gates in the lowered position (Poytress et al. 2014, Poytress 2016). The model for BY2017 relied on 79 mark-recapture trials using wild fish and conducted with the RBDD gates raised between 2002 and 2017 ($r^2 = 0.70$, $P < 0.001$, df = 78; Figure 3).

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

1.

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

and,

2.

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

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

3.

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

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

4.

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

where,

5.

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

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

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

6.

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

Estimated Variance.—

7.

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

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

8.

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

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

9.

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

where,

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

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

11.

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

where,

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

for some

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

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

13.

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

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

14.

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

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 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.

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 2018) 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 and fall Chinook fecundity estimates were obtained from CNFH annual spawning records.

Results

Sampling effort.—Weekly sampling effort throughout the BY2017 winter Chinook salmon emigration period was fairly high and ranged from 0.43 to 1.00 ($\bar{x}$ = 0.79; *N* = 52 weeks; Table 1). Weekly sampling effort ranged from 0.50 to 1.00 ($\bar{x}$ = 0.89; *N* = 26 weeks) between July and the end of December, the period of greatest juvenile winter Chinook emigration, and 0.43 to 1.00 ($\bar{x}$ = 0.69; *N* = 26 weeks) during the latter half of the emigration period (Table 1).

Weekly sampling effort throughout the BY2017 spring Chinook emigration period ranged from 0.43 to 1.00 ($\bar{x}$ = 0.80; *N* = 52 weeks; Table 2). Weekly sampling effort ranged from 0.43 to 1.00 ($\bar{x}$ = 0.77; *N* = 26 weeks) between mid-October and mid-April, the period of greatest juvenile spring Chinook emigration, and 0.43 to 1.00 ($\bar{x}$ = 0.83; *N* = 26 weeks) during the latter half of the emigration period (Table 2).

Weekly sampling effort throughout the BY2017 fall Chinook emigration period ranged from 0.43 to 1.00 ($\bar{x}$ = 0.81; *N* = 52 weeks; Table 3). Weekly sampling effort ranged from 0.43 to 1.00 ($\bar{x}$ = 0.72; *N* = 26 weeks) between December and the end of May, the first half of the juvenile fall Chinook 2017 brood year, and 0.64 to 1.00 ($\bar{x}$ = 0.89; *N* = 26 weeks) during the latter half of the emigration period (Table 3).

Weekly sampling effort throughout the BY2017 late-fall Chinook emigration period ranged from 0.23 to 1.00 ($\bar{x}$ = 0.81; *N* = 52 weeks; Table 4). Weekly sampling effort ranged from 0.23 to 1.00 ($\bar{x}$ = 0.80; *N* = 26 weeks) between April and the end of September, the first half of the juvenile late-fall Chinook 2017 brood year, and 0.50 to 1.00 ($\bar{x}$ = 0.81; *N* = 26 weeks) during the latter half of the emigration period (Table 4).

Weekly sampling effort throughout the BY2017 *O. mykiss* emigration period ranged from 0 to 1.00 ($\bar{x}$ = 0.72; *N* = 52 weeks; Table 5). Weekly sampling effort ranged from 0 to 1.00 ($\bar{x}$ = 0.55; *N* = 26 weeks) between January and the end of June, the first half of the juvenile *O. mykiss* 2017 brood year, and 0.50 to 1.00 ($\bar{x}$ = 0.89; *N* = 26 weeks) during the latter half of the emigration period (Table 5).

The high variance in sampling effort throughout the reporting period was attributed to several sources. They included: (1) intentional reductions in effort resulting from sampling < 4 traps, cone modification(s), non-sampled days due to hatchery releases upstream of the transect or staffing limitations, (2) unintentional reductions in effort resulting from high flows and debris loads, (3) Section 10(a)(1)(A) permit catch limitations.

Trap efficiency modeling.— Elevated river flows and low fall Chinook catch numbers did not allow the opportunity to conduct mark-recapture trials in 2017. Three mark-recapture trials were conducted near the end of the reporting period in the fall of 2018; however, these and any additional trials conducted prior to July 1, 2019 will be incorporated into the model beginning with BY2019 winter Chinook. The 79-trial model (r^2 = 0.70, P < 0.001, df = 78; Figure 3) was employed for passage estimation during the entire BY2017 winter, spring, late-fall and fall Chinook outmigration period as well as the entire BY2017 *O. mykiss* outmigration period.

LAD genetic-based run corrections.—Genetic tissue samples from up to ten Chinook salmon per run, according to LAD, were collected on a daily basis as part of two genetic sampling projects known as "Improving Vital Rates Estimation Using Parentage-Based Mark Recapture Methods" and "Central Valley Salmonid Coordinated Genetic Monitoring Project". Samples collected from LAD winter and spring Chinook were analyzed (see Appendix 1) to evaluate the accuracy of field-based run assignments used to generate Chinook passage and production estimates. A review of the genetic run analysis data indicated that winter Chinook were incorrectly assigned to spring Chinook using LAD criteria for a period of 34 days during BY2017 from mid-October thru late November. In-river spawner data analysis by California Department of Fish and Wildlife estimated the timing of last emergence for winter Chinook fry would occur in early November based upon later than average adult winter Chinook spawn timing in 2017 (D. Killam, CDFW, pers. comm.).

Based upon genetic and spawner data, LAD spring Chinook captured between October 16 and November 18, 2017 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 passage and production estimates and is reflected in the values reported herein. A genetic reassignment memo dated April 10, 2018 further outlines details of genetic-based revisions made to BY2017 winter and spring Chinook real-time biweekly passage estimates (Appendix II)[4].

Winter Chinook fork length evaluations.— BY2017 winter Chinook fork lengths ranged between 28 and 168 mm (Figure 4a). Winter Chinook were weighted (78.6%) to the fry size-class category (<46mm) with 97.1% of those measuring less than 40 mm (Figure 5). The remaining 21.4% were attributed to the pre-smolt/smolt category (>45 mm) with 94.6% of the fish sampled between 46 and 95 mm.

Winter Chinook passage.—BY2017 winter Chinook juvenile estimated passage at RBDD was 601,677 fry and pre-smolt/smolts combined (Table 1). Fry sized juveniles (<46 mm FL) comprised 68.5% of total estimated winter Chinook passage (Table 1). Fry passage occurred from July through the end of November (weeks 27 thru 47; Figure 4b). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 31.5% of total passage and the first observed emigration past RBDD occurred in early September (week 35; Table 1). Weekly pre-smolt/smolt passage for the brood year concluded in early May (week 18; Figure 4b).

Winter Chinook JPI to adult comparisons.—The BY2017 winter Chinook fry-equivalent JPI was 734,432 with the lower and upper 90% CI extending from 471,292 to 997,572 juveniles, respectively (Table 6). Adult females contributing to in-river spawning of BY2017 winter Chinook were estimated to have been 367 individuals (D. Killam, CDFW, pers. comm.). The estimated ETF survival rate, based on the BY2017 winter Chinook fry-equivalent JPI and estimated number of female spawners and egg deposition in-river, was 48.7%. The range of ETF survival based on 90% CI's was 31.3% to 66.2% (Table 6).

Adult female spawner estimates derived from winter Chinook carcass surveys and rotary-screw trap data from brood years 1996-2017 were used to evaluate the linear relationship between the estimates. Twenty 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

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[4] Genetic reassignment memo and affected biweekly reports can be found at the following web address: https://www.fws.gov/redbluff/RBDD%20JSM%20Biweekly/2017/rbdd_jsmp_2017.html

conducted in 2000 and 2001. Rotary trap JPI's were significantly correlated in trend to adult female spawner estimates ($r^2 = 0.87$, $P < 0.001$, df = 19; Figure 6).

Spring Chinook fork length evaluations.— BY2017 spring Chinook fork lengths ranged between 30 and 138 mm (Figure 5b). Spring Chinook were heavily weighted to the pre-smolt/smolt size-class category (>45mm). Only 5.8% of all fish sampled as spring Chinook were designated fry with 91.3% measuring less than 40 mm FL (Figure 8a). The bulk of the catch (94.2%) was attributed to the pre-smolt/smolt category (>45 mm) with fish between 60 and 115 mm comprising 96.3% of this size group.

Spring Chinook passage.—BY2017 spring Chinook juvenile estimated passage at RBDD was 311,973 fry and pre-smolt/smolts combined (Table 2). Fry sized juveniles (<46 mm FL) comprised only 2.6% of total estimated spring Chinook passage (Table 2). Fry passage occurred from the end of November through early January (weeks 47 thru 1; Table 2). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 97.4% of total passage and the first observed emigration past RBDD occurred in early December (week 49; Table 2). Weekly pre-smolt/smolt passage for the brood year ended in June (week 23; Figure 8b). The fry-equivalent rotary trap JPI for BY2017 was 524,627 with the lower and upper 90% CI extending from -270,106 to 779,149 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.—BY2017 fall Chinook fork lengths ranged between 26 and 173 mm (Figure 5c). BY2017 fall Chinook were composed of 11.2% in the fry size-class category (<46 mm) with 96.9% of those fry measuring less than 40 mm FL (Figure 9a). The remaining 88.8% were attributed to the pre-smolt/smolt category (>45 mm) with fish between 65 and 100 mm comprising 94.5% of the size group.

Fall Chinook passage.—BY2017 fall Chinook juvenile estimated passage at RBDD was 2,170,361 fry and pre-smolt/smolts combined (Table 3) which represents the lowest total passage estimate on record since the RBDD Juvenile Fish Monitoring Program began in 1995. Fry sized juveniles (<46 mm FL) comprised 13.6% of total estimated fall Chinook passage (Table 3). Fry passage occurred from December through the beginning of May (weeks 48 thru 18; Figure 9b). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 86.4% of total passage. The first observed pre-smolt/smolt passage occurred in mid-January (week 3; Table 3). Weekly pre-smolt/smolt passage for the brood year ended in November (week 47; Table 3).

Fall Chinook JPI to adult comparisons.—The fry-equivalent rotary trap JPI for BY2017 was 3,482,430 with the lower and upper 90% CI extending from 1,927,884 to 5,036,976 juveniles, respectively (Table 3). The total number of adult BY2017 fall Chinook females contributing to in-river spawning upstream of RBDD was estimated to be 4,437 individuals. The estimated ETF survival rate, based on the BY2017 fall Chinook fry-equivalent JPI, estimated number of female spawners and eggs deposited in-river, was 17.6%. The range of ETF survival based on 90% CI's was 9.8% to 25.5% (Table 7).

Late-Fall Chinook fork length evaluations.—BY2017 late-fall Chinook were sampled between 30 and 186 mm (Figure 5d). BY2017 late-fall Chinook sampled were heavily weighted to the pre-smolt/smolt size-class category (>45 mm). Only 8.0% of all fish sampled as late-fall were designated fry (<46 mm), with 89.6% of the fry measuring less than 40 mm FL (Figure 9a). The remaining 92.0% of juveniles were attributed to the pre-smolt/smolt category, with fish between 70 and 150 mm comprising 91.6% of that value.

Late-fall Chinook passage.—BY2017 late-fall Chinook juvenile estimated passage at RBDD was 77,885 fry and pre-smolt/smolts combined (Table 4). Fry sized juveniles (<46 mm FL) comprised 24.8% of total estimated late-fall Chinook passage (Table 4). Fry passage occurred from April through the end of June (weeks 14 thru 26; Figure 9b). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 75.2% of total passage and the first observed emigration past RBDD occurred in late May (week 21; Table 4). Weekly pre-smolt/smolt passage for the brood year ended in February (week 6; Figure 9b). The fry-equivalent rotary trap JPI for BY2017 was 118,896 with the lower and upper 90% CI extending from 46,821 to 190,971 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.—BY2017 juvenile *O. mykiss* were sampled between 20 and 273 mm (Figure 10a). Yearling (139-280 mm) and fry (<41 mm) *O. mykiss* were amongst the first sampled at the beginning of calendar year 2017 (Table 5). *O. mykiss* fry captures were highly variable, as the first and smallest fry of the year was captured in early March, with a fork length of 20 mm; another 20 mm fry was captured 12 weeks later (early June; Figure 10a). Fry captures continued through week 29 (mid-July). Sub-yearling (41-138mm) captures began in April (week 17; Table 5) and continued through the end of the calendar year. Yearling captures occurred sporadically through the end of the calendar year (Table 5).

O. mykiss passage.—BY2017 *O. mykiss* juvenile total estimated passage at RBDD was 10,159 fry, sub-yearling and yearlings combined (Table 5). Fry sized juveniles (<41 mm) comprised only 9.5% of total *O. mykiss* passage. Fry passage occurred from March through the middle of July (weeks 10 thru 29; Figure 10b). Sub-yearling/yearling sized juveniles (≥41 mm) comprised 90.5% of total passage and the first observed emigration past RBDD occurred in week 5 (January; Table 5). Weekly sub-yearling/yearling passage for the brood year ended during week 52 (late December).

Discussion

Sampling effort. —Fluctuating river flows resulted in moderate sampling effort for the reporting period of January 1, 2017 through November 30, 2018 ($\bar{x}$ = 0.76). Mean sampling effort for BY2017 winter, spring, fall, late-fall Chinook and *O. mykiss* was 0.79, 0.80, 0.81, 0.81 and 0.72, respectively (Tables 1-5). During the primary juvenile winter Chinook salmon capture and passage period of July through December of 2017, mean sampling effort was fairly high (0.89), whereas the latter half of the brood year was markedly lower and more variable, averaging only 0.69.

Decreased sampling effort was primarily a product of winter storm activity resulting in high flows and debris loads occurring intermittently from early January 2018 through late April 2018 (Figure 11a). Cones were modified to exclude half of the catch for a period of three days in mid-March of 2018 in order to lessen impacts to dual-marked (adipose and left-pelvic fin clipped) winter Chinook salmon, released as part of the "Jump-start" reintroduction effort into Battle Creek. Non-sample days to reduce impact on BY2017 fall hatchery releases totaled nine for the month of April. A high flow event the first week of April coincided with the release of approximately 4 million CNFH fall Chinook into Battle Creek (Table 8; Figure 11a).

Patterns of abundance.—Juvenile winter Chinook began to emerge in early July in low numbers. Catch and subsequent passage generally increased through September and peaked in late October (Table 1; Figure 4b). Fry passage declined thereafter until the middle of November 2017 (week 46), when the first runoff event of the winter season resulted in elevated Sacramento River flows reaching 13,172 cfs maximum daily discharge (Figure 11a). Although this event only resulted in an addition of approximately 6,000 cfs of in-river flow, the runoff generated over 7 times greater turbidity values as compared with river conditions two days prior (i.e., from 3.9 to 29.6 NTU). Coinciding with the mid-November runoff event, a substantial pulse of winter Chinook pre-smolt/smolts were encountered in the RSTs, accounting for 38.8% of all pre-smolt/smolt passage during the brood year (Table 1; Figure 4b).

Winter Chinook fry out-migrants represented 68.5% of total winter Chinook passage, with pre-smolt/smolts representing the remaining 31.5%. By the end of December 2017, 92.0% of the total annual passage estimate for BY2017 winter Chinook was collected (Table 1). With 92.0% of passage occurring in the first half of the brood year, the effects of lower sampling effort ($\bar{x}$ = 0.69) during the second half of the brood year appear minimal. Overall, interpolation for missed days of sampling accounted for a mere 1.8% of the total BY2017 estimate of 601,677 winter Chinook passing the RBDD. The BY2017 winter Chinook total passage estimate was the fifth lowest on record since the RBDD Juvenile Fish Monitoring Program began.

Capture of BY2017 juvenile spring Chinook began on October 16, 2017 according to LAD criteria; however, genetic assignment results from tissue samples taken between mid-October and December of 2017 from RBDD traps indicated spring Chinook passage began in late November of 2017. Sampling effort remained relatively high throughout the fry passage period of weeks 47 thru 1 ($\bar{x}$ = 0.85, Table 2). A pronounced peak of fry passage occurred in early December (week 48; Table 2) and accounted for 50.9% of total spring Chinook fry passage. Sampling effort during the remainder of the brood year was slightly lower and more variable ($\bar{x}$ = 0.79; Table 2) for a couple of reasons. Storm activity and hatchery releases accounted for reductions in effort during periods of spring Chinook pre-smolt/smolt passage. Interpolation for missed days of sampling accounted for 29.6% of the total BY2017 estimate of 311,973 spring Chinook passing the RBDD.

Spring Chinook fry out-migrants represented 2.6% of total passage, with pre-smolt/smolts representing the remaining 97.4%. This low percentage of fry out-migrants is similar to BY2016 numbers (5.0%); however, both values were substantially less than the 54% average noted in Poytress et al (2014). Positive bias of spring Chinook passage estimates associated with 75% *unmarked*[5] CNFH production releases of fall Chinook that exceeded the fall LAD criteria were detected, similar to prior brood years (Voss and Poytress 2017, 2018). Brood year 2017 fall Chinook releases into Battle Creek (Figure 1) began in early April and continued through the latter half of April (weeks 14 thru 16; Table 8). 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 two weeks of recapture immediately following (weeks 14-18; Table 8), 17.3% of the marked CNFH fall Chinook fell into the spring LAD size category. Large numbers of unmarked hatchery fish falling into the spring size category encountered shortly after production releases, as well as data interpolation for missed samples, contributed greatly to increased spring Chinook fish passage in April thru early May (weeks 12-18; Figure 7b). Moreover, random sub-sampling around hatchery releases was likely a contributing factor to increased variance and wide confidence intervals in the total passage estimate for spring Chinook. Spring Chinook passage *prior* to hatchery releases accounted for 14.7% (45,958) of the brood year total. Passage during week 15 (160,119) accounted for 51.3% of the brood year total. Interpolation accounted for 29.6% of total spring Chinook passage estimate for BY2017 indicating substantial positive bias in the annual estimate.

Fall Chinook fry passage only accounted for 13.6% of the total passage for brood year 2017, which is an inverse trend to the prior 16 years of passage when the average fry-to-smolt ratio was 71% (Poytress et al. 2014). Passage of fry began the first week of December, increasing through the end of the month. Fry passage in January 2018 was influenced by a number of runoff events, which resulted in peak fry passage at the end of the month (Figure 8b & 11a). Sampling effort during fry passage was moderate, averaging 0.73 from week 48 thru week 18. Interpolation for missed samples during the fry passage period accounted for 32,984 or 11.1% of the total fry passage estimate. Low fall Chinook fry passage numbers likely resulted from poor adult returns, which were the lowest recorded on the main stem Sacramento R. and third lowest recorded on Battle Creek since 1975 (Azat 2018). Low numbers of naturally produced fall Chinook fry in the mainstem Sacramento River and tributaries, coupled with releases of unmarked pre-smolt/smolt sized CNFH fall Chinook production fish contributed greatly towards skewing the fry-to-smolt ratios for unmarked BY2017 fall Chinook passage.

Fall Chinook passage in the pre-smolt/smolt size category, which comprised 86.4% of total brood year passage, began in mid-January. Spikes in pre-smolt/smolt passage began in early April (Table 3), coinciding with the timing of CNFH fall Chinook production releases and runoff events (Table 8 & Figure 8b), resulting in substantial positive bias to unmarked fall Chinook estimates. Pre-smolt/smolt passage during the CNFH fall BY2017 release period (weeks 14-18) accounted for 56.1% (1,051,047) of all pre-smolt/smolt passage for BY2017. This value

[5] Since 2007 CNFH fall Chinook production fish have been coded-wire tagged and adipose fin-clipped (i.e., marked) at a constant fractional mark rate of 25%. The remainder have no internal or external mark and cannot be field-identified as either natural or hatchery origin.

likely would have been much greater had CNFH achieved their annual production goal of 12 million fall Chinook. Due to inadequate adult returns for BY2017, only half or ~ 5.5 million fall Chinook were produced by CNFH. Interpolation for missed samples accounted for 24.9% of total pre-smolt/smolt passage. Overall, interpolation accounted for 827,067 or 23.7% of the BY2017 fall Chinook fry-equivalent JPI. Using the BY2017 fall Chinook fry-equivalent JPI of 3,482,430 results in an ETF survival estimate of 17.6% for BY2017 (Table 7). The BY2017 fall Chinook fry-equivalent JPI prior to CNFH releases was 331,231 with an ETF survival estimate of 1.7%.

Late-fall Chinook fry passage began the first week of April and continued through late June. Pre-smolt/smolts began to appear in a sporadic fashion from late May through late September when passage increased, abruptly peaking in mid-November (Table 4; Figure 9b). Fry passage accounted for 24.8% of the brood year total, which falls below the reported mean value of 38% (Poytress et al. 2014) but within one standard deviation.

O. mykiss passage began the first week in February (Table 5), with the first fry passing in early March. Passage peaked in May and remained variable throughout the rest of the calendar year. Total passage for the brood year was 10,159 and interpolation accounted for only 8.4% of the total.

Bias associated with unmarked CNFH fall Chinook.—Similar to BY2016, we reduced bias to BY2017 spring and fall Chinook natural production and passage estimates resultant from the capture of 75% unmarked CNFH fall Chinook (Voss and Poytress 2018). For the period April 6 through May 21, 2017 (weeks 14 through 20), daily captures of marked hatchery Chinook falling into the spring and fall Chinook runs using LAD criteria were multiplied by a factor of 3 to estimate unmarked hatchery fish within daily catch. The adjusted daily values were subtracted from the original catch totals and daily passage estimates for each run were then calculated. If calculated daily passage of unmarked hatchery Chinook was greater than the original unmarked daily passage value, that day was given a value of zero. After daily passage estimates were recalculated to exclude unmarked hatchery Chinook passage, weekly passage estimates and confidence intervals were recalculated.

Estimates for BY2017 spring Chinook total passage were 311,973 with lower and upper confidence intervals extending from 158,687 to 465,258, respectively. Adjustment to remove unmarked hatchery Chinook resulted in a total passage value of 141,973 with lower and upper confidence intervals extending from 73,216 and 210,730, respectively. Using adjusted values, the percentage of smolt spring Chinook represented 94.2% of total passage, whereas the original estimate was 97.4% smolts. Adjusted values for BY2017 spring Chinook fry-equivalent JPI were 235,629 with lower and upper confidence intervals extending from 124,695 and 346,562, respectively.

Estimates for BY2017 fall Chinook total passage were 2,170,361 with lower and upper confidence intervals extending from 1,184,973 to 3,155,750, respectively. Adjustment to remove unmarked hatchery fall Chinook resulted in a total passage value of 1,135,935 with lower and upper confidence intervals extending from 628,332 and 1,643,539, respectively. This lowered the original total smolt passage by 1,034,426, which resulted in 73.9% of BY2017 fall Chinook passing the RBDD transect as smolts. Adjusted values for BY2017 fall Chinook fry-equivalent JPI were 1,723,831 with lower and upper confidence intervals extending from 980,638 and 2,467,025, respectively, which results in an adjusted ETF survival of 8.7%.

LAD genetic-based run corrections.—An estimated passage total of 120,440 LAD spring Chinook were determined to be winter Chinook from genetic analyses during the period of October 16 thru November 18, 2017. A substantial amount of positive bias (27.9%) would have occurred without revision to spring passage estimates given that total BY2017 spring Chinook passage was estimated at 311,973. Likewise, without corrections made in light of genetic assignment information, (incorrectly assigned) LAD spring Chinook would have resulted in a negative bias of 20.0% of the winter Chinook BY2017 total, which would have reduced the BY2017 total passage estimate to 481,237. Incorporating results of genetic tissue sample analysis, along with data from other sources, to support or refute field-based LAD assignments and implementing any appropriate corrections is a practice that leads to more accurate run-specific juvenile production indices, and therefore should be continued in future brood years.

Winter Chinook JPI and ETF survival estimate.—The BY2017 winter Chinook fry-equivalent JPI value of 734,432 was the fifth lowest production estimate in 20 years of monitoring at RBDD. Conversely, the resultant fry-equivalent based ETF survival rate was estimated at 48.7% (Table 6). The 20-year average ETF survival rate is 24.3% with a standard deviation of 12.8. Higher winter Chinook ETF survival rates than the previous brood year was likely a result of adequate cold-water pool availability in Shasta Reservoir, due to one of the wettest water years on record and efforts to follow the 2017 Sacramento River temperature management plan. This plan targeted a 53°F daily average temperature at the Sacramento River-Clear Creek gauging station and temperatures of 55°F within a seven-day average daily maximum at the most downstream winter Chinook redd (USBR 2017). However, the winter Chinook ETF survival estimate for BY2017 was likely elevated due to uncertainty in the adult spawner estimates. The total escapement was estimated at 1,155 in-river adults, yet the 90% CI about the estimate ranged from a low of 109 to a high of 1,888 (USBR 2017). Difficulties in getting precise estimates was attributed to poor visibility on the carcass survey, resultant from high water early in the survey season and prolonged turbidity throughout the survey season. Re-calculating the ETF using the adult spawner survey estimate's upper CI, which was about 1.5 times higher than the point estimate of 1,155 adults, results in a survival rate of 29.8%, which still suggests that ETF survival for winter Chinook was better than the long-term average for BY2017.

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Tables

Table 1.— Sampling effort, weekly passage estimates, median fork length (Med FL) and juvenile production indices (JPI's) for winter Chinook salmon passing Red Bluff Diversion Dam (RK 391) for the period July 1, 2017 through June 30, 2018 (brood year 2017). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 2.4-m diameter rotary-screw traps sampling 24 hours daily, 7 days per week. Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry-equivalents. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry to pre-smolt/smolt survival rate (59% or approximately 1.7:1; Hallock undated).

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
27 (Jul)	0.52	0	-	0	-	0	-	0
28	0.68	161	34	0	-	161	34	161
29	0.50	265	34	0	-	265	34	265
30	0.80	432	34	0	-	432	34	432
31 (Aug)	1.00	811	34	0	-	811	34	811
32	1.00	1,399	35	0	-	1,399	35	1,399
33	1.00	7,283	35	0	-	7,283	35	7,283
34	1.00	13,150	35	0	-	13,150	35	13,150
35 (Sep)	1.00	23,369	35	35	47	23,403	35	23,428
36	1.00	15,200	34	43	46	15,243	34	15,272
37	1.00	27,871	35	126	47	27,998	35	28,086
38	1.00	33,245	35	800	48	34,045	35	34,605
39	1.00	46,237	35	1,909	54	48,147	35	49,483
40 (Oct)	1.00	35,130	35	2,235	56	37,364	35	38,929
41	1.00	38,737	34	2,839	58	41,576	35	43,563
42	1.00	51,393	34	3,757	58	55,150	34	57,780
43	1.00	53,616	33	7,435	56	61,051	33	66,255
44 (Nov)	0.96	26,261	32	10,044	59	36,305	34	43,335
45	0.89	15,481	33	13,533	60	29,015	41	38,488
46	0.93	21,408	34	73,645	63	95,053	57	146,604
47	0.57	578	40.5	8,646	62	9,224	61	15,276
48 (Dec)	0.82	0	-	2,211	61.5	2,211	61.5	3,759
49	1.00	0	-	3,609	65	3,609	65	6,135
50	1.00	0	-	1,513	63	1,513	63	2,572
51	0.89	0	-	2,161	69	2,161	69	3,674
52	0.63	0	-	6,813	72	6,813	72	11,582

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)	0.50	0	-	745	74	745	74	1,266
2	0.64	0	-	6,057	79	6,057	79	10,298
3	0.54	0	-	12,371	84	12,371	84	21,031
4	0.89	0	-	5,365	80	5,365	80	9,120
5 (Feb)	1.00	0	-	626	81	626	81	1,063
6	0.89	0	-	537	89	537	89	913
7	0.75	0	-	462	91	462	91	786
8	0.75	0	-	598	93	598	93	1,016
9 (Mar)	0.75	0	-	869	93	869	93	1,478
10	0.75	0	-	614	102	614	102	1,043
11	0.61	0	-	17,355	113	17,355	113	29,503
12	0.64	0	-	1,627	113.5	1,627	113.5	2,766
13	0.75	0	-	326	118	326	118	554
14 (Apr)	0.43	0	-	176	116	176	116	298
15	0.44	0	-	0	-	0	-	0
16	0.43	0	-	67	115	67	115	113
17	0.75	0	-	471	124	471	124	801
18 (May)	0.96	0	-	32	125	32	125	55
19	0.71	0	-	0	-	0	-	0
20	0.43	0	-	0	-	0	-	0
21	0.67	0	-	0	-	0	-	0
22 (Jun)	0.68	0	-	0	-	0	-	0
23	0.75	0	-	0	-	0	-	0
24	0.75	0	-	0	-	0	-	0
25	0.75	0	-	0	-	0	-	0
26	0.75	0	-	0	-	0	-	0
BY total		412,028		189,649		601,677		734,432
90% CI (low : high)		(299,049 : 525,007)		(97,172 : 282,127)		(399,435 : 803,919)		(471,292 : 997,572)

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 October 16, 2017 through October 15, 2018 (brood year 2017). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 2.4-m diameter rotary-screw traps sampling 24 hours daily, 7 days per week. Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry-equivalents. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry to pre-smolt/smolt survival rate (59% or approximately 1.7:1; Hallock undated).

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
42	1.00	0	-	0	-	0	-	0
43	1.00	0	-	0	-	0	-	0
44 (Nov)	0.96	0	-	0	-	0	-	0
45	0.89	0	-	0	-	0	-	0
46	0.93	0	-	0	-	0	-	0
47	0.57	1,919	34.5	0	-	1,919	34.5	1,919
48 (Dec)	0.82	4,160	34	0	-	4,160	34	4,160
49	1.00	970	36.5	25	46	995	37	1,013
50	1.00	441	37	23	46	463	37	479
51	0.89	194	39	53	49	247	43.5	285
52	0.63	123	42	205	53	328	48.5	471
1 (Jan)	0.50	373	43.5	42	47	415	44	444
2	0.64	0	-	512	56	512	56	870
3	0.54	0	-	2,029	51	2,029	51	3,450
4	0.89	0	-	1,719	51.5	1,719	51.5	2,922
5 (Feb)	1.00	0	-	371	60	371	60	630
6	0.89	0	-	270	63.5	270	63.5	459
7	0.75	0	-	1,192	62.5	1,192	62.5	2,026
8	0.75	0	-	3,113	66	3,113	66	5,293
9 (Mar)	0.75	0	-	2,841	70	2,841	70	4,829
10	0.75	0	-	2,564	71	2,564	71	4,358
11	0.61	0	-	13,856	76	13,856	76	23,554
12	0.64	0	-	7,806	76	7,806	76	13,270
13	0.75	0	-	1,159	83	1,159	83	1,970
14 (Apr)	0.43	0	-	1,126	87.5	1,126	87.5	1,913
15	0.44	0	-	160,119	83	160,119	83	272,202

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	0.43	0	-	22,566	87	22,566	87	38,363
17	0.75	0	-	19,262	92	19,262	92	32,746
18 (May)	0.96	0	-	29,606	95	29,606	95	50,331
19	0.71	0	-	19,161	100	19,161	100	32,573
20	0.43	0	-	10,804	105	10,804	105	18,367
21	0.67	0	-	1,980	109	1,980	109	3,366
22 (Jun)	0.68	0	-	1,285	115	1,285	115	2,184
23	0.75	0	-	105	116.5	105	116.5	179
24	0.75	0	-	0	-	0	-	0
25	0.75	0	-	0	-	0	-	0
26	0.75	0	-	0	-	0	-	0
27 (Jul)	0.64	0	-	0	-	0	-	0
28	0.75	0	-	0	-	0	-	0
29	0.89	0	-	0	-	0	-	0
30	1.00	0	-	0	-	0	-	0
31 (Aug)	1.00	0	-	0	-	0	-	0
32	1.00	0	-	0	-	0	-	0
33	0.86	0	-	0	-	0	-	0
34	1.00	0	-	0	-	0	-	0
35 (Sep)	0.93	0	-	0	-	0	-	0
36	1.00	0	-	0	-	0	-	0
37	1.00	0	-	0	-	0	-	0
38	1.00	0	-	0	-	0	-	0
39	1.00	0	-	0	-	0	-	0
40 (Oct)	1.00	0	-	0	-	0	-	0
41	1.00	0	-	0	-	0	-	0
BY total		8,180		303,793		311,973		524,627
90% CI (low : high)		(3,070 : 13,290)		(155,332 : 452,253)		(158,687 : 465,258)		(270,106 : 779,149)

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 December 1, 2017 through November 30, 2018 (brood year 2017). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 2.4-m diameter rotary-screw traps sampling 24 hours daily, 7 days per week. Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry-equivalents. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry to pre-smolt/smolt survival rate (59% or approximately 1.7:1; Hallock undated).

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
48 (Dec)	0.82	71	32.5	0	-	71	32.5	71
49	1.00	1,584	34	0	-	1,584	34	1,584
50	1.00	1,929	34.5	0	-	1,929	34.5	1,929
51	0.89	4,757	35	0	-	4,757	35	4,757
52	0.63	9,732	35	0	-	9,732	35	9,732
1 (Jan)	0.50	3,715	36	0	-	3,715	36	3,715
2	0.64	34,204	35	0	-	34,204	35	34,204
3	0.54	71,369	33	196	46	71,566	33	71,703
4	0.89	84,733	33	105	46	84,838	33	84,911
5 (Feb)	1.00	11,175	34	48	47	11,224	34	11,258
6	0.89	8,209	33	79	51	8,288	33	8,344
7	0.75	3,528	34.5	297	53	3,826	35	4,034
8	0.75	3,135	37	714	53	3,849	37	4,349
9 (Mar)	0.75	1,021	37	1,036	55	2,057	40	2,783
10	0.75	6,546	36	1,057	57	7,603	36	8,343
11	0.61	35,989	36	8,382	61.5	44,371	37	50,238
12	0.64	12,090	35	7,771	62	19,861	41	25,301
13	0.75	481	39	2,057	65.5	2,539	63	3,979
14 (Apr)	0.43	0	-	321	64	321	64	546
15	0.44	1,675	40	373,410	74	375,085	74	636,473
16	0.43	0	-	352,100	72	352,100	72	598,570
17	0.75	0	-	100,245	78	100,245	78	170,416
18 (May)	0.96	34	43	224,970	81	225,005	81	382,484
19	0.71	0	-	242,065	82	242,065	82	411,511
20	0.43	0	-	176,648	83	176,648	83	300,302
21	0.67	0	-	77,631	85	77,631	85	131,972

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)	0.68	0	-	91,748	83	91,748	83	155,972
23	0.75	0	-	43,442	80	43,442	80	73,851
24	0.75	0	-	28,538	83	28,538	83	48,515
25	0.75	0	-	41,608	83	41,608	83	70,734
26	0.75	0	-	33,693	88	33,693	88	57,278
27 (Jul)	0.64	0	-	26,051	89	26,051	89	44,287
28	0.75	0	-	9,670	90.5	9,670	90.5	16,440
29	0.89	0	-	6,004	91	6,004	91	10,207
30	1.00	0	-	5,894	97	5,894	97	10,019
31 (Aug)	1.00	0	-	6,392	98.5	6,392	98.5	10,866
32	1.00	0	-	1,769	104	1,769	104	3,006
33	0.86	0	-	2,000	105	2,000	105	3,400
34	1.00	0	-	1,201	103	1,201	103	2,041
35 (Sep)	0.93	0	-	1,420	110	1,376	110	2,339
36	1.00	0	-	556	115	469	115	797
37	1.00	0	-	532	116	440	116	748
38	1.00	0	-	325	116.5	278	116.5	472
39	1.00	0	-	563	121	275	121	468
40 (Oct)	1.00	0	-	4,350	125.5	3,260	125.5	5,542
41	1.00	0	-	252	130	94	130	160
42	0.96	0	-	606	135.5	499	135.5	849
43	0.89	0	-	134	135.5	158	135.5	268
44 (Nov)	0.93	0	-	205	144	120	144	205
45	1.00	0	-	50	146	50	146	85
46	1.00	0	-	75	155	75	155	127
47	0.71	0	-	147	168	147	168	250
BY total		295,977		1,874,384		2,170,361		3,482,430
90% CI (low : high)		(129,477 : 462,478)		(1,053,416 : 2,695,351)		(1,184,973 : 3,155,750)		(1,927,884 : 5,036,976)

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 April 1, 2017 through March 31, 2018 (brood year 2017). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 2.4-m diameter rotary-screw traps sampling 24 hours daily, 7 days per week. Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry-equivalents. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry to pre-smolt/smolt survival rate (59% or approximately 1.7:1; Hallock undated).

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
14 (Apr)	0.71	1126.5824	33	0	-	1126.5824	33	1126.5824
15	0.23	657.4843333	33	0	-	657.4843333	33	657.4843333
16	0.27	10409.13533	36	0	-	10409.13533	36	10409.13533
17	0.39	5555.8272	35	0	-	5555.8272	35	5555.8272
18 (May)	0.55	522.271	36.5	0	-	522.271	36.5	522.271
19	0.70	320.177	36	0	-	320.177	36	320.177
20	1.00	302.655	37	0	-	302.655	37	302.655
21	1.00	218.369	35	39.98	47	258.349	36	286.335
22 (Jun)	1.00	0	-	0	-	0	-	0
23	1.00	0	-	41.276	47	41.276	47	70.168
24	1.00	39.182	36	0	-	39.182	36	39.182
25	0.93	76.461	37.5	0	-	76.461	37.5	76.461
26	0.55	69.073	42	0	-	69.073	42	69.073
27 (Jul)	0.52	0	-	233	58	233	58	396
28	0.68	0	-	0	-	0	-	0
29	0.50	0	-	0	-	0	-	0
30	0.80	0	-	128	67	128	67	218
31 (Aug)	1.00	0	-	151	68.5	151	68.5	257
32	1.00	0	-	324	75	324	75	551
33	1.00	0	-	553	77	553	77	940
34	1.00	0	-	157	76.5	157	76.5	267
35 (Sep)	1.00	0	-	301	85.5	301	85.5	512
36	1.00	0	-	199	90	199	90	339
37	1.00	0	-	549	84	549	84	932
38	1.00	0	-	454	70.5	454	70.5	772
39	1.00	0	-	1,416	70.5	1,416	70.5	2,407

Table 4—(continued)

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolts/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
40 (Oct)	1.00	0	-	1,077	72	1,077	72	1,831
41	1.00	0	-	1,811	82.5	1,811	82.5	3,079
42	1.00	0	-	2,826	78.5	2,826	78.5	4,804
43	1.00	0	-	3,248	82	3,248	82	5,522
44 (Nov)	0.96	0	-	3,883	95	3,883	95	6,601
45	0.89	0	-	4,598	107	4,598	107	7,817
46	0.93	0	-	30,785	101	30,785	101	52,334
47	0.57	0	-	1,781	110	1,781	110	3,027
48 (Dec)	0.82	0	-	1,053	116.5	1,053	116.5	1,791
49	1.00	0	-	304	115.5	304	115.5	517
50	1.00	0	-	225	121	225	121	383
51	0.89	0	-	483	131.5	483	131.5	822
52	0.63	0	-	1,320	124.5	1,320	124.5	2,244
1 (Jan)	0.50	0	-	0	-	0	-	0
2	0.64	0	-	147	120	147	120	249
3	0.54	0	-	451	141.5	451	141.5	767
4	0.89	0	-	0	-	0	-	0
5 (Feb)	1.00	0	-	24	144	24	144	40
6	0.89	0	-	25	141	25	141	43
7	0.75	0	-	0	-	0	-	0
8	0.75	0	-	0	-	0	-	0
9 (Mar)	0.75	0	-	0	-	0	-	0
10	0.75	0	-	0	-	0	-	0
11	0.61	0	-	0	-	0	-	0
12	0.64	0	-	0	-	0	-	0
13	0.75	0	-	0	-	0	-	0
BY total		19,297		58,587		77,885		118,896
90% CI (low : high)		(-8,108 : 46,702)		(30,850 : 86,325)		(22,808 : 132,962)		(46,821 : 190,971)

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 January 1, 2017 through December 31, 2017 (brood year 2017). Full sampling effort indicated by assigning a value of 1.00 to a week consisting of four 2.4-m diameter rotary-screw traps sampling 24 hours daily, 7 days per week. Results include total estimated passage (fry, sub-yearling and yearlings combined).

Week	Sampling Effort	Total Est. passage	Total Med FL	Week (cont.)	Sampling Effort (cont.)	Total Est. passage (cont.)	Total Med FL (cont.)
1 (Jan)	0.57	0	-	27 (Jul)	0.52	89	92
2	0.00	0	-	28	0.68	0	-
3	0.14	0	-	29	0.50	335	47
4	0.43	0	-	30	0.80	114	50
5 (Feb)	0.57	0	266	31 (Aug)	1.00	296	52
6	0.21	0	-	32	1.00	403	59
7	0.00	0	-	33	1.00	511	59
8	0.00	0	-	34	1.00	485	55.5
9 (Mar)	0.00	245	-	35 (Sep)	1.00	716	62
10	0.57	693	23	36	1.00	558	62.5
11	1.00	44	26	37	1.00	320	66.5
12	0.57	73	130.5	38	1.00	110	70
13	0.86	294	133.5	39	1.00	186	70
14 (Apr)	0.71	0	-	40 (Oct)	1.00	364	71
15	0.23	0	-	41	1.00	106	79
16	0.27	0	-	42	1.00	32	73
17	0.39	707.4102	67.5	43	1.00	40	82
18 (May)	0.55	1408.708	60	44 (Nov)	0.96	39	72
19	0.70	505.965	75.5	45	0.89	225	90
20	1.00	269.331	63.5	46	0.93	86	82
21	1.00	42.955	73	47	0.57	0	-
22 (Jun)	1.00	192.341	51	48 (Dec)	0.82	32	94
23	1.00	289.967	27.5	49	1.00	52	100.5
24	1.00	148.381	26.5	50	1.00	23	140
25	0.93	39.43	125	51	0.89	0	-
26	0.55	0	-	52	0.63	82	124
				BY total		10,159	
				90% CI (low : high)		(-468 : 20,785)	

Table 6.— Winter Chinook fry-equivalent juvenile production indices (JPI), lower and upper 90% confidence intervals (CI), estimated adult female spawners above RBDD (Estimated Females), estimates of female fecundity, calculated juveniles per estimated female (Estimated Recruits/Female) and egg-to-fry survival estimates (ETF) with associated lower and upper 90% confidence intervals (L90 CI : U90 CI) by brood year (BY) for Chinook sampled at RBDD rotary traps between July 2002 and June 2018.

BY	Fry Equivalent JPI	Lower 90% CI	Upper 90% CI	Estimated Females[1]	Fecundity[2]	Estimated Recruits/Female	ETF Survival Rate (%)	L90 CI : U90 CI
2002	7,635,469	2,811,132	13,144,325	5,670	4,923	1,347	27.4	(10.1 : 47.1)
2003	5,781,519	3,525,098	8,073,129	5,179	4,854	1,116	23.0	(14.0 : 32.1)
2004	3,677,989	2,129,297	5,232,037	3,185	5,515	1,155	20.9	(12.1 : 29.8)
2005	8,943,194	4,791,726	13,277,637	8,807	5,500	1,015	18.5	(9.9 : 27.4)
2006	7,298,838	4,150,323	10,453,765	8,626	5,484	846	15.4	(8.8 : 22.1)
2007	1,637,804	1,062,780	2,218,745	1,517	5,112	1,080	21.1	(13.7 : 28.6)
2008	1,371,739	858,933	1,885,141	1,443	5,424	951	17.5	(11.0 : 24.1)
2009	4,972,954	2,790,092	7,160,098	2,702	5,519	1,840	33.5	(18.7 : 48.0)
2010	1,572,628	969,016	2,181,572	813	5,161	1,934	37.5	(23.1 : 52.0)
2011	996,621	671,779	1,321,708	424	4,832	2,351	48.6	(32.8 : 64.5)
2012	1,814,244	1,227,386	2,401,102	1,491	4,518	1,217	26.9	(18.2 : 35.6)
2013	2,481,324	1,539,193	3,423,456	3,577	4,596	694	15.1	(9.4 : 20.8)
2014	523,872	301,197	746,546	1,681	5,308	312	5.9	(3.4 : 8.4)
2015	440,951	288,911	592,992	2,022	4,819	218	4.5	(3.0 : 6.1)
2016	640,149	429,876	850,422	653	4,131	980	23.7	(15.9 : 31.5)
2017	734,432	471,292	997,572	367	4,109	2,001	48.7	(31.3 : 66.2)
					Average	1,191	24.3	(14.7 : 34.0)
					Standard Deviation	591	12.8	(8.6 : 17.5)

[1]Estimated females derived from carcass survey data; 2014 estimate includes 1%, 2015 estimate includes 2%, and 2016 estimate includes 0.8% pre-spawn mortality.

[2]Female fecundity estimates based on annual average values from LSNFH winter Chinook spawning data collected between 2002 and 2015. 2016 and 2017 values based on total egg deposition using method 3 from USFWS December 2017 Memo (Appendix 2).

Table 7.— Fall Chinook fry-equivalent juvenile production indices (JPI), lower and upper 90% confidence intervals (CI), estimated adult female spawners above RBDD (Estimated Females), estimates of female fecundity, calculated juveniles per estimated female (Estimated Recruits/Female) and egg-to-fry survival estimates (ETF) with associated lower and upper 90% confidence intervals (L90 CI : U90 CI) by brood year (BY) for Chinook sampled at RBDD rotary traps between December 2002 and November 2017.

BY	Fry Equivalent JPI	Lower 90% CI	Upper 90% CI	Estimated Females[1]	Fecundity[2]	Estimated Recruits/Female	ETF Survival Rate (%)	L90 CI : U90 CI
2002	18,683,720	1,216,244	51,024,926	211,035	5,407	89	1.6	(0.1 : 4.5)
2003	30,624,209	10,162,712	55,109,506	79,509	5,407	385	7.1	(2.4 : 12.8)
2004	18,421,457	6,224,790	33,728,746	31,045	5,407	593	11.0	(3.7 : 20.1)
2005	22,739,315	4,235,720	49,182,045	37,738	5,407	603	11.1	(2.1 : 24.1)
2006	20,276,322	8,670,090	32,604,760	42,730	5,407	475	8.8	(3.8 : 14.1)
2007	13,907,856	7,041,759	20,838,463	16,996	5,407	818	15.1	(7.7 : 22.7)
2008	10,817,397	5,117,059	16,517,847	16,644	5,362	650	12.1	(5.7 : 18.5)
2009	9,674,829	3,678,373	15,723,368	6,531	5,318	1,481	27.9	(10.6 : 45.3)
2010	10,620,144	5,637,617	15,895,197	7,008	5,167	1,515	29.3	(15.6 : 43.9)
2011	7,554,574	4,171,332	10,960,125	9,260	5,945	816	13.7	(7.6 : 19.9)
2012	26,567,379	17,219,525	36,197,837	32,635	5,242	814	15.5	(10.1 : 21.2)
2013	34,163,943	6,247,962	62,079,924	39,422	5,390	867	16.1	(2.9 : 29.2)
2014	4,387,348	2,407,113	6,367,583	35,345	5,453	124	2.3	(1.2 : 3.3)
2015	30,728,228	-533,520	61,973,977	23,302	4,971	1,319	26.5	(-0.5 : 53.5)
2016 [3]	25,812,410	-22,447,165	74,071,986	5,240	4,778	4,926	103.1	(-89.7 : 295.9)
2017	3,482,430	1,927,884	5,036,976	4,437	4,455	785	17.6	(9.8 : 25.5)
					Average	1,016	19.9	(-0.4 : 40.9)
					Standard Deviation	1,122	23.6	(24.2 : 69.4)

[1]Estimated females derived from carcass survey; sex ratios used to determine female spawners based on RBDD fish ladder data between 2003 and 2007 and CNFH data between 2008 and 2016.

[2]Female fecundity estimates for years 2002 thru 2007 based on average values from CNFH fall Chinook spawning data collected between 2008 and 2012 (Poytress 2014).

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

Table 8.— Week number, release dates, total number of fish released per group, mean fork length (FL) of Chinook at release (mm) with 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 of Coleman National Fish Hatchery brood year 2017 fall Chinook into Battle Creek from April 6 through April 20, 2018.

Week	**Release Date(s)**	**# Released**	**Mean FL of release group**	**Fall LAD range**	**Fall % captures**	**Spring LAD range**	**Spring % captures**
14	4/6/2018	3,959,982	72.0	36 - 77	0.0%	78 - 105	0.0%
15	4/13/2018	1,171,749	67.0	37 - 79	73.5%	80 - 107	26.5%
16	4/20/2018	382,068	66.0	38 - 84	97.9%	82 - 114	2.1%
17	--	--	--	39 - 88	93.0%	90 - 120	7.0%
18	--	--	--	41 - 93	95.0%	90 - 126	5.0%
Total		**5,513,799**			**82.7%**		**17.3%**

Figures

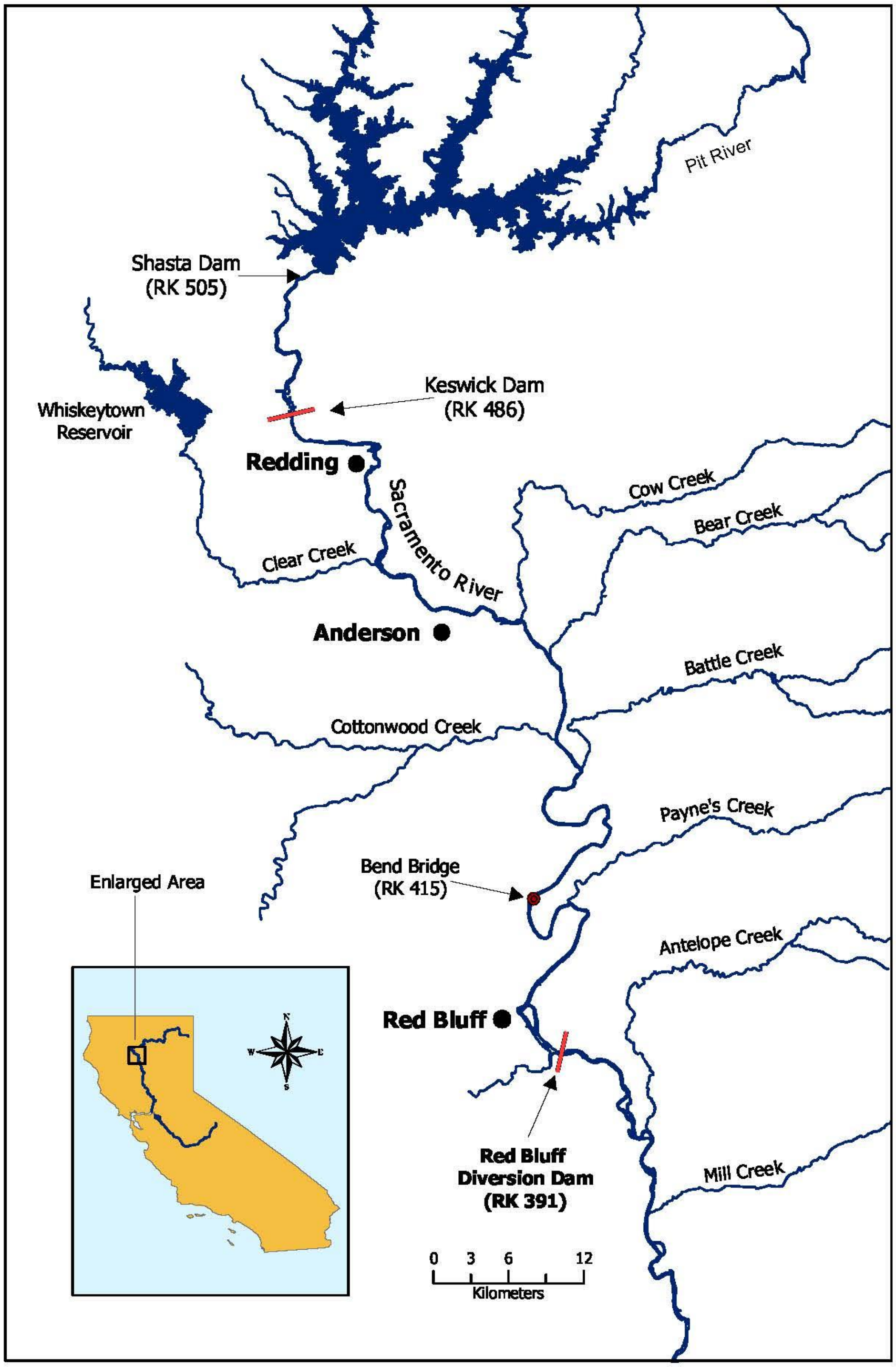

Figure 1. Location of Red Bluff Diversion Dam sample site on the Sacramento River, California, at river kilometer 391 (RKM 391)

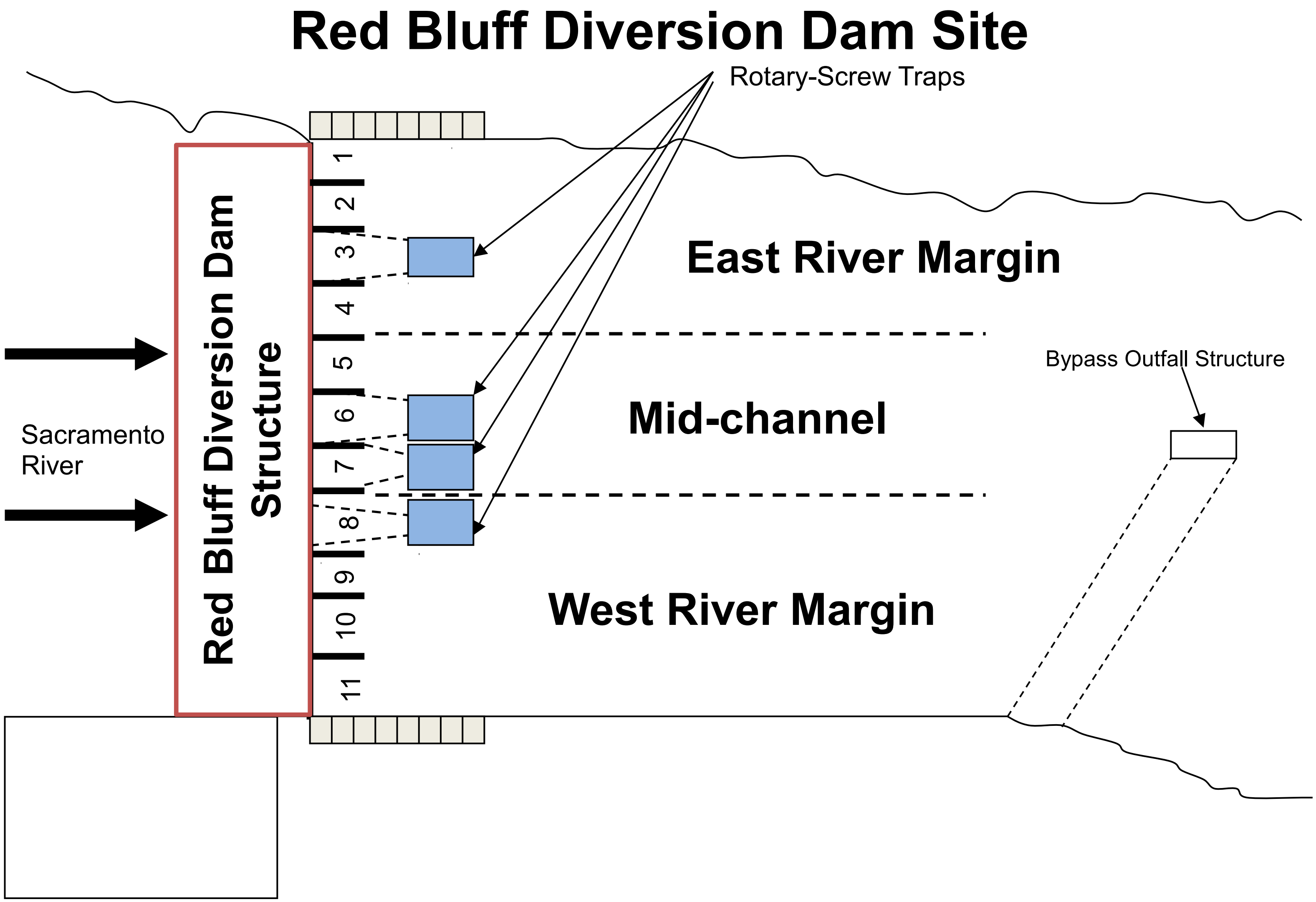

Figure 2. Rotary-screw trap sampling transect schematic of Red Bluff Diversion Dam site (RK 391) on the Sacramento River, CA.

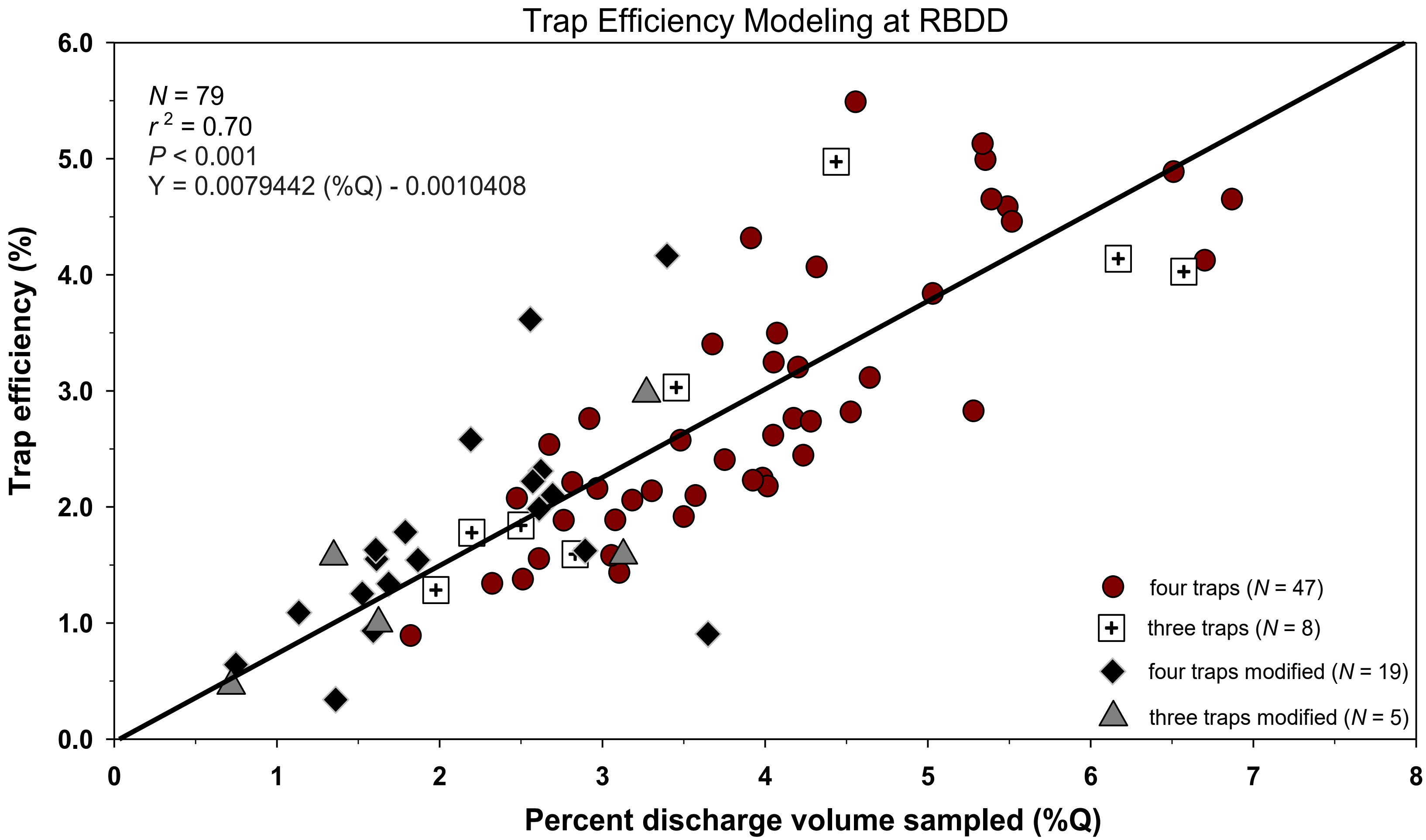

Figure 3. Trap efficiency model for combined 2.4 m diameter rotary screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four traps (N = 47), three traps (N = 8), or with traps modified to sample one-half the normal volume of water (N = 24).

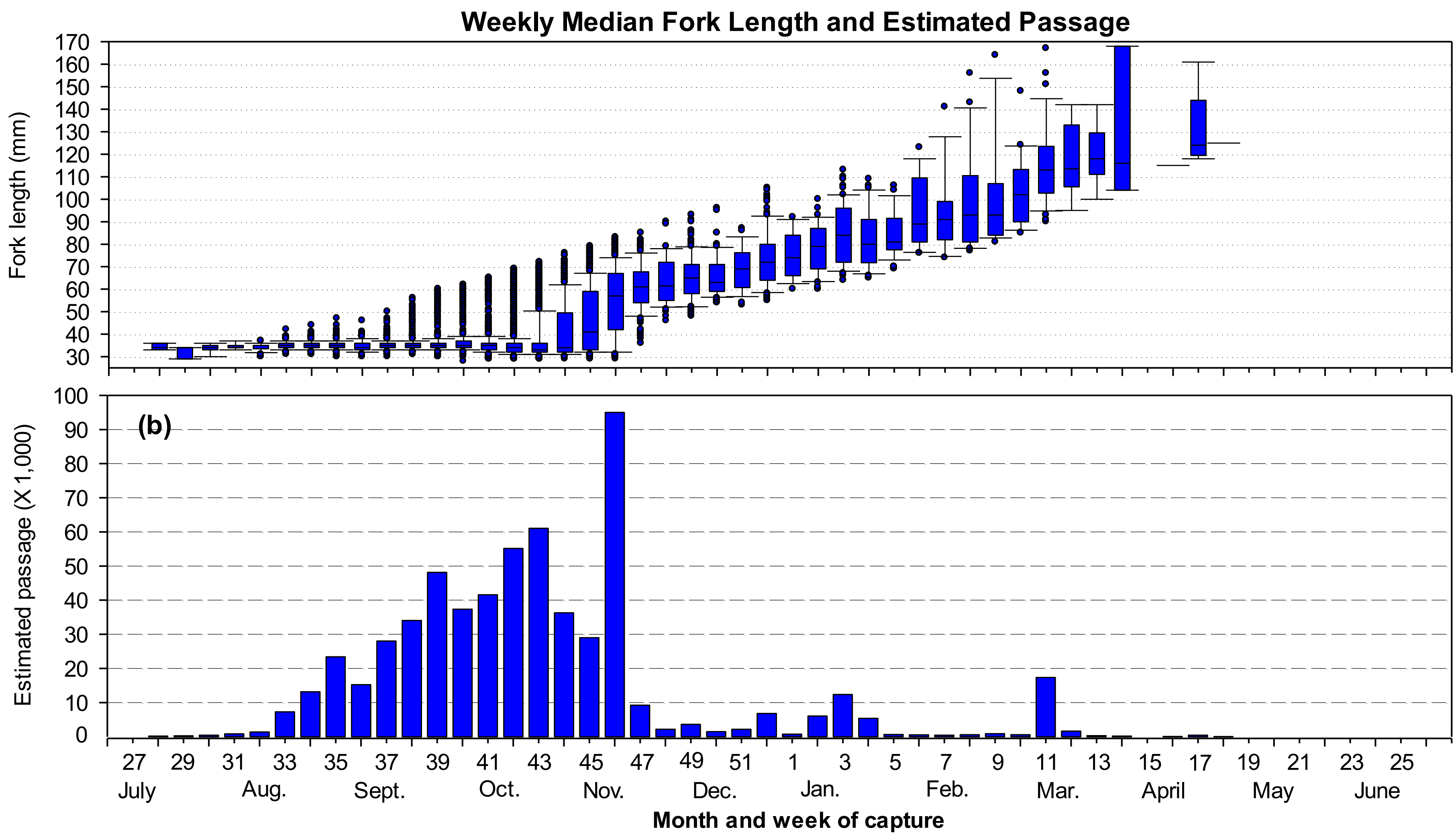

Figure 4. Weekly median fork length (a) and estimated passage (b) of brood year 2017 juvenile winter Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Winter Chinook salmon were sampled by rotary-screw traps for the period July 1, 2017 through June 30, 2018. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

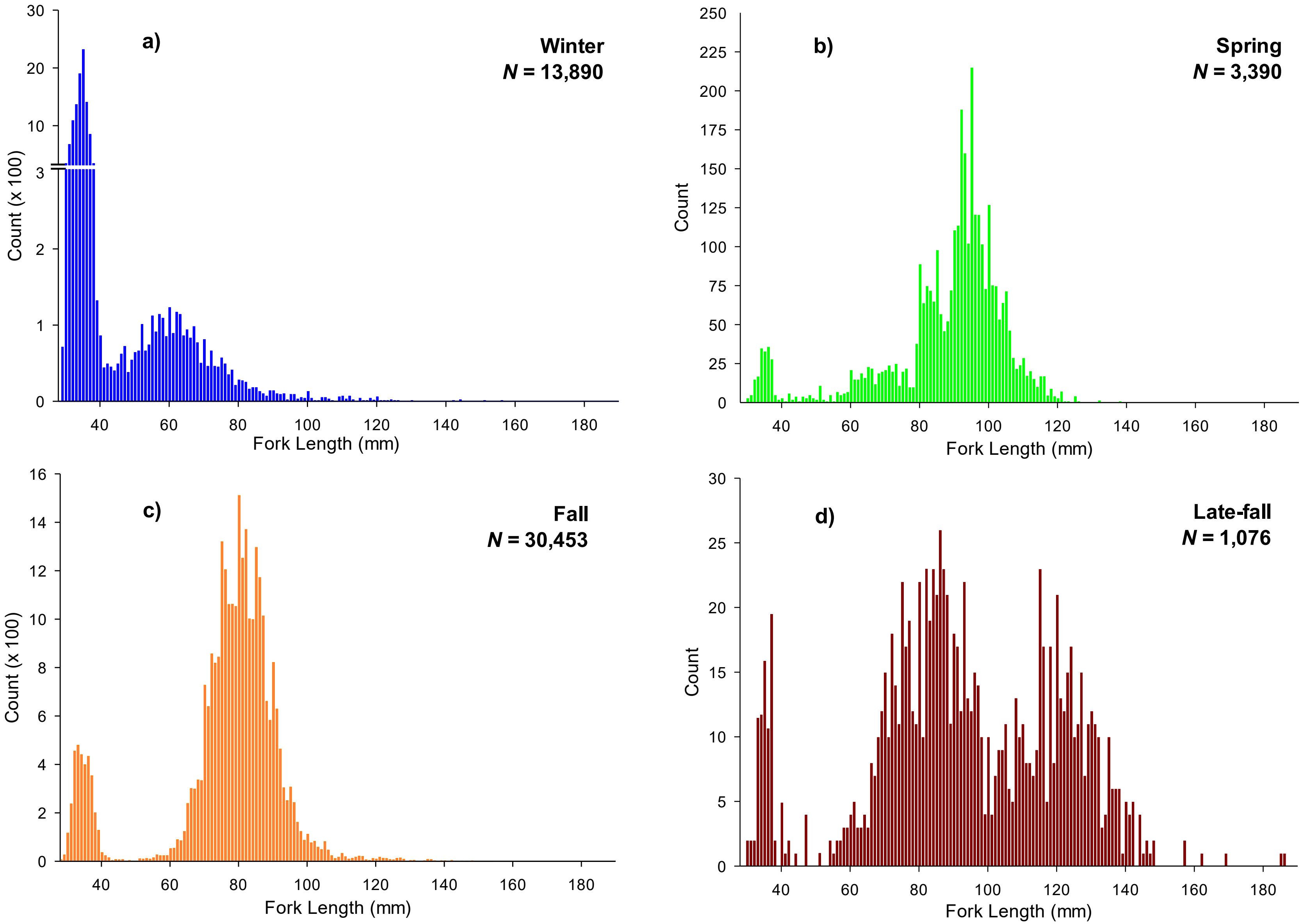

Figure 5. Fork length frequency distribution of brood year 2017 juvenile a) winter, b) spring, c) fall and d) late-fall Chinook salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fork length data were expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from April 1, 2017 through November 30, 2018.

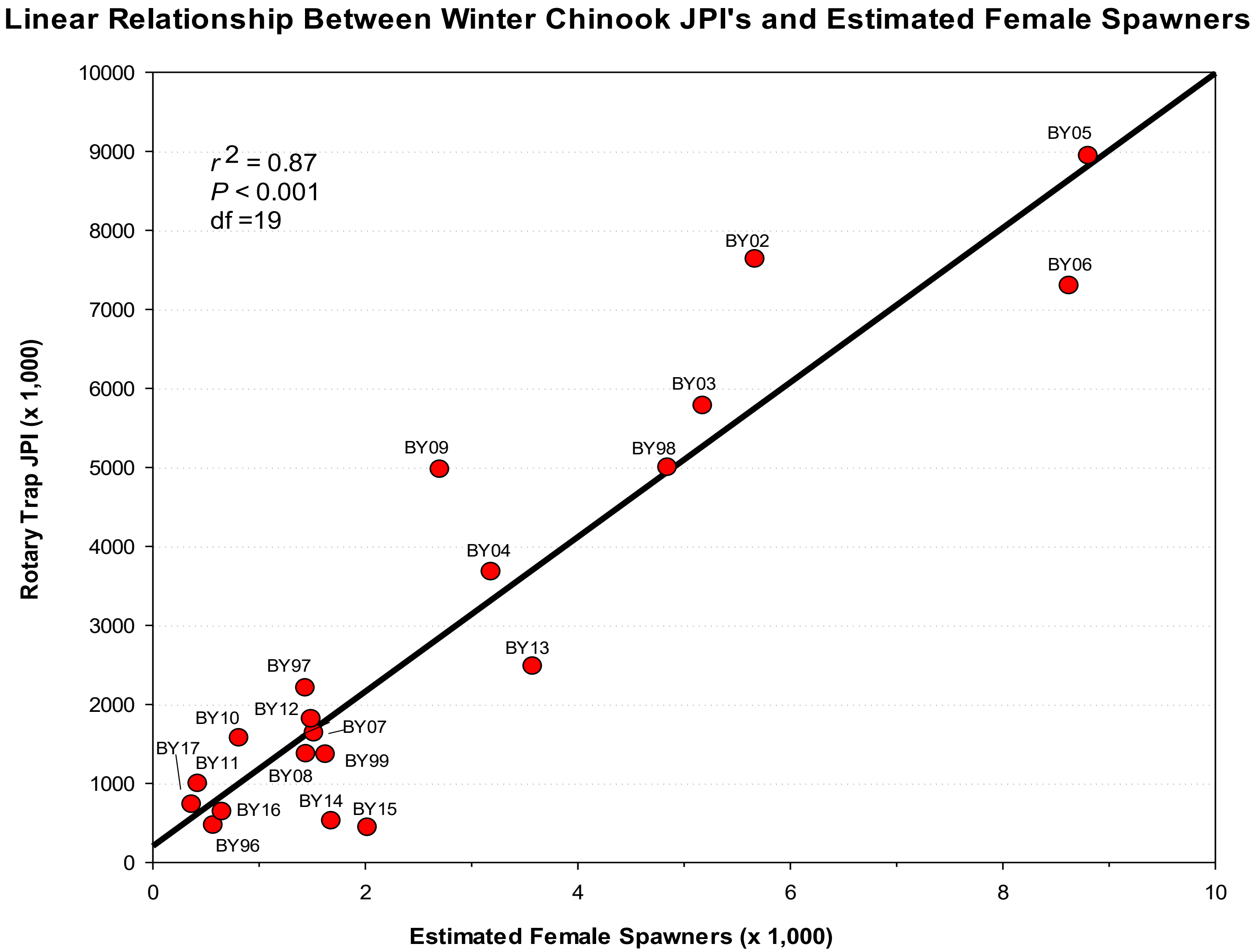

Figure 6. Linear relationship between rotary-screw trap juvenile winter Chinook fry-equivalent production indices (Rotary Trap JPI) and carcass survey derived estimated female spawners.

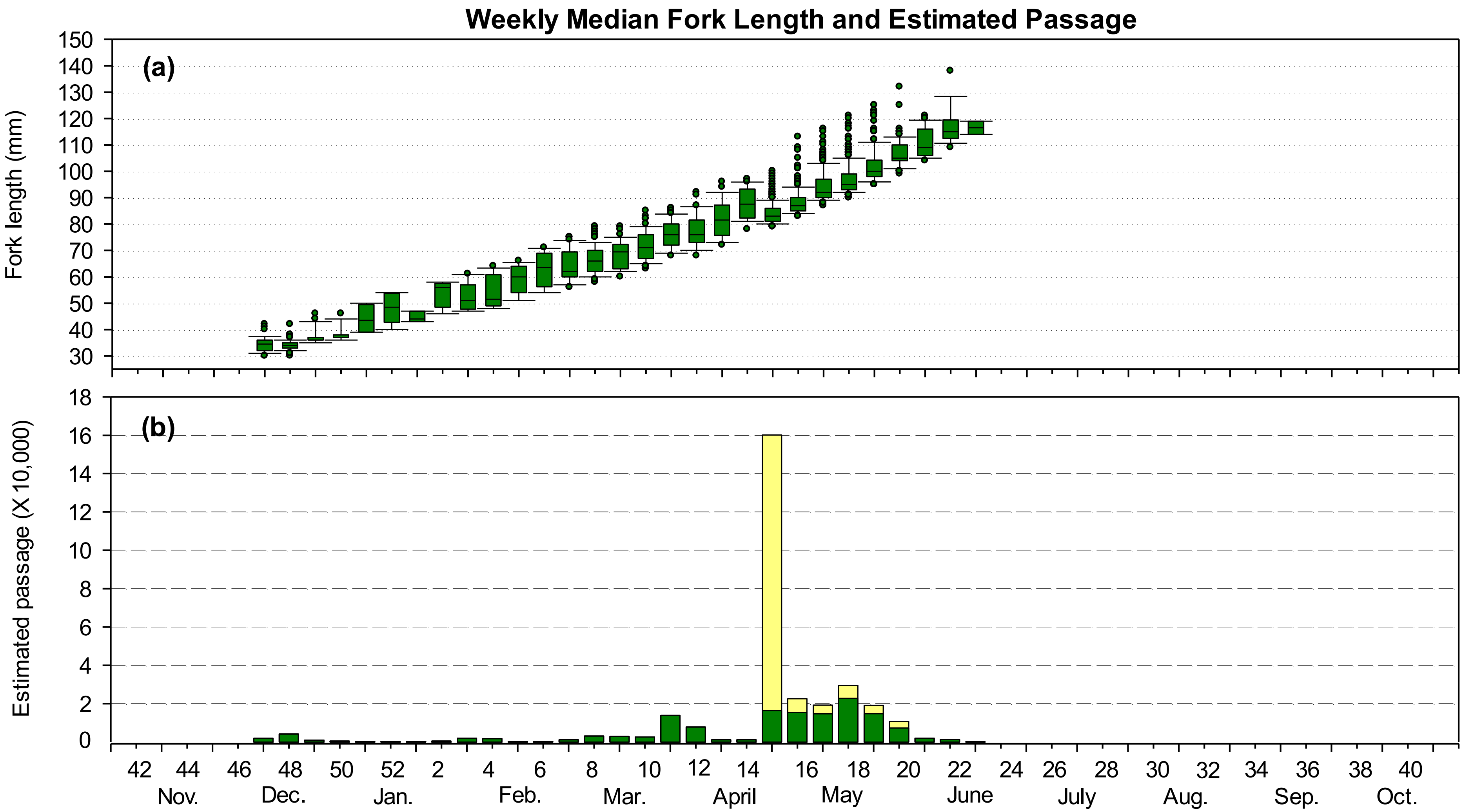

Figure 7. Weekly median fork length (a) and estimated passage (b) of brood year 2017 juvenile spring Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Spring Chinook salmon were sampled by rotary-screw traps for the period October 16, 2017 through October 15, 2018. Box plots display weekly median fork length, 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles and outliers. Yellow bars represent proportion of total passage of LAD spring Chinook that were estimated to be unmarked CNFH hatchery fall Chinook based on 75% unmarked ratio expansions.

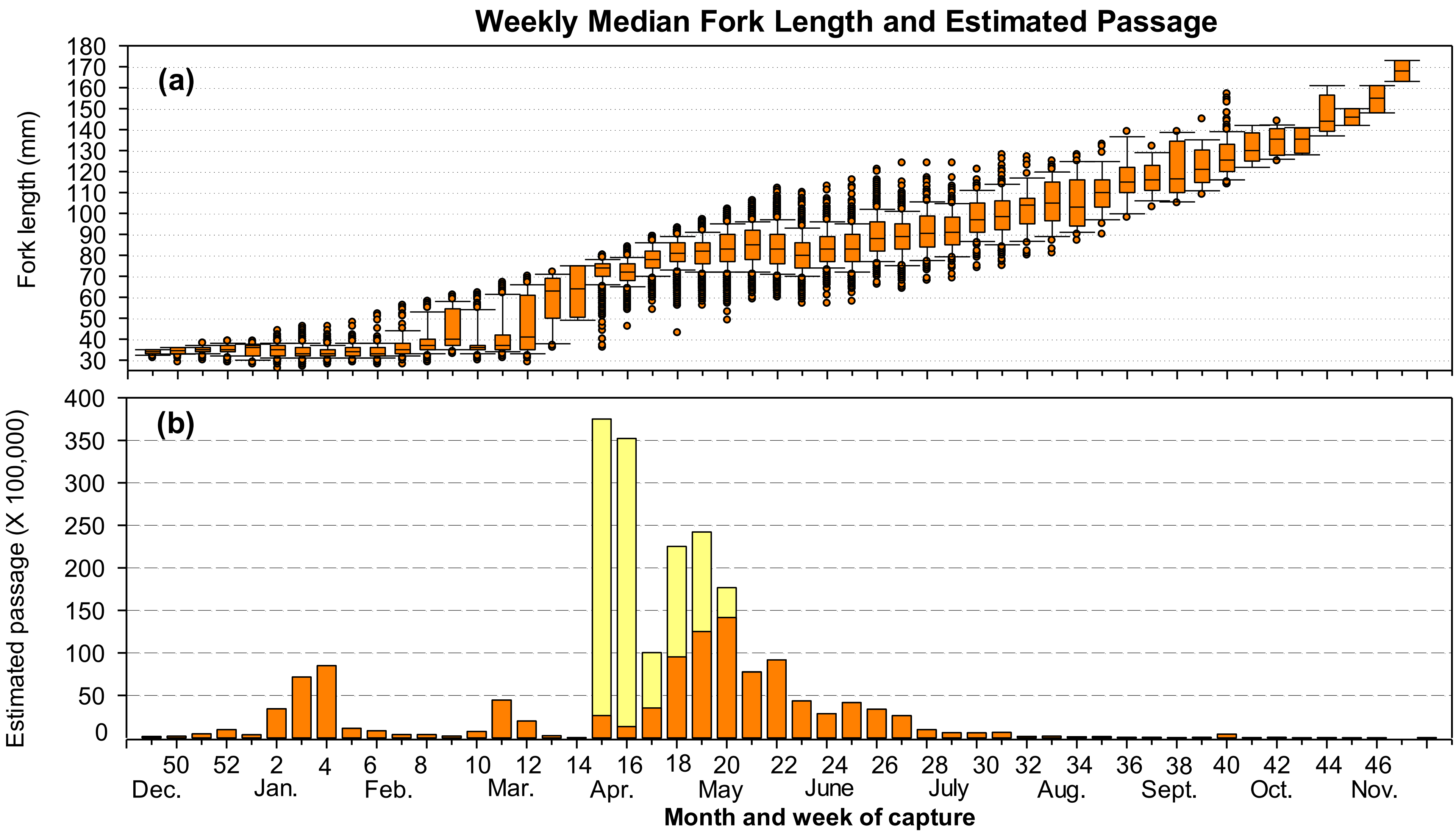

Figure 8. Weekly median fork length (a) and estimated passage (b) of brood year 2017 juvenile fall Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fall Chinook salmon were sampled by rotary-screw traps for the period December 1, 2017 through November 30, 2018. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers. Yellow bars represent proportion of total passage of LAD fall Chinook that were estimated to be unmarked CNFH hatchery fall Chinook based on 75% unmarked ratio expansions.

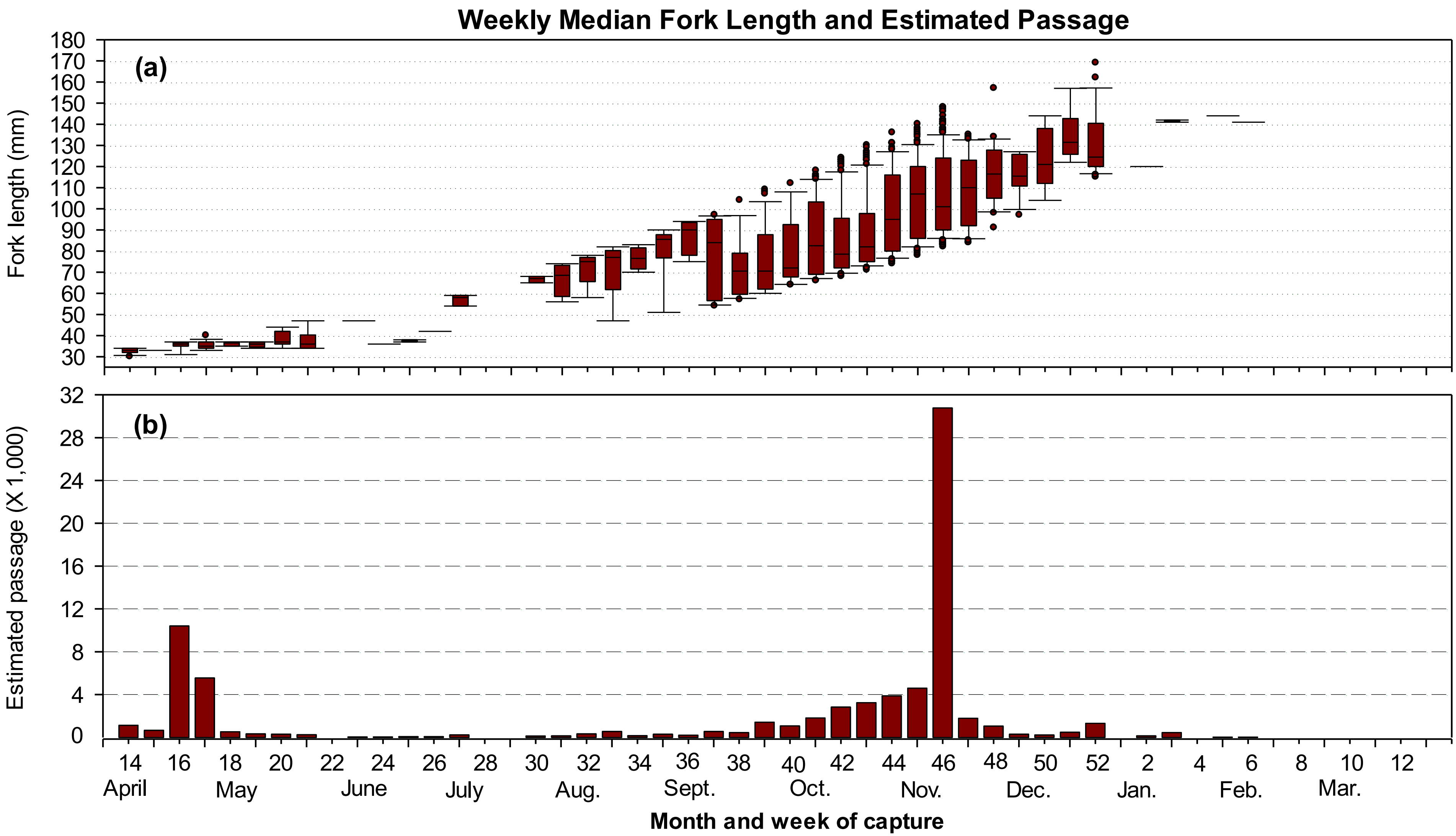

Figure 9. Weekly median fork length (a) and estimated passage (b) of brood year 2017 juvenile late-fall Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Late-fall Chinook salmon were sampled by rotary-screw traps for the period April 1, 2017 through March 31, 2018. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

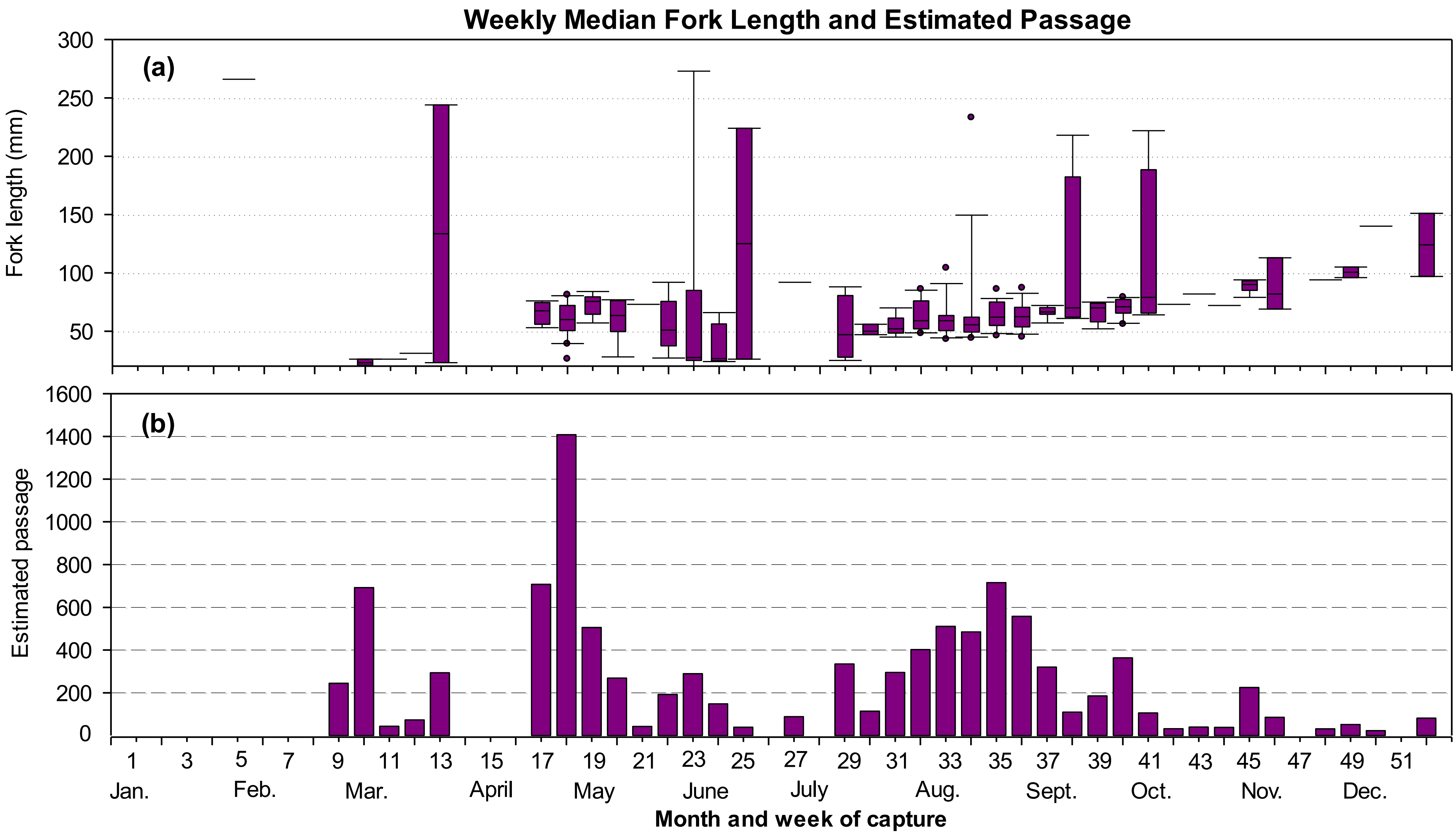

Figure 10. Weekly median fork length (a) and estimated passage (b) of brood year 2017 juvenile *O. mykiss* passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. *O. mykiss* were sampled by rotary-screw traps for the period January 1, 2017 through December 31, 2017. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

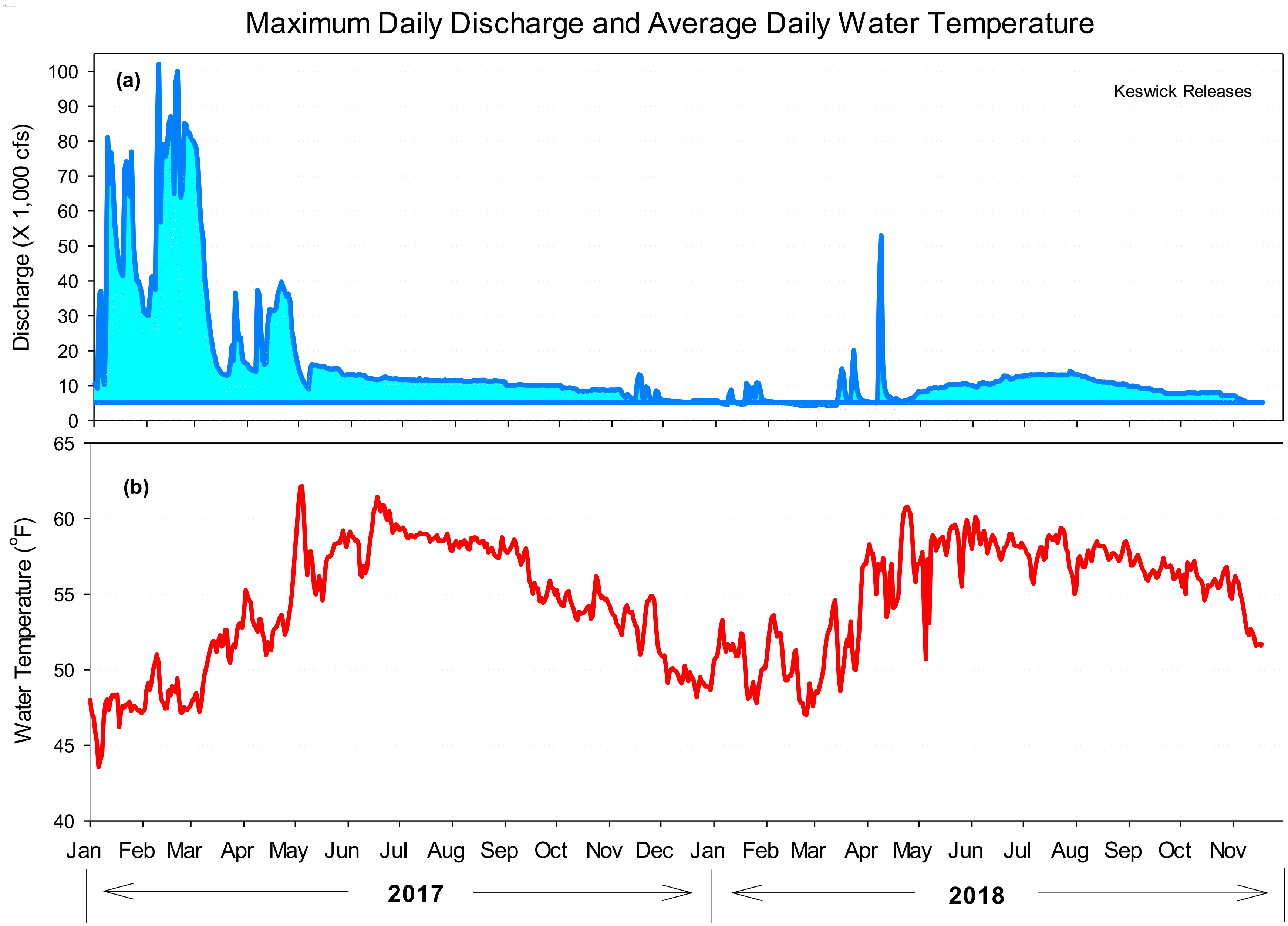

Figure 11. Maximum daily discharge (a) calculated from the California Data Exchange Center's Bend Bridge gauging station showing water releases from Keswick Reservoir (gray shaded area) and average daily water temperatures (b) from rotary-screw traps at RBDD for the period January 1, 2017 through November 30, 2018.

Appendix I.

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

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

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

Appendix II.

United States Department of the Interior

FISH AND WILDLIFE SERVICE

In reply refer to:

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

Memorandum

To: File

From: Bill Poytress, Program Manager, Red Bluff Fish and Wildlife Office, USFWS

Subject: Genetic-based revisions to brood year 2017 winter and spring Chinook passage and production estimates in an effort to improve the accuracy of Red Bluff juvenile monitoring estimates.

During the fall of 2017, we fin clipped and had genetically analyzed juvenile winter and spring Chinook designated by length-at-date criteria to verify run designation as part of two genetic sampling projects. These projects are known as the "Improving Vital Rates Estimation Using Parentage-Based Mark Recapture Methods" and the "Central Valley Salmonid Coordinated Genetic Monitoring Project". Both projects have been conducted for two consecutive years (BY 2016 and BY 2017). Genetic analyses have been conducted in prior years (BY 2015 and BY 2016) on a small sample of fish sacrificed for histological analyses (n=80/yr) by Dr. Scott Foott of the California Nevada Fish Health Center during the latter half of the drought.

Using the data gathered from standardized genetic sampling (fin clips) of up to 10 winter and 10 spring Chinook salmon collected daily, we were able to evaluate the accuracy of our field-based length-at-date (LAD) run assignments used to generate the brood year 2017 winter and spring Chinook passage and production estimates. The LAD run assignment method has been the standard model used by the Red Bluff Fish and Wildlife Office for run assignment at the Red Bluff Diversion Dam rotary-trap sampling site since 1995. Genetic samples were taken from 2 out of 4 traps per day in a standardized rotation. For instance, when fish numbers were adequate in all traps, we would sample IO of each run from 2 traps on day 1 and then do the same for the other 2 traps on day 2. During periods of low winter and/ or spring Chinook abundance, fin clips were collected from 3 or up to 4 traps per day to meet the targeted number of fin clips per day. According to LAD criteria used for initial assignment, the percentage of fish sampled on any given day varied from between 1 % and 80% throughout the mixed run distribution period (mid-October into December).

Reviewing the genetic run analysis data identified a pretty significant break point as to when winter-run migration subsided and genetic spring-run appeared in the system. This break point occurred following the first fall storm event that produced increased flow and turbidity. Of the genetic samples (n = 273) taken between October 16 and November 30, 2017, (initially assigned to spring Chinook according to length-at-date criteria) all of those prior to November 20, 2017 were genetically identified as winter Chinook with one exception. In essence, genetically identified winter Chinook were incorrectly assigned to spring Chinook using LAD criteria for a period of 34 days. As a result, during the latter half of October according to LAD criteria, spring Chinook juvenile estimates far exceeded winter Chinook for the first time in 20 years of monitoring (see original biweekly reports) resulting in substantial negative bias to winter Chinook estimates and concurrent positive bias to spring Chinook estimates. The genetic data indicated the need to revise our passage/production estimates for the two runs to more accurately portray juvenile passage and production in 2017.

Independently collected adult data and information from the California Department of Fish and Wildlife (CDFW) provided additional support for the need to revise the winter and spring Chinook juvenile passage/production estimates. In the summer and fall of 2017, the adult winter Chinook carcass survey data clearly indicated later spawning of adults when compared to average estimated spawn timing from the prior 16 years (Figure 1). Sacramento River water temperature analyses conducted by CDFW coupled with winter Chinook redd data estimated the last emergence timing of winter Chinook fry would occur in early November of 2017. Other survey work of adult carcass and redd survey data collected by CDFW and USFWS indicated that spring-run Chinook adults upstream of our sample site in the mainstem Sacramento River and tributaries numbered in the handfulls. These data, when combined, provided evidence that the substantial numbers of spring Chinook juveniles we estimated passage of using LAD criteria was impossible given the minimal number of spring Chinook adults that returned during the fall of 2017.

In conclusion, by taking multiple data sources into account as well as consultations with the Genetics Project Work Team and the Winter Chinook Project Work Team (IEP PWT's), I felt it necessary to reassign fish that, according to LAD criteria, fell into the spring-run category to the winter-run category based on their genetic assignments. I used the genetic data to determine that the period of October 16 through November 18, 2017 was appropriate to reassign all spring-run fish to winter-run. Biweekly reports' passage data for both runs have been revised for the period of October 8, 20 J 7 through March 25, 2018 to incorporate the revised estimates. These data will be used as the official passage and production estimates and be detailed in an annual report that will be completed in the coming year. Both sets of reports have been placed on the Red Bluff Fish and Wildlife Office's website biweekly report page for 2017 and 2018 for interested parties to compare pre- and post-genetic correction passage estimates for each run.

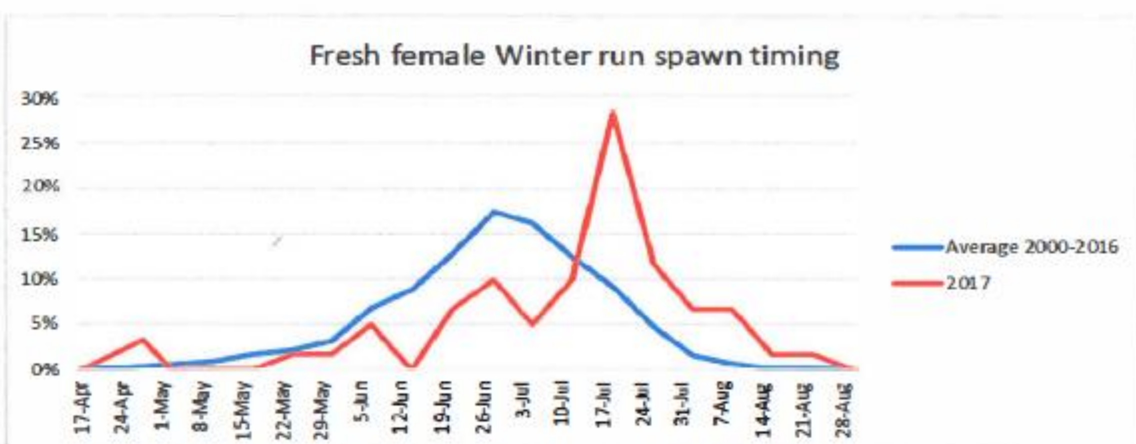

Figure 1. Winter Chinook spawning temporal distribution comparison on 2017 data to average of 2000-2016 data. Data based on carcass recoveries and provided by CDFW.

Appendix III.

Comparison of Methods to Estimate Egg Deposition by Naturally Spawning Winter Chinook Salmon in 2016 and 2017

U.S. Fish and Wildlife Service
Red Bluff Fish and Wildlife Office
Hatchery Evaluation
December 2017

The Juvenile Production Estimate (JPE) is used to estimate the number of juvenile winter Chinook Salmon (WCS) emigrating to the Delta. Methods for estimating the abundance of juvenile WCS passing the Delta have evolved through the years, as new information has become available to improve the confidence of estimation methodologies. For example, recent methodologies for estimating emigration to the Delta start with the Juvenile Production Index (JPI), which is an estimate of juvenile Chinook Salmon passing the Red Bluff Diversion Dam. When combined with estimates of survival through the middle Sacramento River, which are derived from acoustic tagging of juvenile WCS from the Livingston Stone National Fish Hatchery (LSNFH), the JPI can be used to estimate the number of WCS juveniles emigrating past the Delta.

Another method that has been used to estimate the number of WCS juveniles emigrating past the Delta considers the estimated abundance of eggs deposited by female WCS spawners and subtracts estimates of mortality through the stages of incubation, hatching, swim-up, early-rearing, and emigration to the Delta. Implicit in calculating this estimate is knowledge of the abundance of eggs deposited by naturally spawning WCS. In the past, the number of eggs deposited in the river has been estimated by multiplying the number of naturally spawning female WCS, which is estimated by the WCS Carcass Survey, times the average fecundity of WCS spawned at the LSNFH. The validity of this estimation methodology assumes that the fecundity of WCS females spawned at the LSNFH portrays an accurate representation of naturally spawning WCS. In the past, this assumption has generally been accepted as true because LSNFH broodstock typically consist of only natural origin fish and, as such, they are generally considered a representative subset of the naturally spawning population. However, protocols for selecting hatchery broodstock at the LSNFH changed beginning in 2016 when, in an effort to achieve hatchery broodstock targets, it was necessary to dramatically increase the use of hatchery origin WCS. A similar change was also adopted for the collection of WCS broodstock in 2017. Because hatchery and natural origin WCS may adhere to differing maturation schedules, the increased retention of hatchery origin fish as broodstock detracts from the validity of the assumption that fecundity observations at LSNFH are representative of those fish spawning naturally in the Sacramento River. For example, in 2016, 70% of the female broodstock at the LSNFH were classified as age-2 (i.e., “jills”) based on recovery of coded wire tags or estimation of age based on length histograms, which indicated a break in age classes occurring at 630 mm. During that same year, in natural spawning areas females less than 630 mm were estimated to comprise only 15% of the WCS spawners. The opposite relationship was observed in 2017, with a higher percent of jills (<645 mm) spawning naturally (37%) than was observed at the hatchery (4%). These discordances between the age of LSNFH broodstock and naturally spawning WCS may affect the validity of the assumption that the average fecundity observed at LSNFH is representative of the fecundity of natural spawners. However, because a relationship exists between body length and fecundity in Chinook Salmon, it is possible to account for these effects when producing an estimate of natural egg deposition.

We evaluated three methods of estimating egg deposition of naturally spawning WCS, including:

Method 1) estimate egg deposition based on the average fecundity of female WCS spawned at LSNFH multiplied by the number of naturally spawning WCS;

Method 2) estimate egg deposition based on average fecundity for two *size* categories of female WCS spawned at LSNFH, multiplied by the number of naturally spawning females within each size category;

Method 3) estimate egg deposition based on the relationship between fork length and fecundity for two *age* categories of female WCS spawned at LSNFH , assign naturally spawning females into the appropriate age category based on fork length cut-offs, and multiply by the number of naturally spawning females at each fork length by the predicted fecundity based on age.

Method 1 represents the standard methodology used in JPE calculations prior to 2016. Method 2, which was used in 2016, is equivalent to applying a weighted average of fecundity for two discrete length categories of WCS. Method 3 builds upon the changes that were initiated in Method 2 by further examining the relationship between length and fecundity separately for jills and adults and then applying these length-fecundity relationships to the naturally spawning population for each spawning season (Figure 1). Only fresh carcasses were used to determine length frequency expansions because accurate bio-metric data is more reliable on fresh carcasses. Hatchery origin females were categorized as either jill or adult based on coded wire tag recoveries. Natural origin females were categorized as either jill or adult based on length frequency histograms associated with WCS carcass surveys of 2016 and 2017 (Doug Killam, California Dept. Fish and Wildlife, Red Bluff); female WCS < 630mm (2016) and < 645 mm (2017) were categorized as jills.

We recommend Method 3 to estimate natural egg deposition of Sacramento River WCS for the 2016 and 2017 spawning seasons. Estimates of egg deposition resulting from Method 1 are flawed in that they do not account for differing age compositions that were observed for Winter Chinook spawned at LSNFH and those spawning naturally in the Sacramento River. Estimates of Method 2 are also flawed because they use a weighted average to assume natural egg deposition and do not accurately portray the length-fecundity relationships, which are different between jill and adult WCS. Method 3 accounts for the observed differences in ages between WCS spawned at LSNFH and those spawning naturally in the Sacramento River and estimates egg deposition by constructing separate length-fecundity relationships for jills and adults. We consider Method 3 to provide the better estimator of natural egg deposition for the 2016-2017 spawning years.

Application of Method 3 yields an updated naturally spawning egg deposition estimate of 2,697,718 for 2016 (Table 2) and an egg deposition estimate of 1,507,924 for 2017 (Table 1). The egg deposition estimate for 2016 is an increase of 437,685 and 69,118 additional eggs over Method 1 and Method 2, respectively. For 2017, Method 3 yields a decrease of 277,164 and 69,938 fewer eggs than Method 1 and Method 2, respectively.

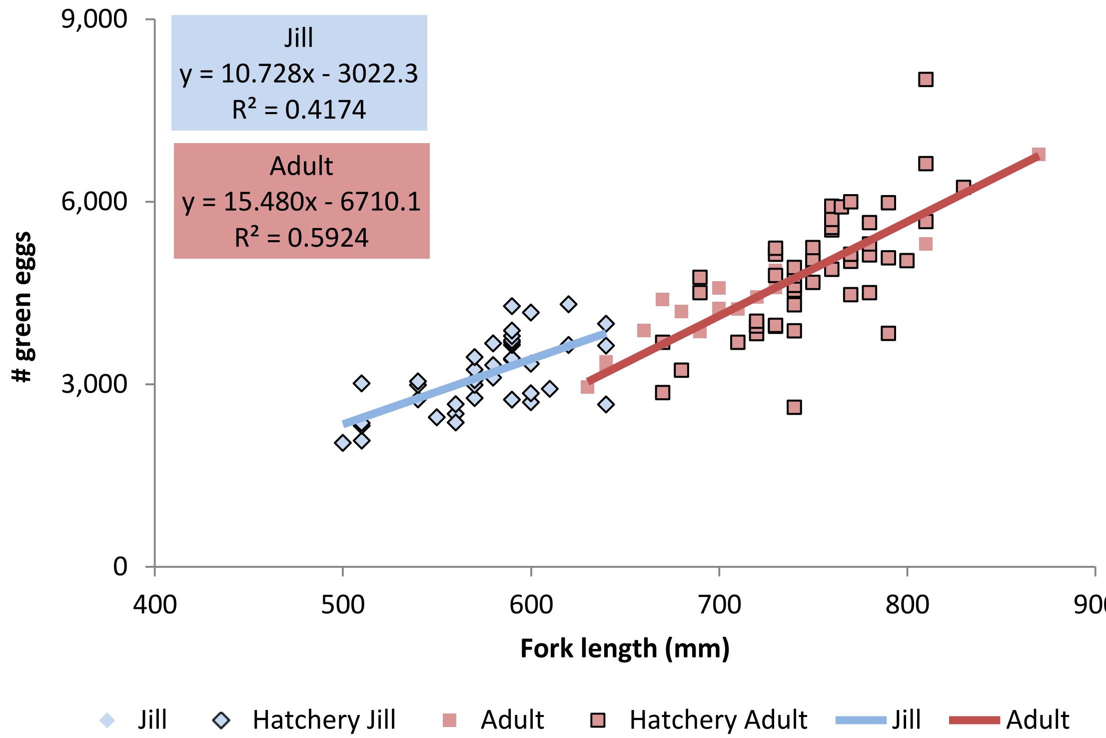

Figure 1. Fork length and fecundity relationship for Jill and adult winter Chinook Salmon spawned at Livingston Stone National Fish Hatchery in 2016 and 2017. Females were assigned to the jill or adult categories based on known age from recovered coded wire tags or assumed age based on fork length cut offs for each year [jill < 630mm (2016) and < 645 mm (2017), and adult ≥ 630mm (2016) and ≥ 645mm (2017)]. Hatchery-origin fish are outlined in black. Fecundity is based on the number of green eggs obtained from each spawned female.

Table 1. Comparison of methods for estimating eggs deposited by naturally spawning winter Chinook Salmon in 2017. The methods evaluated include the following: 1) estimating fecundity using standard methodologies, which consider the average fecundity of female winter Chinook Salmon (WCS) spawned at LSNFH, 2) estimating fecundity for two size categories of female WCS spawned at LSNFH, and then applying these two fecundity estimates to the appropriate fractions of naturally spawning WCS that fall within each size range and 3) estimating the relationship for fork length and fecundity for two size/age categories of female WCS spawned at LSNFH, and then applying these two fecundity relationships to the appropriate fractions of naturally spawning WCS based on fork length.

Method 1		**Method 2**		**Method 3**	
Average Fecundity of winter Chinook Salmon spawned at the LSNFH in 2017		Average fecundity applied to two length categories of female winter Chinook Salmon spawned at the LSNFH in 2017		Relationship for fork length and fecunidty developed for Jills and Adults based on female winter Chinook Salmon spawned at the LSNFH in 2016 and 2017. Applied to expanded length frequency data from 2017 carcass survey	
Average Fecundity at LSNFH (n=53)	4,864	Average Fecundity < 645mm (n=2)	3,274	Jill Equation (females < 645mm) (n=39)	y = 10.728x - 3022.3
		Average Fecundity ≥ 645mm (n=49)	4,896	Adult Equation (females ≥ 645mm) (n=65)	y = 15.480x - 6710.1
Estimated number females spawning naturally	367	Estimated number naturally spawning females < 645mm	135	Estimated number naturally spawning females < 645mm	135
		Estimated number naturally spawning females ≥ 645mm	232	Estimated number naturally spawning females ≥ 645mm	232
		Estimated egg deposition < 645mm	441,990	Estimated egg deposition < 645mm	408,951
		Estimated egg deposition ≥ 645mm	1,135,872	Estimated egg deposition ≥ 645mm	1,098,973
Estimated egg deposition	**1,785,088**	**Estimated egg deposition total**	**1,577,862**	**Estimated egg deposition total**	**1,507,924**
				% lower egg deposition than Method 2	4.4%
				% lower egg deposition than Method 1	15.5%

Table 2. Comparison of methods for estimating eggs deposited by naturally spawning winter Chinook Salmon in 2016. The methods evaluated include the following: 1) estimating fecundity using standard methodologies, which consider the average fecundity of female winter Chinook Salmon (WCS) spawned at LSNFH, 2) estimating fecundity for two size categories of female WCS spawned at LSNFH, and then applying these two fecundity estimates to the appropriate fractions of naturally spawning WCS that fall within each size range and 3) estimating the relationship for fork length and fecundity for two size/age categories of female WCS spawned at LSNFH, and then applying these two fecundity relationships to the appropriate fractions of naturally spawning WCS based on fork length.

Method 1		**Method 2**		**Method 3**	
Average Fecundity of winter Chinook Salmon spawned at the LSNFH in 2016		Average fecundity applied to two length categories of female winter Chinook Salmon spawned at the LSNFH in 2016		Relationship for fork length and fecundity developed for Jills and Adults based on female winter Chinook Salmon spawned at the LSNFH in 2016 and 2017. Applied to expanded length frequency data from 2016 carcass survey	
Average Fecundity at LSNFH (n=53)	3,461	Average Fecundity < 630mm (n=34)	3,150	Jill Equation (females < 630mm) (n=39)	y = 10.728x - 3022.3
		Average Fecundity ≥ 630mm (n=19)	4,180	Adult Equation (females ≥ 630mm) (n=65)	y = 15.480x - 6710.1
Estimated number females spawning naturally	653	Estimated number naturally spawning females < 630mm	98	Estimated number naturally spawning females < 630mm	98
		Estimated number naturally spawning females ≥ 630mm	555	Estimated number naturally spawning females ≥ 630mm	555
		Estimated egg deposition < 630mm	308,700	Estimated egg deposition < 630mm	316,361
		Estimated egg deposition ≥ 630mm	2,319,900	Estimated egg deposition ≥ 630mm	2,381,357
Estimated egg deposition	2,260,033	**Estimated egg deposition total**	**2,628,600**	**Estimated egg deposition total**	**2,697,718**
				% higher egg deposition than Method 2	2.6%
				% higher egg deposition than Method 1	19.4%