BROOD YEAR 2016 JUVENILE SALMONID PRODUCTION AND PASSAGE INDICES AT RED BLUFF DIVERSION DAM

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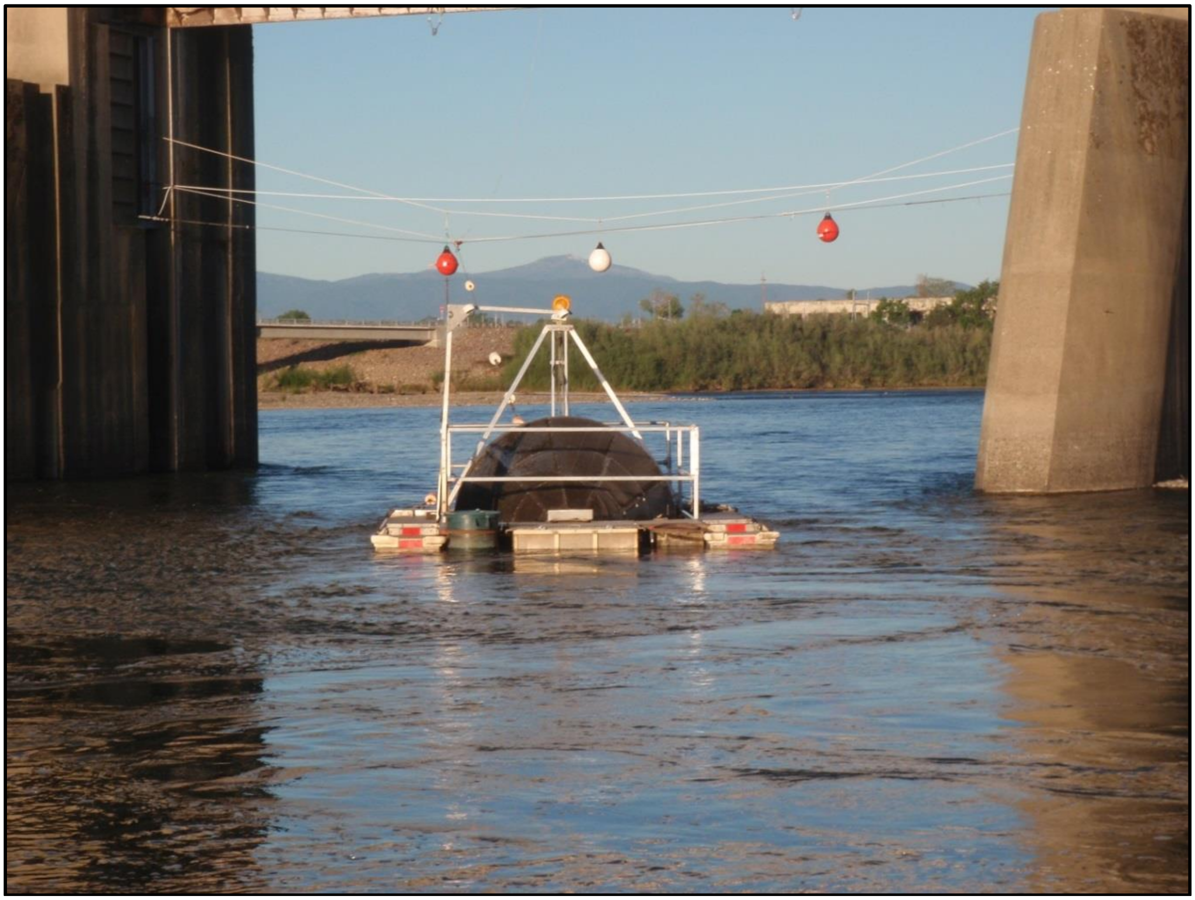

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Brood year 2016 juvenile salmonid production and passage indices at Red Bluff Diversion Dam.

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Abstract.— Brood year 2016 (BY2016) juvenile winter Chinook salmon estimated passage at Red Bluff Diversion Dam (RBDD) was 537,517 for fry and pre-smolt/smolts combined. The fry-equivalent rotary trap juvenile production index (JPI) was estimated at 640,149 with the lower and upper 90% confidence intervals (CI) extending from 429,876 to 850,422 juveniles, respectively. The estimated egg-to-fry (ETF) survival rate, based on the brood year 2016 winter Chinook fry-equivalent JPI was 23.7%. The range of ETF survival rates based on the 90% CI were 15.9% to 31.5%.

BY2016 juvenile spring Chinook salmon estimated passage was 991,691 fry and pre-smolt/smolts combined. The fry-equivalent JPI for 2016 spring Chinook was 1,651,047 with the lower and upper 90% CI extending from -480,487 to 3,782,582 juveniles, respectively. BY2016 fall Chinook juvenile estimated passage at RBDD was 18,612,591 fry and pre-smolt/smolts combined. The fry-equivalent JPI for 2016 fall Chinook was 25,812,410 with the lower and upper 90% CI extending from -22,447,165 to 74,071,986 juveniles, respectively. Overall, interpolation during the primary outmigration period for this run accounted for 58.4% of the brood year fall Chinook fry-equivalent JPI, which resulted in an unrealistic 103.1% ETF survival estimate for BY2016. The BY2016 fall Chinook fry-equivalent prior to CNFH releases was 8,471,017 with an ETF survival estimate of 33.8% which is more realistic, but likely biased because 55 non-sample days occurred from December 2016 through the end of February 2017 due to high flows. BY2016 late-fall Chinook juvenile estimated passage at RBDD was 68,930 fry and pre-smolt/smolts combined. The fry-equivalent JPI for BY2016 late-fall was 108,523 with the lower and upper 90% CI extending from 59,918 to 157,127 juveniles, respectively. ETF survival rates were not estimated for spring and late-fall Chinook due to inaccuracies with run designation and adult counts.

The available cold-water pool in Shasta reservoir along with the implementation of USBR's 2016 water management plan allowed for much better in-river conditions than the previous two years, providing a return to near average ETF survival rates for BY2016 winter Chinook. Additionally, increased flows and lower temperatures as compared to BY2015 may have decreased parasite infectivity in the upper river, further benefiting survival of BY2016 winter Chinook juveniles and likely other runs of juvenile Chinook rearing in the upper river during that time.

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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, CA 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. Beginning in 2014, the RBDD winter Chinook fry-equivalent JPI has been used as the basis of the NMFS' JPE Model. 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) 2016, (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, 2016 through November 30, 2017. This report includes JPI's for the 2016 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

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 numbers 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 assigned using length-at-date (LAD) criteria developed by Greene (1992)[3].

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

[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.

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 BY2016 relied primarily on 79 mark-recapture trials using wild fish and conducted with the RBDD gates raised between 2002 and 2016 (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,…,t) on day d (d = 1,…,n), and X_{di} as volume sampled at trap i (i = 1,…t) on day d (d = 1,…n). Daily salmonid catch and water volume sampled were expressed as:

1.

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

and,

2.

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

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

3.

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

Total salmonid passage was estimated on day d (d = 1,…,n) by

4.

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

where,

5.

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

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.

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

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-presmolt/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 female 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 2017) 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 (Appendix 1) and fall Chinook fecundity estimates were obtained from CNFH annual spawning records.

Results

Sampling effort.—Weekly sampling effort throughout the BY2016 winter Chinook salmon emigration period was moderate and ranged from 0 to 1.00 ($\bar{x}$ = 0.70; *N* = 52 weeks; Table 1). Weekly sampling effort ranged from 0.19 to 1.00 ($\bar{x}$ = 0.85; *N* = 26 weeks) between July and the end of December, the period of greatest juvenile winter Chinook emigration, and 0 to 1.00 ($\bar{x}$ = 0.55; *N* = 26 weeks) during the latter half of the emigration period (Table 1).

Weekly sampling effort throughout the BY2016 spring Chinook emigration period ranged from 0 to 1.00 ($\bar{x}$ = 0.70; *N* = 52 weeks; Table 2). Weekly sampling effort ranged from 0 to 1.00 ($\bar{x}$ = 0.56; *N* = 26 weeks) between mid-October and mid-April, the period of greatest juvenile spring Chinook emigration, and 0.27 to 1.00 ($\bar{x}$ = 0.84; *N* = 26 weeks) during the latter half of the emigration period (Table 2).

Weekly sampling effort throughout the BY2016 fall Chinook emigration period ranged from 0 to 1.00 ($\bar{x}$ = 0.70; *N* = 52 weeks; Table 3). Weekly sampling effort ranged from 0 to 1.00 ($\bar{x}$ = 0.49; *N* = 26 weeks) between December and the end of May, the first half of the juvenile fall Chinook 2016 brood year, and 0.52 to 1.00 ($\bar{x}$ = 0.90; *N* = 26 weeks) during the latter half of the emigration period (Table 3).

Weekly sampling effort throughout the BY2016 late-fall Chinook emigration period ranged from 0 to 1.00 ($\bar{x}$ = 0.62; *N* = 52 weeks; Table 4). Weekly sampling effort ranged from 0.11 to 1.00 ($\bar{x}$ = 0.63; *N* = 26 weeks) between April and the end of September, the first half of the juvenile late-fall Chinook 2016 brood year, and 0 to 1.00 ($\bar{x}$ = 0.60; *N* = 26 weeks) during the latter half of the emigration period (Table 4).

Weekly sampling effort throughout the BY2016 *O. mykiss* emigration period ranged from 0.11 to 1.00 ($\bar{x}$ = 0.66; *N* = 52 weeks; Table 5). Weekly sampling effort ranged from 0.11 to 1.00 ($\bar{x}$ = 0.47; *N* = 26 weeks) between January and the end of June, the first half of the juvenile *O. mykiss* 2016 brood year, and 0.19 to 1.00 ($\bar{x}$ = 0.85; *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), or non-sampled days, (2) unintentional reductions in effort resulting from high flows and debris loads, (3) Section 10(a)(1)(A) permit catch limitations.

Mark-recapture trials.—Environmental and sampling conditions did not allow the opportunity to conduct mark-recapture trials in 2017. Therefore, a 79-trial model (Figure 3; Voss and Poytress 2017) was employed from the beginning of the 2016 winter Chinook brood year through the end of the reporting period, November 30, 2017 (Figure 4).

Trap efficiency modeling.—No mark-recapture trials were conducted during the reporting period, yet three mark-recapture trials conducted during BY2015 were added to a 76-trial linear regression based trap-efficiency model (Voss and Poytress 2017). The 76-trial model was employed for a fraction of the BY2016 late-fall Chinook and *O. mykiss* outmigration period (Figure 4). The 79-trial model (r^2 = 0.70, P < 0.001, df = 78; Figure 3) was employed for passage estimation during the entire BY2016 winter, fall and spring Chinook outmigration period of July 1, 2016 through November 30, 2017 (Figure 4).

Winter Chinook fork length evaluations.— BY2016 Winter Chinook fork lengths ranged between 25 and 150 mm (Figure 5a). Winter Chinook were weighted (83.4%) to the fry size-class category (<46mm) with 95.4% of those measuring less than 40 mm (Figure 6a). The remaining 16.6% 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.—BY2016 winter Chinook juvenile estimated passage at RBDD was 537,517 fry and pre-smolt/smolts combined (Table 1). Fry sized juveniles (<46 mm FL) comprised 72.7% of total estimated winter Chinook passage (Table 1). Fry passage occurred from July through the end of November (weeks 27 thru 47; Figure 5b). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 27.3% 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 April (week 14; Figure 5b).

Winter Chinook JPI to adult comparisons.—The BY2016 winter Chinook fry-equivalent JPI was 640,149 with the lower and upper 90% CI extending from 429,876 to 850,422 juveniles, respectively (Table 6). Adult females contributing to in-river spawning of BY2016 winter Chinook were estimated to have been 653 individuals (D. Killam, CDFW, pers. comm.). The estimated ETF survival rate based on the BY2016 winter Chinook fry-equivalent JPI and estimated number of female spawners and egg deposition in-river was 23.7%. The range of ETF survival based on 90% CI's was 15.9% to 31.5% (Table 6).

Adult female spawner estimates derived from winter Chinook carcass surveys and rotary-screw trap data from brood years 1996-2016 were used to evaluate the linear relationship between the estimates. Nineteen observations were evaluated using the carcass survey data as the winter Chinook carcass survey did not start until 1996 and rotary trapping at RBDD was not conducted in 2000 and 2001. Rotary trap JPI's were significantly correlated in trend to adult female spawner estimates ($r^2 = 0.87$, $P < 0.001$, df = 18; Figure 7).

Spring Chinook fork length evaluations.— BY2016 spring Chinook fork lengths ranged between 28 and 142mm (Figure 6b). Spring Chinook were heavily weighted to the pre-smolt/smolt size-class category (>45mm). Only 11.5% of all fish sampled as spring Chinook were designated fry with 98.5% measuring less than 40 mm FL (Figure 8a). The bulk of the catch (88.5%) was attributed to the pre-smolt/smolt category (>45 mm) with fish between 70 and 95mm comprising 94.1% of this size group.

Spring Chinook passage.—BY2016 spring Chinook juvenile estimated passage at RBDD was 991,691 fry and pre-smolt/smolts combined (Table 2). The 2016 spring brood year total passage estimate had relatively wide 90% confidence intervals (± 127.6%). Fry sized juveniles (<46 mm FL) comprised only 5.0% of total estimated spring Chinook passage (Table 2). Fry passage occurred from mid-October through mid-January (weeks 42 thru 2; Table 2). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 95.0% of total passage and the first observed emigration past RBDD occurred in mid-December (week 51; Table 2). Weekly pre-smolt/smolt passage for the brood year ended in mid-June (week 25; Figure 8b). The fry-equivalent rotary trap JPI for BY2016 was 1,651,047 with the lower and upper 90% CI extending from -480,487 to 3,782,582 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.—BY2016 fall Chinook fork lengths ranged between 24 and 185 mm (Figure 6c). BY2016 fall Chinook were composed of 31.2% in the fry size-class category (<46 mm) with 99.1% of those fry measuring less than 40 mm FL (Figure 9a). The remaining 68.8% were attributed to the pre-smolt/smolt category (>45 mm) with fish between 65 and 85 mm comprising 76.4% of the size group.

Fall Chinook passage.—BY2016 fall Chinook juvenile estimated passage at RBDD was 18,612,591 fry and pre-smolt/smolts combined (Table 3). Fall Chinook exhibited the widest confidence intervals (± 169.2%) surrounding the total passage estimate. Fry sized juveniles (<46 mm FL) comprised 37.8% of total estimated fall Chinook passage (Table 3). Fry passage occurred from December through the beginning of April (weeks 48 thru 15; Figure 9b). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 62.2% of total passage. The first observed pre-smolt/smolt passage occurred in mid-January (week 2; Table 3). Weekly pre-smolt/smolt passage for the brood year ended during mid-November (week 46; Table 3).

Fall Chinook JPI to adult comparisons.—The fry-equivalent rotary trap JPI for BY2016 was 25,812,410 with the lower and upper 90% CI extending from -22,447,165 to 74,071,986 juveniles, respectively (Table 3). The total number of adult BY2016 fall Chinook females contributing to in-river spawning upstream of RBDD was estimated to be 5,240 individuals. The estimated ETF survival rate based on the BY2016 fall Chinook fry-equivalent JPI and estimated number of female spawners and eggs deposited in-river was 103.1%. The range of ETF survival based on 90% CI's was -89.7% to 295.9% (Table 7).

Late-Fall Chinook fork length evaluations.—BY2016 late-fall Chinook were sampled between 26 and 158 mm (Figure 6d). BY2016 late-fall Chinook sampled were heavily weighted to the pre-smolt/smolt size-class category (>45 mm). Only 12.2% of all fish sampled as late-fall were designated fry (<46 mm) with 94.9% of the fry measuring less than 40 mm FL (Figure 10a). The remaining 87.8% of juveniles were attributed to the pre-smolt/smolt category with fish between 70 and 150 mm comprising 83.4% of that value.

Late-fall Chinook passage.—BY2016 late-fall Chinook juvenile estimated passage at RBDD was 68,930 fry and pre-smolt/smolts combined (Table 4). Fry sized juveniles (<46 mm FL) comprised 17.9% of total estimated late-fall Chinook passage (Table 4). Fry passage occurred from April through the middle of August (weeks 14 thru 32; Figure 10b). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 82.1% of total passage and the first observed emigration past RBDD occurred in mid-June (week 25; Table 4). Weekly pre-smolt/smolt passage for the brood year ended in late December (week 52; Figure 10b). The fry-equivalent rotary trap JPI for brood year 2016 was 108,523 with the lower and upper 90% CI extending from 59,918 to 157,127 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.—BY2016 juvenile *O. mykiss* were sampled between 20 and 280 mm (Figure 11a). Sub-yearling (41-138 mm) and yearling (139-280 mm) *O. mykiss* were amongst the first sampled at the beginning of brood year 2016 (Table 5). *O. mykiss* fry (<41 mm) captures were highly variable as the first and smallest fry of the year was captured in early March with a fork length of 23 mm; another 23 mm fry was captured 17 weeks later (late June; Figure 11a). Fry captures continued through week 39 (late September). Sub-yearling and yearling captures continued in a sporadic fashion through the end of the calendar year with sub-yearling catch peaking in early September (week 35; Table 5).

O. mykiss passage.—BY2016 *O. mykiss* juvenile total estimated passage at RBDD was 28,133 fry, sub-yearling and yearlings combined (Table 5). Fry sized juveniles (<41 mm) comprised only 4.3% of total *O. mykiss* passage. Fry passage occurred from March through the end of September (weeks 9 thru 39; Figure 11b). Sub-yearling/yearling sized juveniles (≥41 mm) comprised 95.7% of total passage and the first observed emigration past RBDD occurred in week 2 (January; Table 5). Weekly sub-yearling/yearling passage for the brood year ended during week 51 (late December).

Discussion

Sampling effort. —Fluctuating river flows resulted in moderate sampling effort for the reporting period of January 1, 2016 through November 30, 2017 ($\bar{x}$ = 0.68). Mean sampling effort for BY2016 winter, spring, fall, late-fall Chinook and *O. mykiss* was 0.70, 0.70, 0.70, 0.62 and 0.66, respectively (Tables 1-5). During the primary juvenile winter Chinook salmon capture and passage period of July through December of 2016, mean sampling effort was fairly high (0.85) whereas the latter half of the brood year was markedly lower and more variable, averaging only 0.55.

Decreased sampling effort was primarily a product of winter storm activity resulting in high flows and debris loads as well as hatchery fish releases occurring from mid-December 2016 through early March 2017. Non-sample days due to high flows totaled 11, 20, and 24 days in December, January, and February, respectively. Increased water releases from Shasta and Keswick Reservoirs for flood control augmented natural runoff for most of these non-sample days and warranted trap removal due to unsafe conditions (Figure 12). Traps were removed from the river for 8 of 11 non-sample days in December, 18 of 20 non-sample days in January and all 24 non-sample days in February. The magnitude and duration of these conditions had a significant effect on the accuracy of weekly passage estimates and associated precision of confidence intervals. For example, three consecutive weeks went un-sampled in January and February and passage values were interpolated using monthly mean daily passage estimates. The results of interpolating these periods had the greatest effect on fall Chinook and will be described in detail in respective areas below.

Reduced sampling effort from late May to early June 2016 occurred due to concern for exceeding permitted take limits (NMFS ESA Section 10, research permit No. 1415-3A) of larval threatened Green Sturgeon in the RSTs. From mid-May through the last week of June in 2016, sampling effort was reduced (e.g., sampling with modified cones and/or sampling only three RSTs or abstaining from sampling for a number of days each week) to decrease the number of incidentally captured sturgeon larvae encountered in the RSTs. This period overlapped with sporadic BY2016 late-fall Chinook and *O. mykiss* passage. Reduced sampling efforts during this time reduced the detectability of these runs and precision of weekly passage estimates.

Patterns of abundance.—Juvenile winter Chinook began to emerge in early July in low numbers. Catch and subsequent passage generally increased through October and peaked in early November (Table 1; Figure 5b). Catch and passage declined slightly as fry grew to the pre-smolt/smolt life stage. Passage was variable until the beginning of November 2016 (week 44) when the first runoff event of the winter season resulted in elevated Sacramento River flows reaching a maximum daily discharge of 11,400 cfs (Figure 12). Although this event only resulted in an addition of approximately 3,000 cfs of in-river flow, the runoff generated about 5 times greater turbidity values as compared with river conditions two days prior (i.e., from 6.9 to 32.7 NTU). Coinciding with the early November runoff event, a substantial pulse of winter Chinook pre-smolt/smolts were encountered in the RSTs accounting for 45.9% of all pre-smolt/smolts collected during the brood year (Table 1; Figure 5b).

Winter Chinook fry outmigrants represented 72.7% of total winter Chinook passage with pre-smolt/smolts representing the remaining 27.3%. By the middle of December 2016, 94.6% of the total annual passage estimate for BY2016 winter Chinook was collected (Table 1). With almost 95% of passage occurring in the first half of the brood year, the effects of lower sampling effort ($\bar{x}$ = 0.55) during the second half of the brood year appear minimal. Overall, interpolation for missed days of sampling accounted for 7.3% of the total BY2016 estimate of 537,517 winter Chinook passing the RBDD. The BY2016 winter Chinook total passage estimate was the fourth lowest on record since the RBDD Juvenile Fish Monitoring Program began in 1995.

Capture of BY2016 juvenile spring Chinook began on October 16, 2016 according to LAD criteria. Sampling effort remained relatively high through the end of November ($\bar{x}$ = 0.94, Table 2). A pronounced peak of fry passage, accounting for 30.0% of total fry passage, occurred in early November and coincided with the week 44 runoff event (week 44; Table 2). Sampling effort during the remainder of the brood year was lower and more variable ($\bar{x}$ = 0.67; Table 2) for a number of reasons. Storm activity and resultant increased reservoir releases (Figure 12), personnel constraints, and hatchery releases accounted for reductions in effort during periods of spring Chinook passage. Interpolation for missed days of sampling accounted for 48.4% of the total BY2016 estimate of 991,691 spring Chinook passing the RBDD.

Spring Chinook fry outmigrants represented 5.0% of total passage with pre-smolt/smolts representing the remaining 95.0%. This low percentage of fry outmigrants contradicts the 54% average and supersedes the previously noted brood year low of 24% (BY2008) as described in Poytress et al. 2014. Positive bias of spring Chinook passage estimates associated with 75% *unmarked*[4] CNFH production releases of fall Chinook that exceeded the fall LAD criteria were detected, similar to BY2015 (Voss and Poytress 2017). Brood year 2016 fall Chinook releases into Battle Creek (Figure 1) began during the latter half of March and continued through the latter half of April (weeks 12 thru 16; Table 8). Much like BY2015 production releases, the timing was earlier in the spring than described in Poytress et al. 2014. Releases occurred

[4] 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.

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 a week of recapture immediately following (weeks 12-17; Table 8), 17.8% 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 and data interpolation for missed samples contributed greatly to increased spring Chinook fish passage between late-March and April (weeks 12-17; Figure 8b). Moreover, 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 11.1% (109,939) of the brood year total. Passage during week 15 (673,118) accounted for 67.9% of the brood year total. Interpolation accounted for 48.4% of total spring Chinook passage estimate for BY2016 indicating substantial positive bias in the annual estimate.

Fall Chinook fry passage accounted for 44.7% of the total passage for brood year 2016, which is substantially less than the prior 15 years of passage when the average fry-to-smolt ratio was 73%. Passage of fry began the first week of December and increased by two orders of magnitude by week 51, influenced heavily by historic precipitation and associated runoff events (Figure 9b & 12). Fry passage continued to peak during the next several storm events occurring in mid-January and early February (Table 3; Figure 12), but sampling was greatly reduced due to unfavorable conditions. Sampling effort during fry passage was low, averaging 0.45 from week 48 thru week 15. Interpolation for missed samples during the fry passage period accounted for 1,966,591 or 23.6% of the total fry passage estimate and negatively biased the annual estimate.

Fall Chinook in the pre-smolt/smolt size category, which comprised 55.3% of total brood year passage, began during the third week in January. Spikes in pre-smolt/smolt passage occurred from early to mid-April (Table 3) coinciding with the timing of CNFH fall Chinook production releases and runoff events (Table 8 & Figure 9b) resulting in substantial positive bias to unmarked fall Chinook estimates. Pre-smolt/smolt passage during the CNFH fall BY2016 release period, including a week following the final release, (weeks 12-17) accounted for 90.9% (9,351,437) of all pre-smolt/smolt passage for BY2016. Interpolation for missed samples was the highest in the last 15 years and accounted for 61.7% of total pre-smolt/smolt passage. Overall, interpolation accounted for 58.4% of the BY2016 fall Chinook fry-equivalent JPI which resulted in an unrealistic 103.1% ETF survival estimate for BY2016 (Table 7). The BY2016 fall Chinook fry-equivalent JPI prior to CNFH releases was 8,471,017 with an ETF survival estimate of 33.8%, which is more realistic, but likely biased due to underestimation noted above during the fry outmigration period.

Late-fall Chinook fry passage began the first week of April and continued through early August. Pre-smolt/smolts began to appear in a sporadic fashion from late June through mid-October when passage increased, abruptly peaking in early November (Table 4; Figure 10b). Fry passage accounted for 17.9% 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 second week in January (Table 5) with the first fry passing in early March. Passage peaked in September and remained variable throughout the rest of the calendar year. Total passage for the brood year was 28,133 and interpolation accounted for 18.8% of the total. Interpolation from May through July (weeks 18-30) accounted for 32.4% for the three month period when sampling efforts were reduced for take of larval Green Sturgeon.

Bias associated with unmarked CNFH fall Chinook.—A method was formulated to reduce bias to BY2016 spring and fall Chinook natural production and passage estimates resultant from the capture of 75% unmarked CNFH fall Chinook. For the period March 22 through April 30, 2016 (weeks 12 through 18), 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 estimates. The adjusted daily values were subsequently subtracted from the original total passage and production estimates for each run. 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 the estimates of unmarked hatchery Chinook passage, weekly passage estimates and confidence intervals were recalculated.

Estimates for BY2016 spring Chinook adjusted to account for unmarked hatchery Chinook resulted in a total passage value of 219,051 with lower and upper confidence intervals extending from 7,709 and 430,393, respectively. Using adjusted values, the percentage of smolt spring Chinook represented 77.3% of total passage, whereas the original estimate was 95.0% smolts. Adjusted values for BY2016 spring Chinook fry-equivalent JPI were 337,559 with lower and upper confidence intervals extending from -2,777 and 677,895, respectively.

BY2016 fall Chinook adjusted total passage was 9,244,293 with lower and upper confidence intervals extending from -2,910,149 and 21,398,734 respectively. This lowered the original total smolt passage by 9,368,298, which resulted in only 9.9% of BY2016 fall Chinook passing the RBDD transect as smolts. Adjusted values for BY2016 fall Chinook fry-equivalent JPI were 9,886,303 with lower and upper confidence intervals extending from -2,666,309 and 22,438,916 respectively, which results in an adjusted ETF survival of 39.5%.

Calculating passage estimates to exclude 75% unmarked hatchery Chinook bias from the annual estimate in this way can potentially be a useful approach to produce a more accurate estimate of natural fish passage and production. Removing unmarked hatchery Chinook using this method does not affect the uncertainty that sub-sampling and/or missed samples may have imparted upon annual estimates.

Winter Chinook JPI and ETF survival estimate.—The BY2016 winter Chinook fry-equivalent JPI value of 640,149 was the fourth lowest production estimate in 19 years of monitoring at RBDD. This follows two years of low adult returns coupled with record-low ETF survival estimates (Voss and Poytress 2017). For BY2016 winter Chinook, the fry-equivalent based ETF survival rate was estimated at 23.7% (Table 6). The 19-year average ETF survival rate is 22.6% with a standard deviation of 11.4. The difference in ETF survival rates over the prior two years was likely a result of different in-river conditions experienced by 2016 brood year adults, eggs, and alevins in relation to a new temperature management plan prescribed by NMFS and enacted by the USBR (USBR 2016). The plan outlined management of the cold water pool in Shasta Reservoir during the summer and fall of 2016 focusing on maintaining a temperature target not to exceed 56°F daily average temperature at Balls Ferry and allowing flexibility in Keswick release schedules in order to minimize any potential for winter and fall Chinook redd dewatering. Revnak and Memeo (2017) reported that none of the 49 winter Chinook redds surveyed in 2016 were dewatered.

Winter Chinook pathogen monitoring.—Pathogen monitoring of naturally produced winter Chinook juveniles was studied via histological analyses (Foott 2017) from samples collected (*N*=80) at RBDD from September through November 2016. Additionally, water samples were taken across eight different sites from RBDD upstream to Redding CA to determine the spore concentration of *Ceratonova shasta (eDNA)* within a portion of the Sacramento River from July through November 2016. From histological analyses of RBDD RST samples, Foott (2017) determined prevalence of infection for the parasites *C. shasta* and *Parvocapsula minibicornis* were 7.6% and 9.7%, respectively. Also, Foott (2017) exposed CNFH late-fall Chinook sentinel fish to the Sacramento River for a period of five days across four separate sites, replicating exposures five times from July through October. Histological analyses of sentinel groups indicated a trend of increasing prevalence of infection moving from Anderson downstream to RBDD (Figure 1). River samples exhibited a similar pattern of increasing concentrations moving downstream with low *C. shasta* spore concentrations from Redding to Anderson and increasing concentrations from Anderson downstream to RBDD. Although there was prevalence of infection detected in RST collected winter run, as well as CNFH sentinel groups, no samples indicated a diseased state. Foott (2017) hypothesized that reduced *C. shasta* infectivity from BY2016 studies compared to BY2015 was influenced by higher in-river flows in 2016, which may have decreased parasite host densities via both dilution and temperature reduction during the summer months.

Water management impacts to salmonids during brood year 2016.—Following a period of prolonged drought conditions and record low winter Chinook ETF survival in brood years 2014 and 2015, the BY2016 ETF data suggest much better in-river temperature and flow conditions for salmonids. Timely rains in the winter and early spring months of 2016 resulted in a substantial increase in the amount of cold water storage within Shasta reservoir. The 2016 USBR temperature management plan allowed for a modeled flow release schedule that would keep daily average water temperatures under 56.0°F at the Balls Ferry compliance point for winter Chinook (USBR 2016). The available cold water pool in Shasta reservoir along with the implementation of USBR's 2016 water management plan resulted in better in-river conditions than the previous two years, providing a return to near average ETF survival rates for BY2016 winter Chinook. Additionally, increased flows and lower temperatures as compared to BY2015 may have decreased parasite infectivity in the upper river further benefiting survival of BY2016 winter Chinook juveniles as well as other runs of Chinook rearing in the upper river during that time.

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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, 2016 through June 30, 2017 (brood year 2016). 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)	0.46	561	33	0	-	561	33	561
28	0.86	1,070	34	0	-	1,070	34	1,070
29	1.00	1,241	35	0	-	1,241	35	1,241
30	1.00	1,883	35	0	-	1,883	35	1,883
31 (Aug)	0.96	4,169	36	0	-	4,169	36	4,169
32	0.71	7,925	35	0	-	7,925	35	7,925
33	0.86	5,615	35	0	-	5,615	35	5,615
34	0.86	10,820	35	0	-	10,820	35	10,820
35 (Sep)	0.86	26,511	36	250	46.5	26,761	36	26,937
36	0.86	40,166	35	249	48	40,415	35	40,590
37	1.00	30,409	35	338	48.5	30,747	36	30,983
38	1.00	33,005	35	505	53	33,510	35	33,864
39	1.00	53,942	35	1,360	52	55,302	35	56,254
40 (Oct)	1.00	53,826	35	1,507	54	55,333	35	56,387
41	1.00	58,050	35	2,756	52	60,806	35	62,735
42	0.86	22,899	36	4,777	56.5	27,676	36	31,020
43	1.00	15,657	37	11,612	57	27,269	41	35,398
44 (Nov)	1.00	22,241	41	67,321	55	89,563	51	136,688
45	1.00	388	42	2,784	59	3,172	58	5,121
46	1.00	137	44	866	57	1,003	56	1,609
47	0.80	384	44.5	13,270	61	13,654	60	22,944
48 (Dec)	0.71	0	-	1,107	66	1,107	66	1,882
49	1.00	0	-	738	64	738	64	1,255
50	0.19	0	-	8,247	70	8,247	70	14,019
51	0.54	0	-	8,483	70	8,483	70	14,421
52	0.59	0	-	4,116	68	4,116	68	6,998

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)	0.57	0	-	379	75.5	379	75.5	645
2	0.00	0	-	477	-	477	-	811
3	0.14	0	-	0	-	0	-	0
4	0.43	0	-	1,118	122	1,118	122	1,900
5 (Feb)	0.57	0	-	638	125	638	125	1,085
6	0.21	0	-	0	-	0	-	0
7	0.00	0	-	638	-	638	-	1,085
8	0.00	0	-	638	-	638	-	1,085
9 (Mar)	0.00	0	-	2,455	-	2,455	-	4,173
10	0.57	0	-	3,620	124	3,620	124	6,155
11	1.00	0	-	2,364	118.5	2,364	118.5	4,018
12	0.57	0	-	2,725	116.5	2,725	116.5	4,633
13	0.86	0	-	1,195	114	1,195	114	2,031
14 (Apr)	0.71	0	-	83	127	83	127	141
15	0.23	0	-	0	-	0	-	0
16	0.27	0	-	0	-	0	-	0
17	0.39	0	-	0	-	0	-	0
18 (May)	0.55	0	-	0	-	0	-	0
19	0.70	0	-	0	-	0	-	0
20	1.00	0	-	0	-	0	-	0
21	1.00	0	-	0	-	0	-	0
22 (Jun)	1.00	0	-	0	-	0	-	0
23	1.00	0	-	0	-	0	-	0
24	1.00	0	-	0	-	0	-	0
25	0.93	0	-	0	-	0	-	0
26	0.55	0	-	0	-	0	-	0
BY total		390,899		146,618		537,517		640,149
90% CI (low : high)		(291,208 : 490,590)		(77,365 : 215,870)		(371,480 : 703,554)		(429,876 : 850,422)

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, 2016 through October 15, 2016 (brood year 2016). 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	0.86	2,829	33	0	-	2,829	33	2,829
43	1.00	11,038	34	0	-	11,038	34	11,038
44 (Nov)	1.00	14,927	35	0	-	14,927	35	14,927
45	1.00	1,486	34	0	-	1,486	34	1,486
46	1.00	1,062	32	0	-	1,062	32	1,062
47	0.80	4,488	33	0	-	4,488	33	4,488
48 (Dec)	0.71	8,645	34	0	-	8,645	34	8,645
49	1.00	2,610	35	0	-	2,610	35	2,610
50	0.19	1,008	36	0	-	1,008	36	1,008
51	0.54	1,375	39	115	50	1,490	39	1,490
52	0.59	138	41	185	51	323	42	323
1 (Jan)	0.57	102	43	157	48	259	45.5	259
2	0.00	46	-	561	-	607	-	607
3	0.14	0	-	0	-	0	-	0
4	0.43	0	-	1,794	50.5	1,794	50.5	1,794
5 (Feb)	0.57	0	-	636	66	636	66	636
6	0.21	0	-	10,442	52	10,442	52	10,442
7	0.00	0	-	5,857	-	5,857	-	5,857
8	0.00	0	-	5,857	-	5,857	-	5,857
9 (Mar)	0.00	0	-	30,428	-	30,428	-	30,428
10	0.57	0	-	810	70	810	70	810
11	1.00	0	-	3,345	72	3,345	72	3,345
12	0.57	0	-	5,467	76	5,467	76	5,467
13	0.86	0	-	97,696	75	97,696	75	97,696
14 (Apr)	0.71	0	-	17,356	81	17,356	81	29,505
15	0.23	0	-	673,118	81	673,118	81	1,144,300

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	0.27	0	-	9,601	86	9,601	86	16,322
17	0.39	0	-	33,727	91	33,727	91	57,335
18 (May)	0.55	0	-	30,374	95	30,374	95	51,636
19	0.70	0	-	9,370	98.5	9,370	98.5	15,929
20	1.00	0	-	2,297	104	2,297	104	3,905
21	1.00	0	-	835	108	835	108	1,420
22 (Jun)	1.00	0	-	854	112	854	112	1,452
23	1.00	0	-	640	117	640	117	1,088
24	1.00	0	-	237	126	237	126	403
25	0.93	0	-	180	132.5	180	132.5	306
26	0.55	0	-	0	-	0	-	0
27 (Jul)	0.52	0	-	0	-	0	-	0
28	0.68	0	-	0	-	0	-	0
29	0.50	0	-	0	-	0	-	0
30	0.80	0	-	0	-	0	-	0
31 (Aug)	1.00	0	-	0	-	0	-	0
32	1.00	0	-	0	-	0	-	0
33	1.00	0	-	0	-	0	-	0
34	1.00	0	-	0	-	0	-	0
35 (Sep)	1.00	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		49,754		941,937		991,691		1,651,047
90% CI (low : high)		(28,754 : 70,754)		(-302,850 : 2,186,725)		(-273,472 : 2,256,854)		(-480,487 : 3,782,582)

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, 2016 through November 30, 2016 (brood year 2016). 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)	0.71	186	32.5	0	-	186	32.5	186
49	1.00	6,674	33	0	-	6,674	33	6,674
50	0.19	29,613	34	0	-	32,148	34	33,922
51	0.54	103,426	35	0	-	103,426	35	103,426
52	0.59	373,409	35	0	-	373,409	35	373,409
1 (Jan)	0.57	535,303	36	0	-	535,303	36	535,303
2	0.00	706,373	-	1,100	-	707,473	-	708,243
3	0.14	2,682,053	35	0	-	2,682,053	35	2,682,053
4	0.43	546,960	36	929	47	547,888	36	548,539
5 (Feb)	0.57	388,376	36	3,759	47	392,135	36	394,767
6	0.21	1,222,260	36	22,935	47	1,245,195	36	1,261,250
7	0.00	806,841	-	12,898	-	819,740	-	828,769
8	0.00	806,841	-	12,898	-	819,740	-	828,769
9 (Mar)	0.00	23,560	-	54,203	-	77,763	-	115,705
10	0.57	17,961	36	6,247	57	24,208	37	28,581
11	1.00	17,616	36	4,773	61	22,389	37	25,730
12	0.57	10,906	36	5,524	64	16,430	37	20,297
13	0.86	42,663	36	176,295	69	218,958	68	342,365
14 (Apr)	0.71	4,928	36	11,765	72	16,694	70.5	24,929
15	0.23	1,188	40	4,790,646	75	4,791,834	75	8,145,286
16	0.27	0	-	3,534,540	73	3,534,540	73	6,008,718
17	0.39	0	-	832,667	76	832,667	76	1,415,533
18 (May)	0.55	0	-	285,374	79	285,374	79	485,137
19	0.70	0	-	160,075	82	160,075	82	272,127
20	1.00	0	-	105,615	83	105,615	83	179,545
21	1.00	0	-	58,934	87	58,934	87	100,189

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)	1.00	0	-	45,658	88	45,658	88	77,619
23	1.00	0	-	42,689	91	42,689	91	72,571
24	1.00	0	-	44,122	90	44,122	90	75,008
25	0.93	0	-	22,379	87	22,379	87	38,044
26	0.55	0	-	12,466	89	12,466	89	21,193
27 (Jul)	0.52	0	-	9,590	92	9,590	92	16,302
28	0.68	0	-	8,275	91	8,275	91	14,068
29	0.50	0	-	1,869	88	1,869	88	3,177
30	0.80	0	-	2,390	95	2,390	95	4,063
31 (Aug)	1.00	0	-	1,890	99	1,890	99	3,213
32	1.00	0	-	1,535	104	1,535	104	2,609
33	1.00	0	-	2,045	97	2,045	97	3,477
34	1.00	0	-	948	107	948	107	1,611
35 (Sep)	1.00	0	-	704	105.5	704	105.5	1,197
36	1.00	0	-	593	110	593	110	1,009
37	1.00	0	-	961	115	961	115	1,633
38	1.00	0	-	1,306	124.5	1,306	124.5	2,220
39	1.00	0	-	894	122.5	894	122.5	1,520
40 (Oct)	1.00	0	-	798	128.5	798	128.5	1,357
41	1.00	0	-	943	127	943	127	1,603
42	1.00	0	-	506	134	506	134	861
43	1.00	0	-	295	139.5	295	139.5	502
44 (Nov)	0.96	0	-	491	141	491	141	834
45	0.89	0	-	293	149	293	149	498
46	0.93	0	-	636	159	636	159	1081
47	0.57	0	-	0	-	0	-	0
BY total		8,327,135		10,285,456		18,612,591		25,812,410
90% CI (low : high)		(-3,257,434 : 19,911,704)		(-11,311,359 : 31,882,271)		(-14,543,284 : 51,768,466)		(-22,447,165 : 74,071,986)

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, 2016 through March 31, 2016 (brood year 2016). 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)	1.00	1,311	34	0	-	1,311	34	1,311
15	0.32	8,465	33.5	0	-	8,465	33.5	8,465
16	0.55	141	36	0	-	141	36	141
17	0.46	350	36	0	-	350	36	350
18 (May)	0.30	279	34	0	-	279	34	279
19	0.41	99	35	0	-	99	35	99
20	0.46	60	34	0	-	60	34	60
21	0.21	0	-	0	-	0	-	0
22 (Jun)	0.11	0	-	0	-	0	-	0
23	0.11	0	-	0	-	0	-	0
24	0.16	0	-	0	-	0	-	0
25	0.39	441	36	61	56	503	36	546
26	0.46	446	38	86	55	533	38	593
27 (Jul)	0.46	213	38	0	-	213	38	213
28	0.86	85	36.5	124	64	209	61	296
29	1.00	227	38	316	65	544	59	765
30	1.00	38	41	774	67	812	67	1,354
31 (Aug)	0.96	102	43.5	1,177	67	1,279	66	2,103
32	0.71	111	45	2,216	68	2,328	68	3,879
33	0.86	0	-	848	74	848	74	1,442
34	0.86	0	-	2,217	78	2,217	78	3,769
35 (Sep)	0.86	0	-	1,489	75.5	1,489	75.5	2,531
36	0.86	0	-	1,321	79	1,321	79	2,245
37	1.00	0	-	1,098	80	1,098	80	1,866
38	1.00	0	-	1,373	73	1,373	73	2,335
39	1.00	0	-	1,790	76	1,790	76	3,043

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	-	1,291	81.5	1,291	81.5	2,194
41	1.00	0	-	1,431	80	1,431	80	2,433
42	0.86	0	-	3,073	92	3,073	92	5,223
43	1.00	0	-	5,863	88.5	5,863	88.5	9,967
44 (Nov)	1.00	0	-	18,437	92	18,437	92	31,343
45	1.00	0	-	1,072	114	1,072	114	1,823
46	1.00	0	-	546	117	546	117	929
47	0.80	0	-	2,325	110.5	2,325	110.5	3,953
48 (Dec)	0.71	0	-	1,093	109.5	1,093	109.5	1,857
49	1.00	0	-	213	116	213	116	362
50	0.19	0	-	3,797	141	3,797	141	6,455
51	0.54	0	-	1,282	120	1,282	120	2,179
52	0.59	0	-	1,246	116	1,246	116	2,119
1 (Jan)	0.57	0	-	0	-	0	-	0
2	0.00	0	-	0	-	0	-	0
3	0.14	0	-	0	-	0	-	0
4	0.43	0	-	0	-	0	-	0
5 (Feb)	0.57	0	-	0	-	0	-	0
6	0.21	0	-	0	-	0	-	0
7	0.00	0	-	0	-	0	-	0
8	0.00	0	-	0	-	0	-	0
9 (Mar)	0.00	0	-	0	-	0	-	0
10	0.57	0	-	0	-	0	-	0
11	1.00	0	-	0	-	0	-	0
12	0.57	0	-	0	-	0	-	0
13	0.86	0	-	0	-	0	-	0
BY total		12,369		56,561		68,930		108,523
90% CI (low : high)		(3,599 : 21,140)		(31,076 : 82,046)		(35,316 : 102,545)		(59,918 : 157,127)

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, 2016 through December 31, 2016 (brood year 2016). 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)	0.32	0	-	27 (Jul)	0.46	439	77.5
2	0.41	1,501	197	28	0.86	332	55.5
3	0.14	0	-	29	1.00	859	61.5
4	0.34	103	268	30	1.00	1,151	59
5 (Feb)	0.57	125	293	31 (Aug)	0.96	1,757	63
6	1.00	0	-	32	0.71	1,393	61.5
7	1.00	0	-	33	0.86	1,854	62
8	0.79	0	-	34	0.86	2,071	62
9 (Mar)	1.00	43	24	35 (Sep)	0.86	2,381	60.5
10	0.57	513	97.5	36	0.86	1,771	62
11	0.11	0	-	37	1.00	1,556	60
12	0.36	0	-	38	1.00	799	69
13	0.63	0	-	39	1.00	931	66
14 (Apr)	1.00	199	122.5	40 (Oct)	1.00	287	78
15	0.32	945	57.5	41	1.00	160	93.5
16	0.55	818	69	42	0.86	522	107
17	0.46	60	55	43	1.00	63	176
18 (May)	0.30	573	72	44 (Nov)	1.00	536	84
19	0.41	394	66	45	1.00	118	80
20	0.46	339	58.5	46	1.00	56	137.5
21	0.21	573	55	47	0.80	90	99.5
22 (Jun)	0.11	927	99	48 (Dec)	0.71	0	-
23	0.11	0	-	49	1.00	61	72
24	0.16	216	36	50	0.19	0	-
25	0.39	560	74	51	0.54	200	83
26	0.46	863	47	52	0.59	0	-
				BY total		28,133	
				90% CI (low : high)		(9,234 : 47,032)	

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 (recruits per 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 2016.

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)
					Average	1,137	22.6	(13.6 : 31.9)
					Standard Deviation	569	11.4	(7.6 : 15.8)

[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 value based on total egg deposition using method 3 from USFWS December 2017 Memo (Appendix 1).

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 (recruits per 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)
					Average	1,032	20.1	(-1.1 : 41.9)
					Standard Deviation	1,159	24.4	(24.9 : 71.7)

[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 2016 fall Chinook into Battle Creek from March 22, 2017 through April 21, 2017.

Week	Release Date(s)	# Released	Mean FL of release group	Fall LAD range	Fall % captures	Spring LAD range	Spring % captures
12	3/22/2017	1,692,533	67.5	0 -69	0.0%	70- 94	14.0%
13	--	--	--	0 - 73	71.7%	72 - 99	26.0%
14	4/5/2017	6,948,690	75.0	36 - 77	44.9%	78 - 105	53.1%
15	4/12/2017	1,663,691	75.0	37 - 79	83.2%	80 - 107	16.8%
16	4/21/2017	1,841,170	71.3	38 - 84	97.1%	82 - 114	2.9%
17	--	--	--	39 - 88	99.3%	90 - 120	0.7%
Total		**12,146,084**			**74.2%**		**17.8%**

Figures

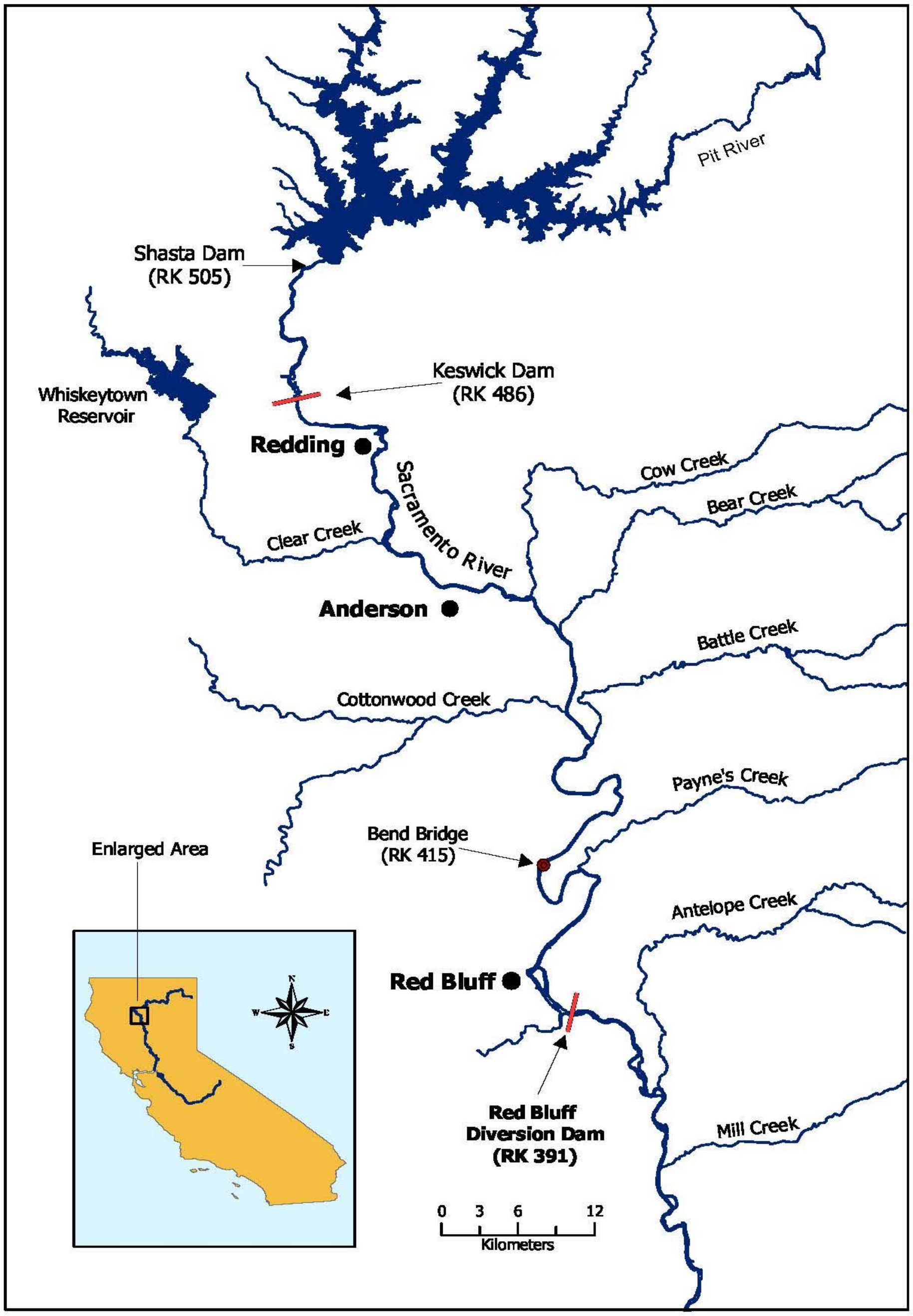

Figure 1. Location of Red Bluff Diversion Dam sample site on the Sacramento River, California, at river kilometer 391 (RKM 391)

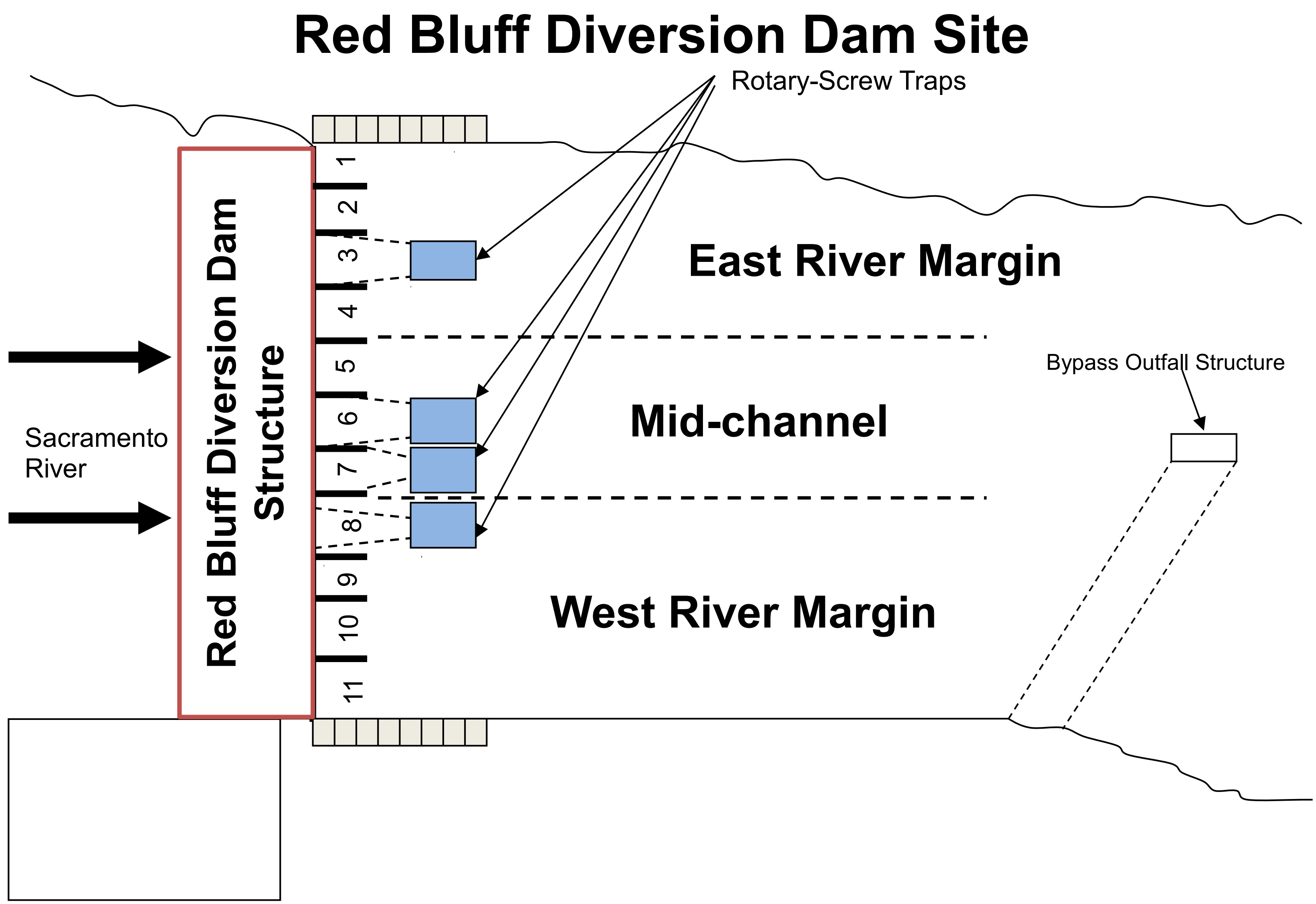

Figure 2. Rotary-screw trap sampling transect schematic of Red Bluff Diversion Dam site (RK 391) on the Sacramento River, CA.

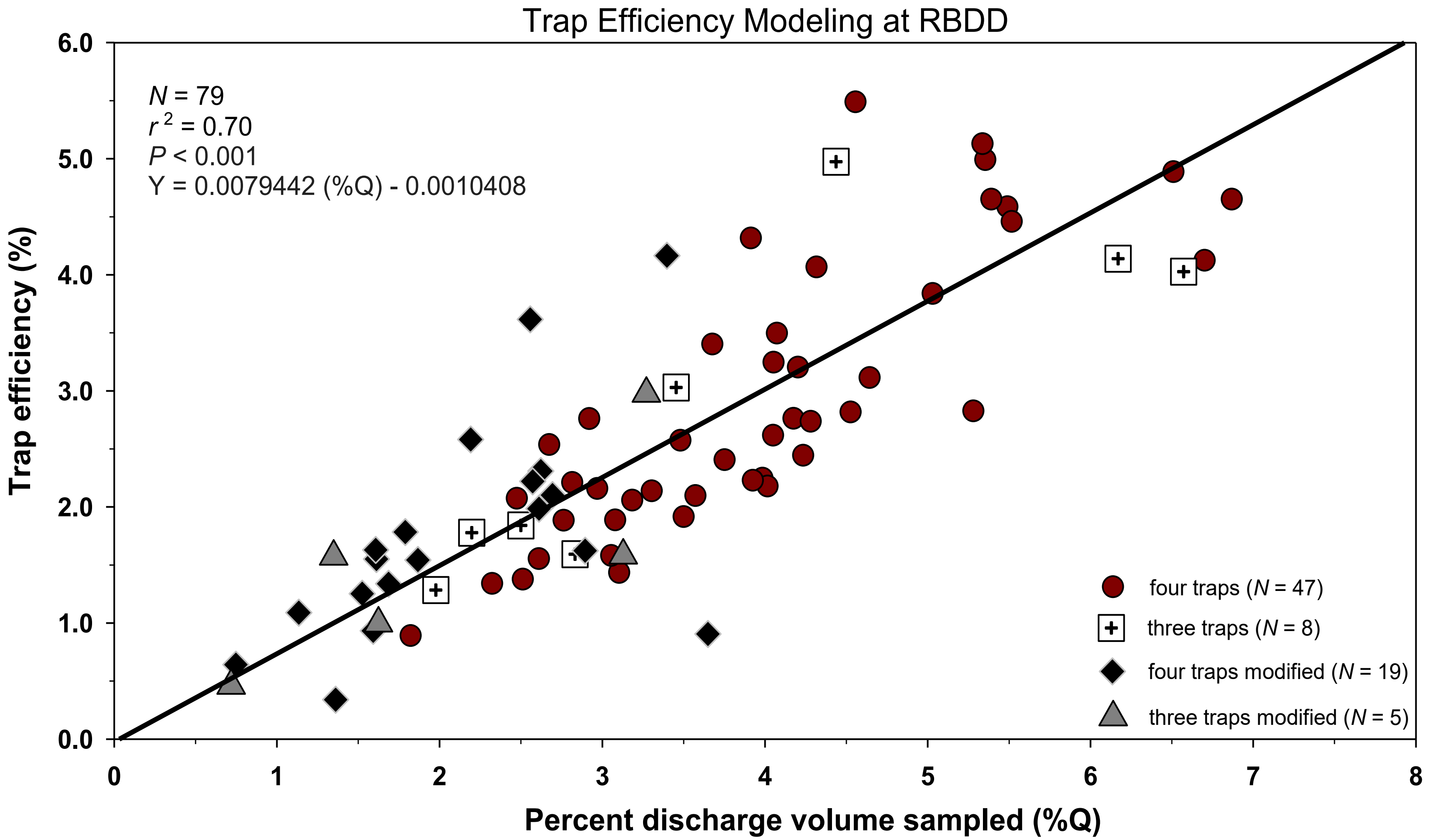

Figure 3. Trap efficiency model for combined 2.4 m diameter rotary screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four traps (N = 47), three traps (N = 8), or with traps modified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

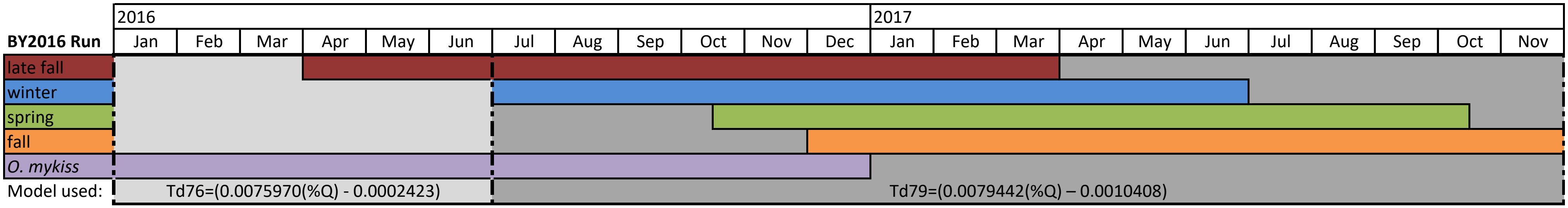

Figure 4.—Summary of trap efficiency models used for passage estimates during brood year 2016 for juvenile winter, spring, fall, late-fall Chinook salmon and *O. mykiss* from January 1, 2016, the start of the *O. mykiss* 2016 brood year through November 30, 2017, the end of the 2016 fall Chinook brood year.

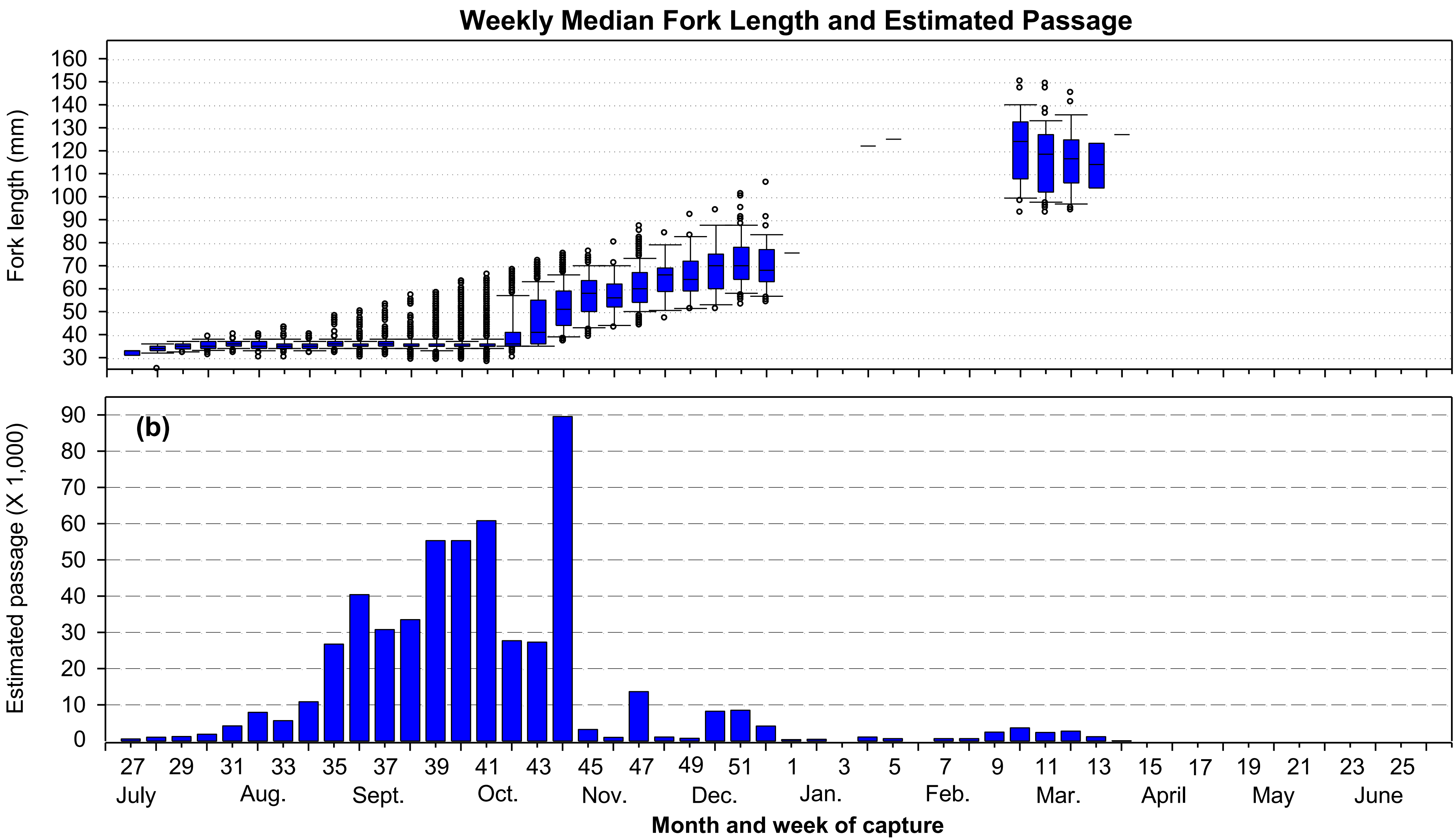

Figure 5. Weekly median fork length (a) and estimated passage (b) of brood year 2016 juvenile winter Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Winter Chinook salmon were sampled by rotary-screw traps for the period July 1, 2016 through June 30, 2017. Box plots display weekly median fork length, 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles and outliers.

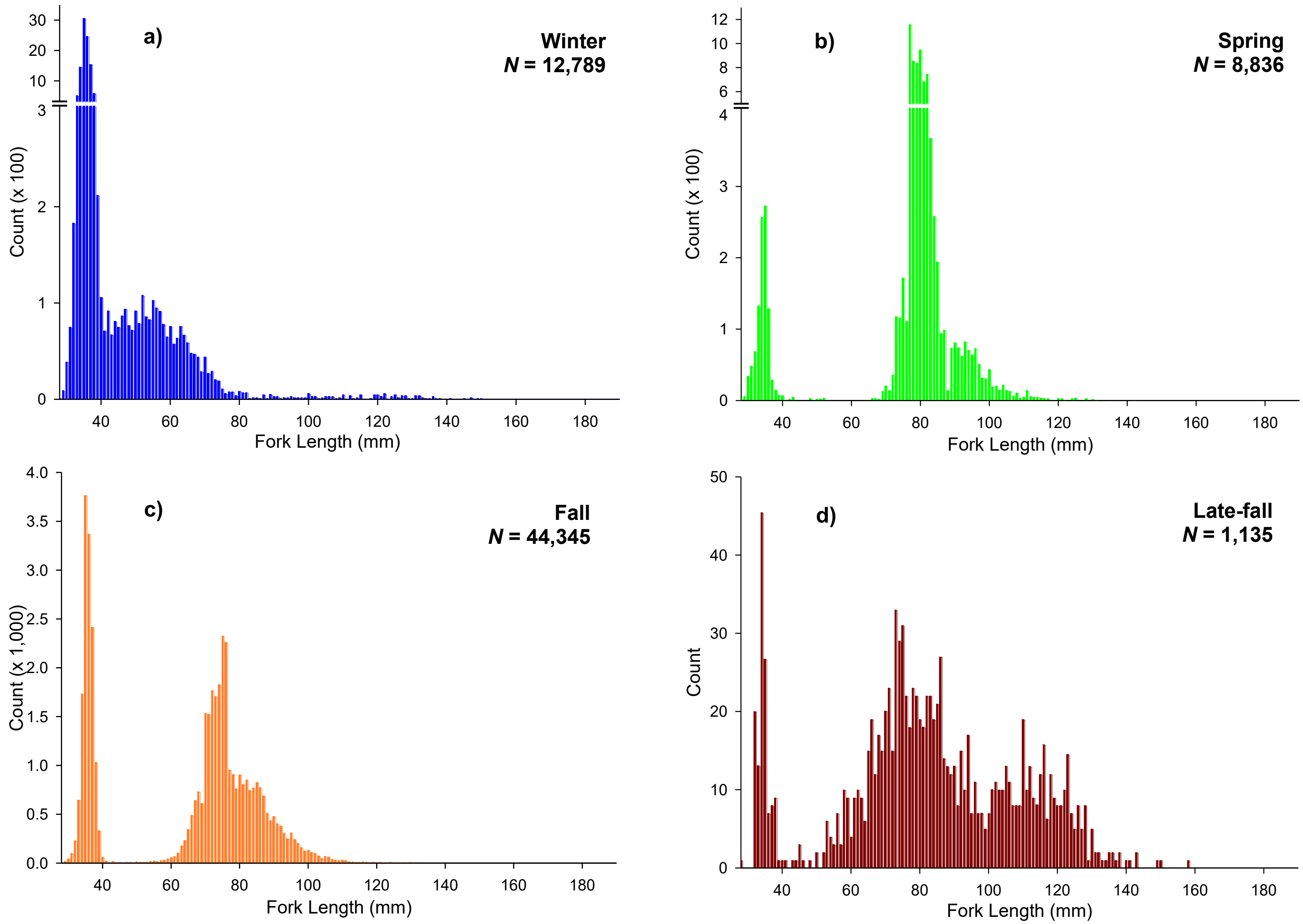

Figure 6. Fork length frequency distribution of brood year 2016 juvenile a) winter, b) spring, c) fall and d) late-fall Chinook salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fork length data were expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from April 1, 2016 through November 30, 2017.

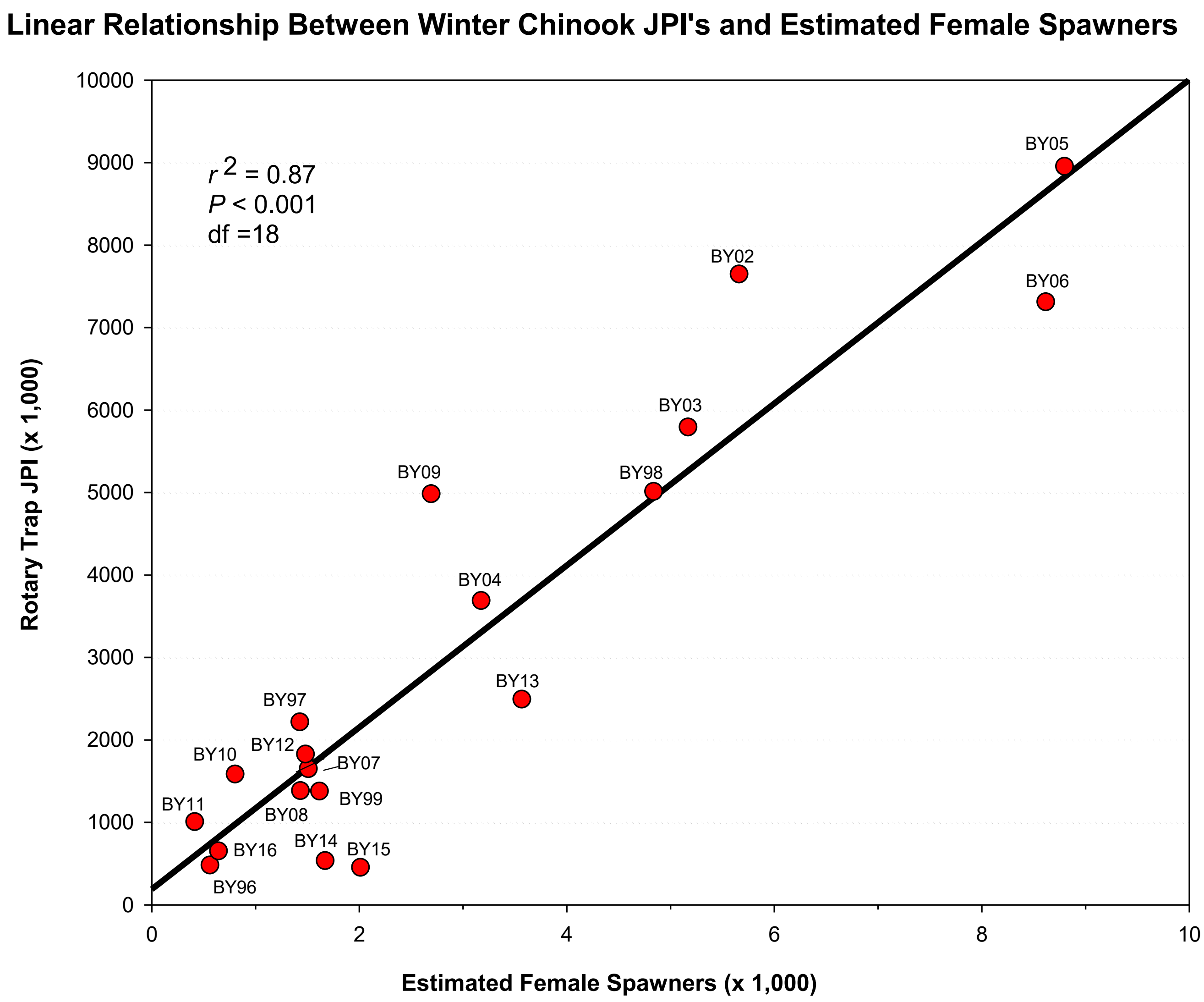

Figure 7. Linear relationship between rotary-screw trap juvenile winter Chinook fry-equivalent production indices (Rotary Trap JPI) and carcass survey derived estimated female spawners.

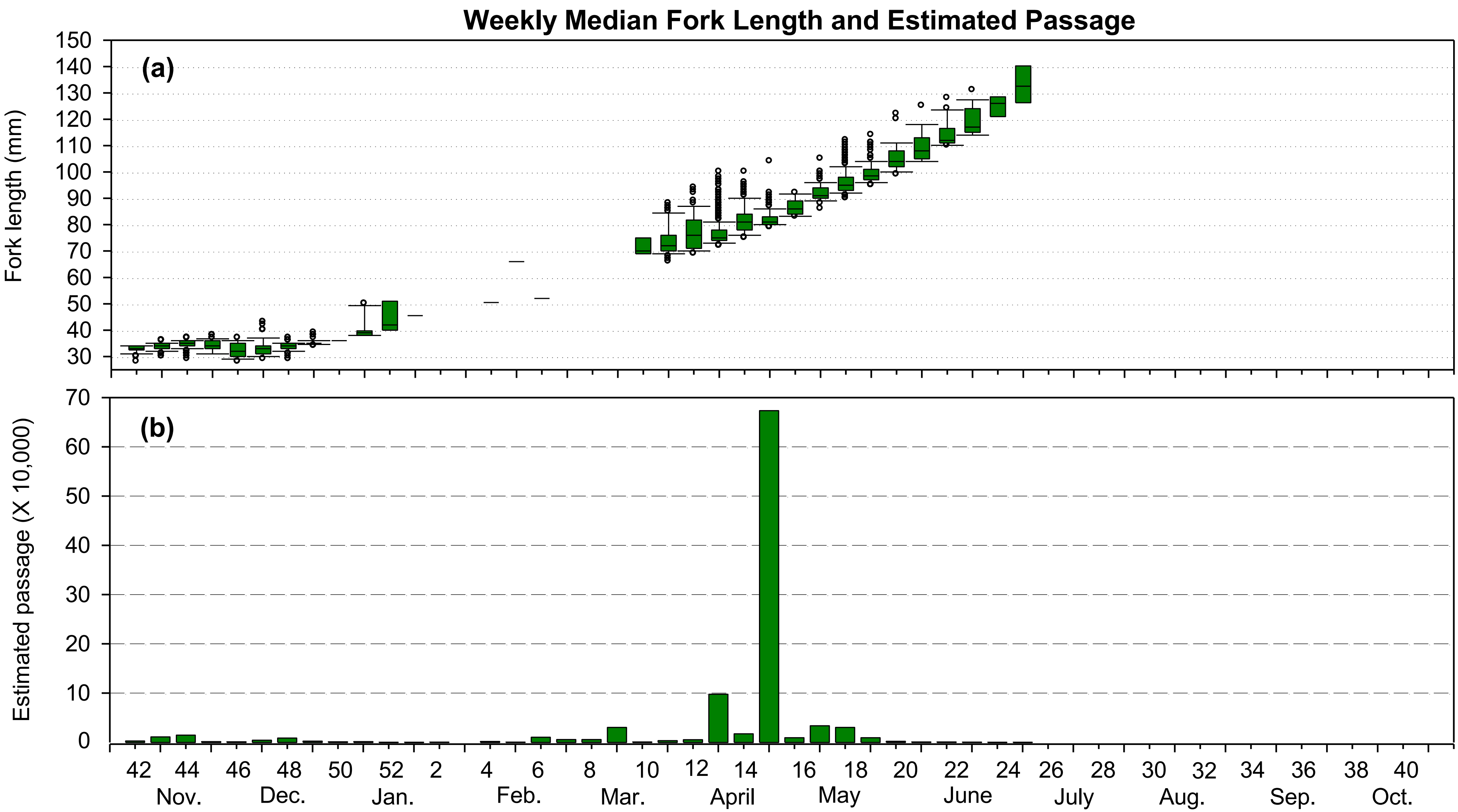

Figure 8. Weekly median fork length (a) and estimated passage (b) of brood year 2016 juvenile spring Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Spring Chinook salmon were sampled by rotary-screw traps for the period October 16, 2016 through October 15, 2017. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

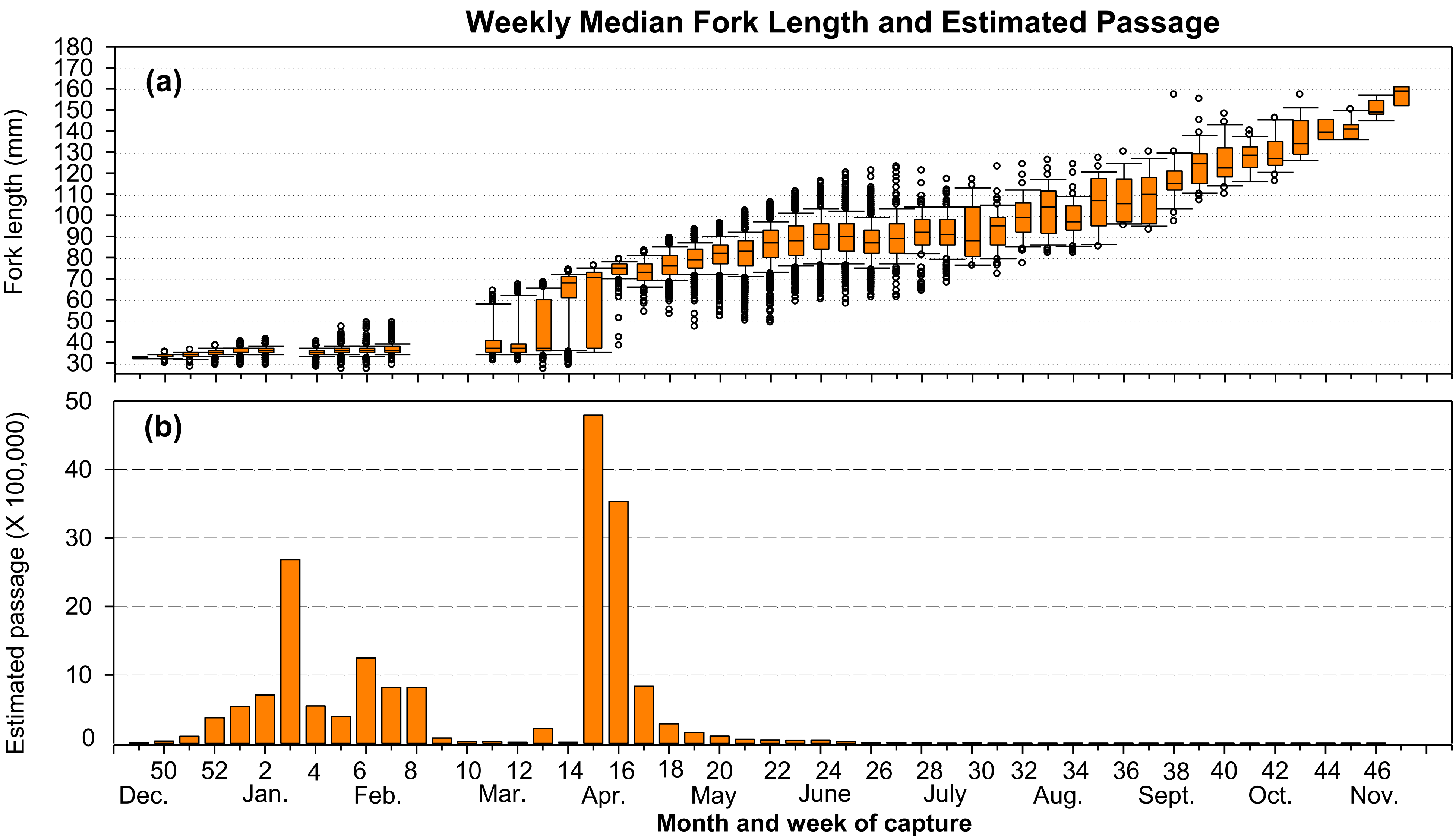

Figure 9. Weekly median fork length (a) and estimated passage (b) of brood year 2016 juvenile fall Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fall Chinook salmon were sampled by rotary-screw traps for the period December 1, 2016 through November 30, 2017. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

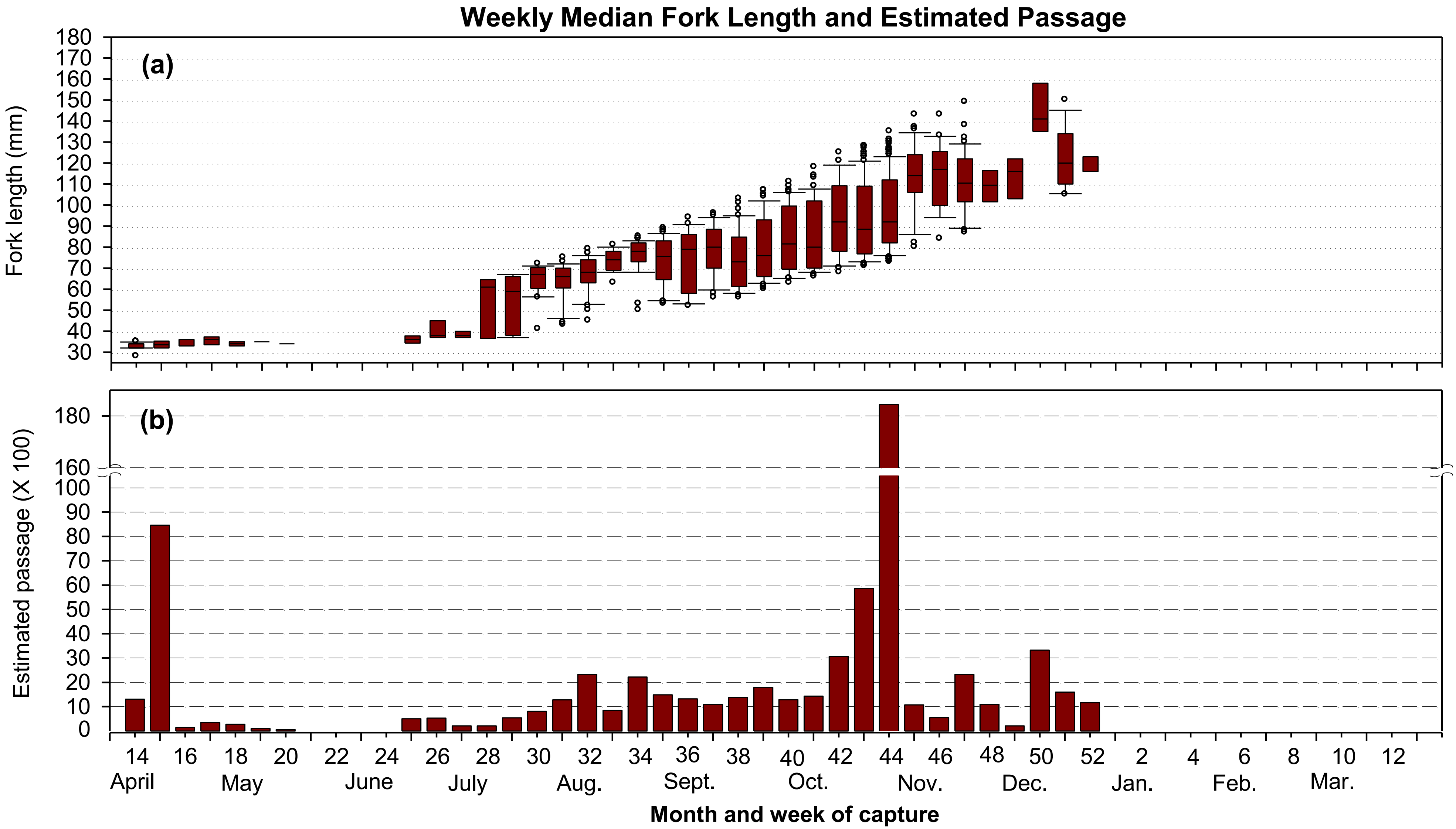

Figure 10. Weekly median fork length (a) and estimated passage (b) of brood year 2016 juvenile late-fall Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Late-fall Chinook salmon were sampled by rotary-screw traps for the period April 1, 2016 through March 31, 2017. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

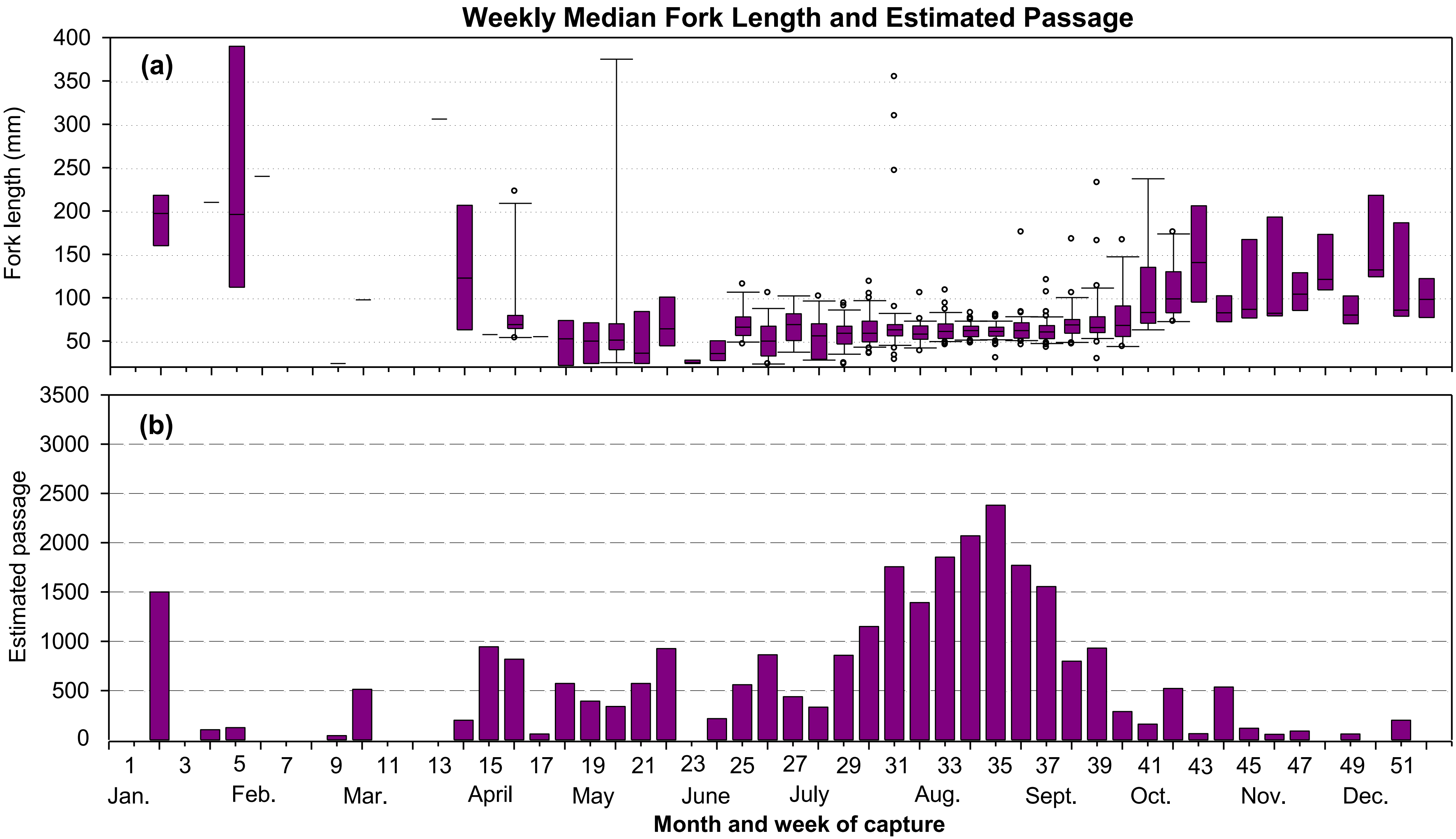

Figure 11. Weekly median fork length (a) and estimated passage (b) of brood year 2016 juvenile *O. mykiss* passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. *O. mykiss* were sampled by rotary-screw traps for the period January 1, 2016 through December 31, 2016. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

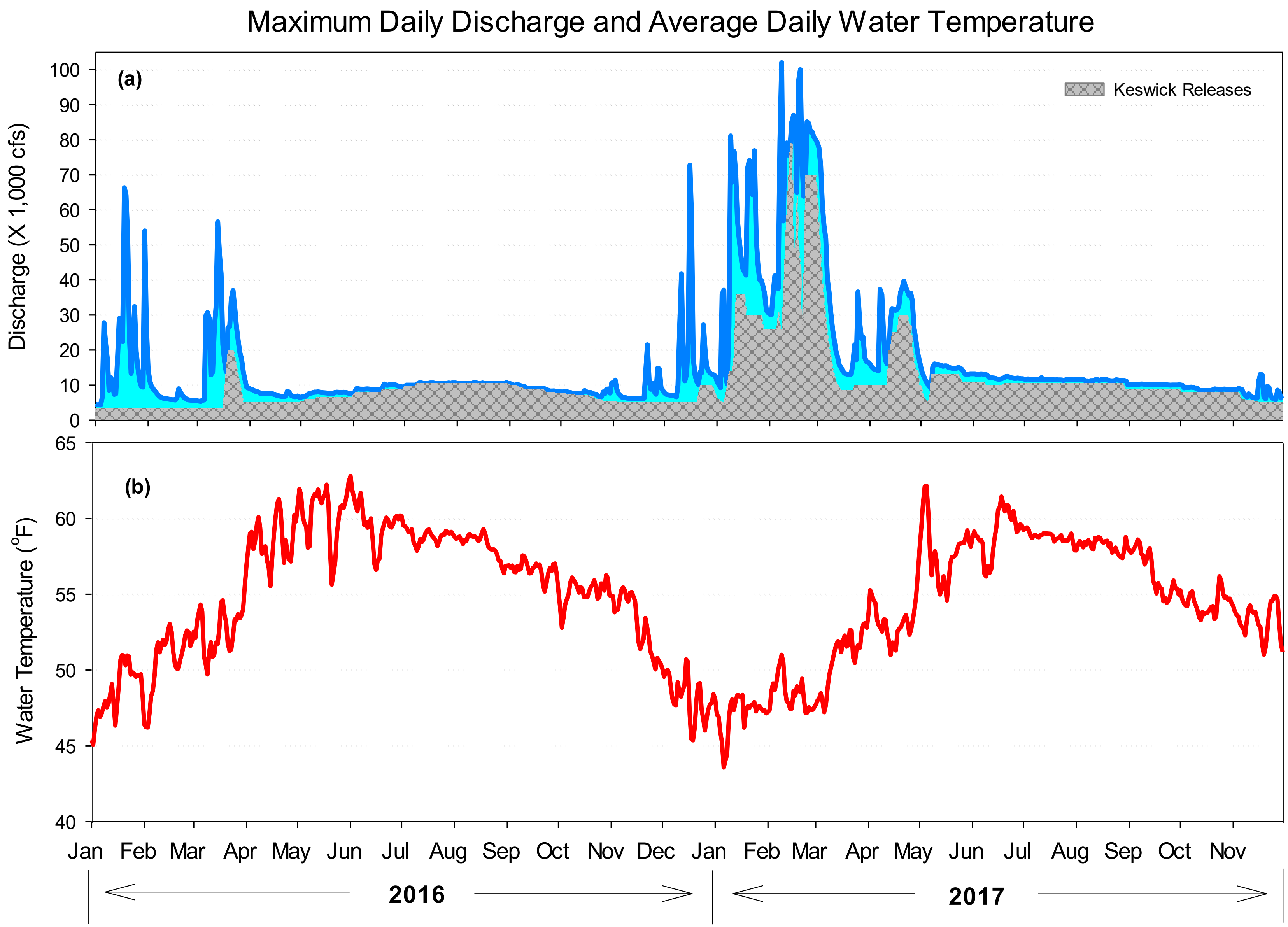

Figure 12. Maximum daily discharge (a) calculated from the California Data Exchange Center's Bend Bridge gauging station showing water releases from Keswick Reservoir (gray shaded area) and average daily water temperatures (b) from rotary-screw traps at RBDD for the period January 1, 2016 through November 30, 2017.

Appendix 1.

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.

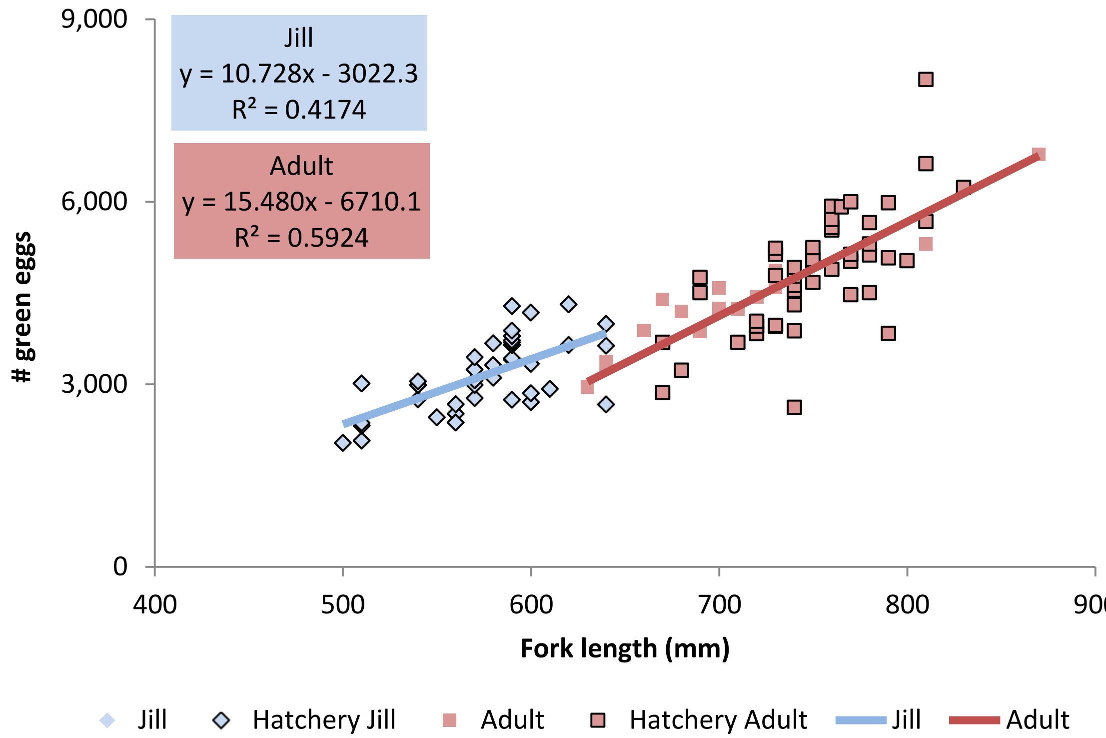

Figure 1. Fork length and fecundity relationship for Jill and adult winter Chinook Salmon spawned at Livingston Stone National Fish Hatchery in 2016 and 2017. Females were assigned to the jill or adult categories based on known age from recovered coded wire tags or assumed age based on fork length cut 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%