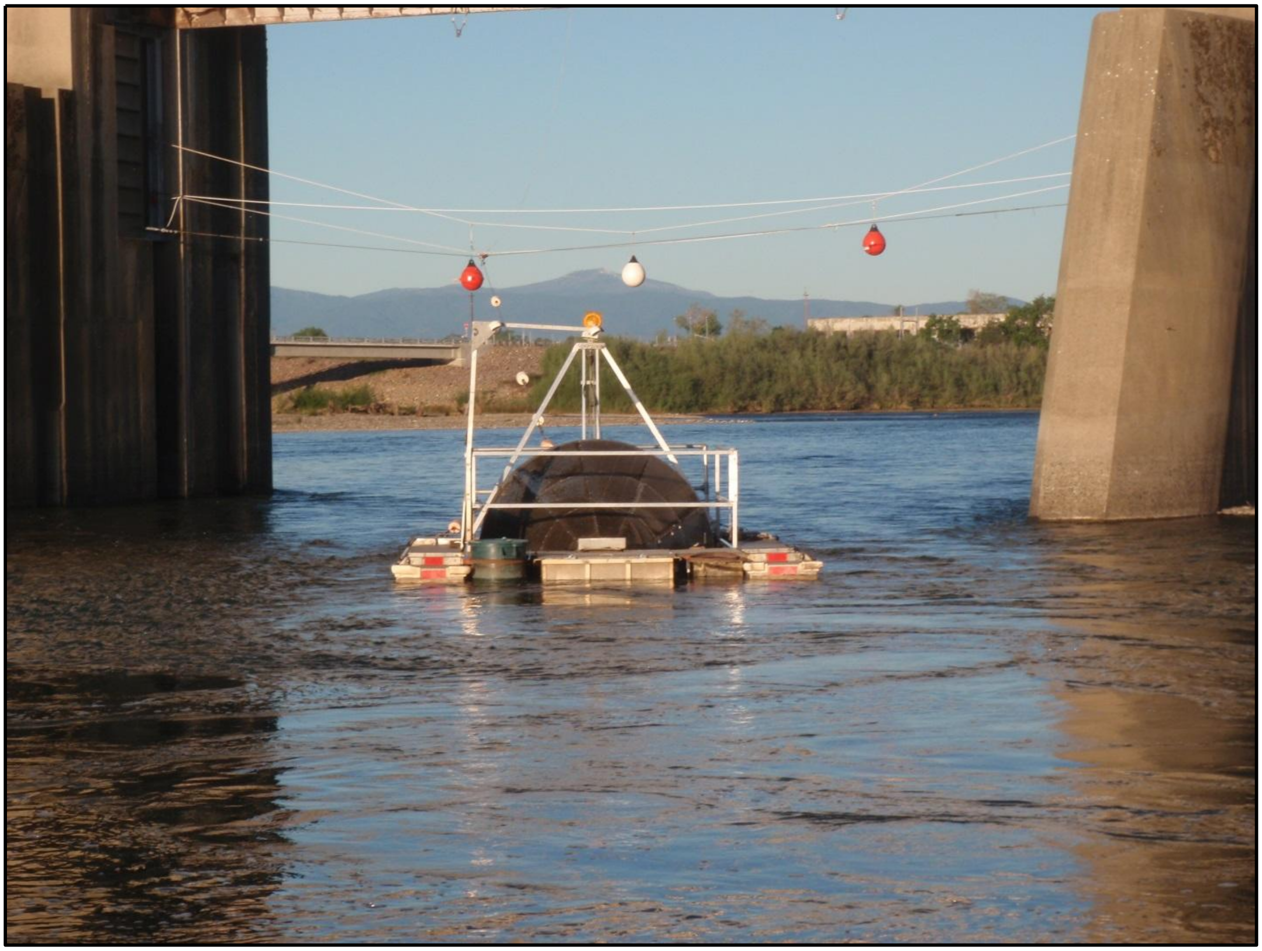
BROOD YEAR 2015 JUVENILE SALMONID PRODUCTION AND PASSAGE INDICES AT RED BLUFF DIVERSION DAM

Prepared for:
U.S. Bureau of Reclamation
2015 Annual RBDD Juvenile Fish Monitoring Report



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

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

October 2017

Disclaimer

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

The correct citation for this report is:

Voss, S. D. and W. R. Poytress. 2017. Brood year 2015 juvenile salmonid production and passage indices at the Red Bluff Diversion Dam. Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation, Sacramento, CA.

Brood year 2015 juvenile salmonid production and passage indices at Red Bluff Diversion Dam.

Scott D. Voss and William R. Poytress

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

Abstract.— Brood year 2015 juvenile winter Chinook Salmon estimated passage at Red Bluff Diversion Dam (RBDD) was 338,901 for fry and pre-smolt/smolts combined. The fry-equivalent rotary trap juvenile production index (JPI) was estimated at 440,951 with the lower and upper 90% confidence intervals (CI) extending from 288,911 to 592,992 juveniles, respectively. Brood year 2015 juvenile winter Chinook production represented the lowest estimate since 1996. The estimated egg-to-fry survival rate, based on the brood year 2015 winter Chinook fry-equivalent JPI was 4.5%. The range of egg-to-fry survival rates based on the 90% confidence intervals was 3.0% to 6.1%.

Brood year 2015 juvenile spring Chinook Salmon estimated passage was 1,682,077 fry and pre-smolt/smolts combined. The fry-equivalent JPI for 2015 spring Chinook was 2,806,514 with the lower and upper 90% CI extending from -442,595 to 6,055,623 juveniles, respectively. Brood year 2015 fall Chinook juvenile estimated passage at RBDD was 25,721,574 fry and pre-smolt/smolts combined. The fry-equivalent JPI for 2015 fall Chinook was 30,720,228 with the lower and upper 90% CI extending from -533,520 to 61,973,977 juveniles, respectively. In contrast to winter Chinook, fall Chinook egg-to-fry survival (32.1%) was the highest since estimates were calculated beginning in 2002. The disparity in egg-to-fry survival between winter and fall Chinook estimates for BY2015 is likely due to vastly different in-river conditions experienced by the two runs. Fall Chinook progeny experienced more favorable water temperatures (<58°F) that decreased through their spawning, egg incubation and fry emergence periods. Brood year 2015 late-fall Chinook juvenile estimated passage at RBDD was 67,831 fry and pre-smolt/smolts combined. The fry-equivalent JPI for 2015 late-fall was 112,631 with the lower and upper 90% CI extending from 72,046 to 153,216 juveniles, respectively. Egg-to-fry survival rates were not estimated for spring and late-fall Chinook due to inaccuracies with run designation and adult counts.

Prolonged drought conditions and management of the available cold-water resources within Shasta Lake had considerable impacts to juvenile salmonid survival during the reporting period. The 2015 winter Chinook egg-to-fry survival estimate of 4.5% was the lowest on record following the prior all time low value of 5.9% in 2014. Overall, passage estimates for 2015 winter Chinook, 2015 late-fall Chinook and 2015 *Oncorhynchus mykiss* were the lowest in the history of the 18-year monitoring program. Brood year 2015 fall Chinook production estimates were considerably higher in 2015 as compared to 2014; which was the lowest estimate on record for the RBDD Juvenile Fish Monitoring Program.

Table of Contents

Table of Contents Continued

List of Tables

Table **Page**

List of Tables continued

Table **Page**

List of Figures

Figure **Page**

List of Figures continued

Figure **Page**

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).

Since 2002, the USFWS RST winter Chinook juvenile production indices (JPI's) have primarily been used in support of production estimates generated from carcass survey derived adult escapement data using NMFS' Juvenile Production Estimate Model. 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 sample 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 purposes of measuring juvenile fish passage.

[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).

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) 2015, (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 fish monitoring activities at RBDD for the period January 1, 2015 through November 30, 2016. This report includes JPI's for the 2015 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 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

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

Sacramento River and Cow, Bear, Battle and Payne's creeks 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 (NMFS 2009) in an effort to reduce the impact to spring Chinook Salmon and Green Sturgeon. 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 only 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 unable to be sampled, mean daily passage estimates were imputed for missed days based on weekly or monthly interpolated mean daily estimates.

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 BY2015 relied primarily on 76 mark-recapture trials using wild fish and conducted with the RBDD gates raised between 2002 and 2015 (r^2 = 0.69, P < 0.001, df = 75; 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. $$\hat{T}_d = (a)(\%\hat{Q}_d) + b$$

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

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

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

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. $$Cov(\hat{T}_i,\hat{T}_j) = Var(\hat{\alpha}) + x_iCov(\hat{\alpha},\hat{\beta}) + x_jCov(\hat{\alpha},\hat{\beta}) + x_ix_jVar(\hat{\beta})$$

for some $\hat{T}_i = \hat{\alpha} + \hat{\beta}x_i$

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

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

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) assuming a 1:1 male to female ratio. Average female winter Chinook fecundity data were obtained from the Livingston Stone National Fish Hatchery and fall Chinook fecundity estimates were obtained from Coleman National Fish Hatchery (CNFH) annual spawning records.

Results

Sampling effort.—Weekly sampling effort throughout the BY2015 winter Chinook Salmon emigration period was moderate and ranged from 0.11 to 1.00 ($\bar{x}$ = 0.71; *N* = 52 weeks; Table 1). Weekly sampling effort ranged from 0.54 to 1.00 ($\bar{x}$ = 0.95; *N* = 26 weeks) between July and the end of December, the period of greatest juvenile winter Chinook emigration, and 0.11 to 1.00 ($\bar{x}$ = 0.47; *N* = 26 weeks) during the latter half of the emigration period (Table 1).

Weekly sampling effort throughout the BY2015 spring Chinook emigration period ranged from 0.11 to 1.00 ($\bar{x}$ = 0.70; *N* = 52 weeks; Table 2). Weekly sampling effort ranged from 0.32 to 1.00 ($\bar{x}$ = 0.74; *N* = 26 weeks) between mid-October and mid-April, the period of greatest juvenile spring Chinook emigration, and 0.11 to 1.00 ($\bar{x}$ = 0.66; *N* = 26 weeks) during the latter half of the emigration period (Table 2).

Weekly sampling effort throughout the BY2015 fall Chinook emigration period ranged from 0.11 to 1.00 ($\bar{x}$ = 0.69; *N* = 52 weeks; Table 3). Weekly sampling effort ranged from 0.14 to 1.00 ($\bar{x}$ = 0.60; *N* = 26 weeks) between December and the end of May, the first half of the juvenile fall Chinook 2015 brood year, and 0.11 to 1.00 ($\bar{x}$ = 0.78; *N* = 26 weeks) during the latter half of the emigration period (Table 3).

Weekly sampling effort throughout the BY2015 late-fall Chinook emigration period ranged from 0.11 to 1.00 ($\bar{x}$ = 0.82; *N* = 52 weeks; Table 4). Weekly sampling effort ranged from 0.54 to 1.00 ($\bar{x}$ = 0.90; *N* = 26 weeks) between April and the end of September, the first half of the juvenile late-fall Chinook 2015 brood year, and 0.11 to 1.00 ($\bar{x}$ = 0.74; *N* = 26 weeks) during the latter half of the emigration period (Table 4).

Weekly sampling effort throughout the BY2015 *O. mykiss* emigration period ranged from 0.21 to 1.00 ($\bar{x}$ = 0.82; *N* = 52 weeks; Table 5). Weekly sampling effort ranged from 0.21 to 1.00 ($\bar{x}$ = 0.70; *N* = 26 weeks) between January and the end of June, the first half of the juvenile *O. mykiss* 2015 brood year, and 0.54 to 1.00 ($\bar{x}$ = 0.95; *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) low staffing levels preventing 7 day per week sampling and (4) Section 10(a)(1)(A) permit catch limitations.

Mark-recapture trials.—Three mark-recapture trials were conducted using naturally produced fall Chinook between February 3, 2016 and February 15, 2016 to estimate and validate RST efficiency (Table 6). Sacramento River discharge sampled during the trials ranged from 6,078 to 8,394 cubic feet per second (cfs). Estimated *%Q* during trap efficiency trials ranged from 4.32% to 5.78% ($\bar{x}$ = 5.20%; Table 6).

Trials (*N* =3) were conducted using four traps with rotary traps sampling with unmodified cones. All trials were conducted using Chinook sampled from rotary traps, and trap efficiencies ranged from 4.06% to 6.32% ($\bar{x}$ = 4.99%). The number of marked fish released per trial ranged from 1,155 to 1,442 ($\bar{x}$ = 1,301) and the number of marked fish recaptured ranged from 53 to 73 ($\bar{x}$ = 64). All fish were released after sunset and 99.5% of recaptures occurred within the first 24 hours, and 100% within 48 hrs.

Sub-sampled fork lengths of fish marked and released ranged from 32 to 45 mm ($\bar{x}$ = 35.9 mm). Fork lengths of recaptured marked fish ranged from 31 to 42 mm ($\bar{x}$ = 35.7 mm). The distribution of fork lengths of fish marked and released in mark-recapture trials was commensurate with the distribution of fork lengths of fish recaptured by RSTs and fish were considered fry size class.

The horizontal distribution of recaptured marked fish differed slightly compared to the distribution of unmarked fish for all three trials. All three trials resulted in similar distribution proportions among the mid-channel traps compared to the unmarked fish. Trials two and three showed slightly higher proportions of marked fish in the east margin compared to unmarked fish.

Trap efficiency modeling.—One mark-recapture trial conducted during BY2014 (Poytress 2016) was added into the existing 75-trial linear regression based trap-efficiency model. The result was a 76-trial model (r^2 = 0.69, P < 0.001, df = 75; Figure 3) employed for passage estimation during the entire BY2015 winter Chinook period of July 1, 2015 through June 30, 2016. The former 75-trial model was employed for a fraction of the BY2015 late-fall Chinook and *O. mykiss* outmigration period (i.e., until July 1, 2015). BY2015 fall and spring Chinook passage was estimated using the 76-trial model until July 1, 2016 whereby the three additional trials conducted during 2016 were added to produce a 79-trial model (r^2 = 0.70, P < 0.001, df = 78). The 79-trial model was used for passage estimates covering portions of BY2015 fall and spring Chinook beyond June 30, 2016 extending until November 30, 2016 (Figure 4).

Winter Chinook fork length evaluations.— BY2015 Winter Chinook fork lengths ranged between 29 and 174 mm (Figure 5a). Winter Chinook were weighted (64.9%) to the fry size-class category (<46mm) with 94.9% of those measuring less than 40 mm (Figure 6a). The remaining 35.1% were attributed to the pre-smolt/smolt category (>45 mm) with 94.9% of the fish sampled between 46 and 85 mm.

Winter Chinook passage.—BY2015 winter Chinook juvenile estimated passage at RBDD was 338,901 fry and pre-smolt/smolts combined (Table 1). Fry-sized juveniles (<46 mm FL) comprised 57.0% 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 43.0% of total passage and the first observed emigration past RBDD occurred in mid-September (week 37; Table 1). Weekly pre-smolt/smolt passage for the brood year concluded in late April (week 17; Figure 5b).

Winter Chinook JPI to adult comparisons.—The BY2015 winter Chinook fry-equivalent JPI was 440,951 with the lower and upper 90% CI extending from 288,911 to 592,992 juveniles, respectively (Table 7). Adult females contributing to in-river spawning of BY2015 winter Chinook were estimated to have been 2,022 individuals (D. Killam, CDFW, pers. comm.). The estimated ETF survival rate based on the BY2015 winter Chinook fry-equivalent JPI and estimated number of female spawners and egg deposition in-river was 4.5%. The range of ETF survival based on 90% CI's was 3.0% to 6.1% (Table 7).

Adult female spawner estimates derived from winter Chinook carcass surveys and rotary-screw trap data from brood years 1996-2015 were used to evaluate the linear relationship between the estimates. Eighteen 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 = 0.86, P < 0.001, df = 17; Figure 7).

Spring Chinook fork length evaluations.— BY2015 spring Chinook fork lengths ranged between 29 and 121mm (Figure 6b). Spring Chinook were heavily weighted to the pre-smolt/smolt size-class category (>45mm). Only 12.8% of all fish sampled as spring were designated fry with 94.9% measuring less than 40 mm FL (Figure 8a). The bulk of the catch (87.2%) was attributed to the pre-smolt/smolt category (>45 mm) with fish between 70 and 95 mm comprising 95.1% of this size group.

Spring Chinook passage.—BY2015 spring Chinook juvenile estimated passage at RBDD was 1,682,077 fry and pre-smolt/smolts combined (Table 2). Spring Chinook exhibited the widest confidence intervals (± 114.5%) surrounding the total passage estimate. Fry sized juveniles (<46 mm FL) comprised only 4.5% 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 95.5% of total passage and the first observed emigration past RBDD occurred in mid-December (week 50; Table 2). Weekly pre-smolt/smolt passage for the brood year ended in early June (week 22; Figure 8b). The fry-equivalent rotary trap JPI for BY2015 was 2,806,514 with the lower and upper 90% CI extending from -442,595 to 6,055,623 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.—BY2015 fall Chinook fork lengths ranged between 26 and 200 mm (Figure 6c). BY2015 fall Chinook were composed of 66.7% in the fry size-class category (<46 mm) with 97.8% of those fry measuring less than 40 mm FL (Figure 9a). The remaining 33.3% were attributed to the pre-smolt/smolt category (>45 mm) with fish between 65 and 85 mm comprising 77.1% of the size group.

Fall Chinook passage.—BY2015 fall Chinook juvenile estimated passage at RBDD was 25,721,574 fry and pre-smolt/smolts combined (Table 3). The 2015 fall brood year total passage estimate had relatively wide 90% confidence intervals (±101.2%). Fry sized juveniles (<46 mm FL) comprised 72.2% of total estimated fall Chinook passage (Table 3). Fry passage occurred from December through the middle of April (weeks 48 thru 16; Figure 9b). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 27.8% of total passage. The first observed pre-smolt/smolt passage occurred in late January (week 4; Table 3). Weekly pre-smolt/smolt passage for the brood year ended during early November (week 44; Table 3).

Fall Chinook JPI to adult comparisons.—The fry-equivalent rotary trap JPI for BY2015 was 30,720,228 with the lower and upper 90% CI extending from -533,520 to 61,973,977 juveniles, respectively (Table 3). The total number of adult BY2015 fall Chinook females contributing to in-river spawning upstream of RBDD was estimated to be 65,435 individuals. The estimated ETF survival rate based on the BY2015 fall Chinook fry-equivalent JPI and estimated number of female spawners and eggs deposited in-river was 32.1%. The range of ETF survival based on 90% CI's was -0.6% to 64.7% (Table 8).

Late-Fall Chinook fork length evaluations.—BY2015 late-fall Chinook were sampled between 26 and 183 mm (Figure 6d). BY2015 late-fall Chinook sampled were heavily weighted to the pre-smolt/smolt size-class category (>45mm). Only 6.6% of all fish sampled as late-fall were designated fry (<46 mm) with 86.4% of the fry measuring less than 40 mm FL (Figure 10a). The remaining 93.4% of juveniles were attributed to the pre-smolt/smolt category with fish between 90 and 160 mm comprising 74.6% of that value.

*Late-fall Chinook passage***.**—BY2015 late-fall Chinook juvenile estimated passage at RBDD was 67,831 fry and pre-smolt/smolts combined (Table 4). Fry sized juveniles (<46 mm FL) comprised only 5.6% of total estimated late-fall Chinook passage (Table 4). Fry passage occurred from April through the middle of July (weeks 14 thru 29; Figure 10b). Pre-smolt/smolt sized juveniles (>45 mm FL) comprised 94.4% 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 early February (week 5; Figure 10b). The fry-equivalent rotary trap JPI for brood year 2015 was 112,631 with the lower and upper 90% CI extending from 72,046 to 153,216 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.—BY2015 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 2015 (Table 5). *O. mykiss* fry (<41mm) captures were highly variable as the first fry of the year was captured in mid-March with a fork length of 35 mm while the smallest fry at a fork length of 20 mm was captured eight weeks later (early May; Figure 11a). Fry captures continued through week 29 (mid-July). Sub-yearling and yearling captures peaked during mid-April (week 16) and continued in a sporadic fashion through the end of the calendar year.

O. mykiss passage.—BY2015 *O. mykiss* juvenile total estimated passage at RBDD was 16,511 fry, sub-yearling and yearlings combined (Table 5). Fry sized juveniles (<41mm) comprised only 4.6% of total *O. mykiss* passage. Fry passage occurred from April through the middle of July (weeks 14 thru 29; Figure 11b). Sub-yearling/yearling sized juveniles (≥41 mm) comprised 95.4% of total passage and the first observed emigration past RBDD occurred in week 2 (January; Table 5). Weekly sub-yearling/yearling passage for the brood year ended during week 52 (end of December).

Discussion

*Sampling effort***.** —Stable river flows resulted in reliable sampling effort for the reporting period of January 1, 2015 through November 30, 2016 ($\bar{x}$ = 0.75). Mean sampling effort for BY2015 winter, spring, fall, late-fall Chinook and *O. mykiss* was 0.71, 0.70, 0.69, 0.82 and 0.82 respectively (Tables 1-5). During the primary juvenile winter Chinook Salmon capture and passage period of July through December of 2015, mean sampling effort was high (0.95) whereas the latter half of the brood year was lower and more variable, averaging only 0.47.

Decreased sampling effort was a product of winter storm activity resulting in high flows and debris loads from January through March 2016, as well as reduced effort surrounding hatchery fish releases. Additional reductions in sampling effort were out of concern for exceeding permitted take limits (NMFS ESA Section 10, research permit No. 1415-3A) of larval threatened Green Sturgeon, *Acipenser medirostris* in the RSTs. From mid-May through the last week of June in 2016, sampling effort was greatly reduced to decrease the number of incidentally captured sturgeon larvae encountered in the RSTs. As per our Section 10 permit, we were limited to a total yearly take of 3,000 Green Sturgeon. By May 19, 2016, we had already captured over 2,000 larval sturgeon while experiencing the highest catch index of larval sturgeon encountered in the RST program's history. Consultations to increase our permitted take level were underway while efforts were made to decrease catch by either sampling with modified cones and/or sampling only three RSTs across the transect or abstaining from sampling for a number of days each week.

Although reduced effort from late May to early June overlapped with BY2015 spring and fall Chinook, it had little effect on annual passage estimates for these runs as catch was comprised of consistent or decreasing numbers of smolt-sized individuals during relatively stable flow conditions. However, 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 increased in August and peaked in September (Table 1; Figure 5b). Catch and passage declined as fry grew into the pre-smolt/smolt life stage and passage was variable until mid-December when the first significant storm event of the winter season resulted in elevated Sacramento River flows reaching 10,000 cfs maximum daily discharge (Figure 12). This event nearly doubled in-river flow and resulted in over ten times greater turbidity values as compared with river conditions two days prior (i.e., from 2.6 to 27.9 NTU). Coinciding with the week 50 runoff event, a substantial pulse of winter Chinook pre-smolt/smolts were detected (Table 1; Figure 5b). The week 50 pulse accounted for 28.1% of all pre-smolt/smolts collected during the brood year.

Winter Chinook fry outmigrants represented 57.0% of total winter Chinook passage with pre-smolt/smolts (>45 mm FL) representing the remaining 43.0%. By the middle of January 2016, 95.0% of the total annual passage estimate for BY2015 winter Chinook was collected (Table 1). Overall, interpolation for missed days of sampling accounted for a mere 4.3% of the total BY2015 estimate of 338,901 winter Chinook passing the RBDD. The BY2015 winter Chinook total passage estimate was slightly lower than BY1996 (Martin et al 2001) and the lowest on record since the RBDD Juvenile Fish Monitoring Program began in 1995.

Capture of BY2015 juvenile spring Chinook began on October 16, 2015 according to LAD criteria. Sampling effort remained relatively high through the end of December ($\bar{x}$ = 0.91, Table 2) resulting in a pronounced peak of fry passage occurring in mid-December and coinciding with the December runoff event (week 50; Table 2). Sampling effort during the remainder of the brood year was lower and more variable ($\bar{x}$ = 0.64; Table 2) for a number of reasons. Storm activity, personnel constraints, and hatchery releases accounted for most of the reduction in effort during periods of spring Chinook passage. Interpolation for missed days of sampling accounted for 35% of the total BY2015 estimate of 1,682,077 spring Chinook passing the RBDD.

Spring Chinook fry outmigrants represented 4.5% of total passage with pre-smolt/smolts (>45 mm FL) representing the remaining 95.5%. 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 previous years (Poytress et al. 2014). However, unlike previous years' releases, BY2015 CNFH fall Chinook production releases into Battle Creek (Figure 1) began in mid-March of 2016 and continued through the end of April (weeks 11 thru 18; Table 9). This temporal shift to earlier releases resulted in more overlap with LAD spring Chinook than in prior years[5], accounting for an average of 22.9% of marked fish falling into the spring size category during the release period (Table 9). Many of the releases occurred coincident with elevated Battle Creek flows in an effort to increase the downstream movement and subsequent survival of production fish. 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 May (weeks 11-18; 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 5.4% (90,838) of the brood year total. Passage data collected by the start of May, following the CNFH production releases, accounted for 99.2% of the total BY2015 spring Chinook annual estimate (Table 2).

Fall Chinook fry passage accounted for 72.2% of the total passage for the brood year and began the first week of December (Table 3). Passage increased by two orders of magnitude by week 50, influenced heavily by runoff events (Figure 9b & 12). Fry passage continued to peak around the next several storm events occurring in January (Table 3; Figure 12). Fall Chinook in the pre-smolt/smolt size category, which comprised 27.8% of total brood year passage, began during the last week in January. Spikes in pre-smolt/smolt passage occurred in mid-March and mid-April (Table 3) coinciding with the timing of CNFH fall Chinook production releases and runoff events (Table 9 & Figure 9b) resulting in positive bias of unmarked fall Chinook estimates.

Although there was likely a significant amount of positive bias in fall/spring passage estimates following CNFH fall Chinook production releases due to capture of unmarked hatchery Chinook, there was likely also elevated numbers of naturally produced smolts emigrating during periods of increased river flow. Aside from the influence of increased river flows on migration behavior, Hansen and Jonsson (1985) and Hillman and Mullan (1989) suggested that hatchery release groups can influence emigration of naturally-produced salmonids through shoaling effect under certain conditions.

---

[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.

[5] "Between 2007 and 2012, on average, 4.3% of the marked fall production fish fell within the spring-run size-class using LAD criteria." (Poytress et al. 2014)

Late-fall Chinook fry passage began the first week of April and continued through mid-July. Pre-smolt/smolts began to appear in a sporadic fashion from late May through mid-September when passage steadily increased, peaking in December (Table 4; Figure 10b). Fry passage accounted for 5.6% of the brood year total, resulting in the lowest fry to pre-smolt/smolt ratio on record. Total late-fall Chinook passage of 67,831 during BY2015 was the lowest on record for the RBDD Juvenile Fish Monitoring Program.

O. mykiss passage began the last week in January (Table 5) with the first fry passing in mid-March. Passage peaked in mid-April and remained variable throughout the rest of the calendar year. Total passage for the brood year was 16,511 representing the lowest passage estimate of *O. mykiss* on record for the RBDD Juvenile Fish Monitoring Program.

Winter Chinook JPI and ETF survival estimate.—Physical and biological factors contribute directly and indirectly to Chinook Salmon ETF survival estimates calculated by the RBDD Juvenile Fish Monitoring Project. These factors are diverse, oftentimes difficult to measure or quantify, and can occur over discrete or prolonged temporal scales. These factors can arise during the adult upstream migration and spawning period, through egg incubation and fry emergence, as well as the juvenile rearing period. Management of Sacramento River flows and water temperatures can greatly affect spawning efficiency (Wales and Coots 1955) and the total number of juvenile Chinook produced below Keswick Dam.

Below average precipitation in California during 2015 resulted in a fourth consecutive year of drought conditions (CDFW undated). The effect of multiple, consecutive years of below average precipitation limited the cold-water pool within Shasta Lake. By the end of March 2015, USBR began consultation with NMFS regarding a Drought Contingency Plan for augmented CVP-Shasta operations (USBR letter March 24, 2015) as required under the NMFS 2009 Coordinated Long-term Operation of the Central Valley Project and State Water Project Biological Opinion (NMFS 2009). At that time, USBR recognized CVP-Shasta operations could not maintain Sacramento River water temperatures of 56°F throughout the winter Chinook Salmon spawning, egg incubation and fry development stage as described in NMFS (2009). The Drought Contingency Plan for Water Year 2015 included a river temperature target of 57° F daily average, not to exceed 58° F, upstream from the mouth of Clear Creek below the Bonnyview Bridge (CDEC ID: CCR). This value exceeded the maximum daily average temperature allowed under NMFS (2009) by 1-2° and would require moving the water temperature compliance point upstream forty-eight miles[6].

The BY2015 winter Chinook fry-equivalent JPI value of 440,951 was the lowest production estimate in 18 years of monitoring at RBDD. Although the timing and size class of fish sampled during the brood year were comparable to previous years, the juvenile production estimate was far lower than expected based on adult returns and estimates of in-river female spawners.

[6] NMFS (2009) describes the water temperature compliance point as RBDD (RK 391), but acknowledges that since the State Water Resources Control Board issued order # 90-5 the compliance point has been modified upstream when the objective cannot be met. The typical, modified compliance point during normal operations has been Balls Ferry Bridge (RM 276). The compliance point in 2015 was moved upstream ~14 river miles to CCR as compared to typical operations.

For BY2015, winter Chinook fry-equivalent based ETF survival rate was estimated at a record low 4.5% (Table 7). The 18-year average ETF survival rate is 23.6% with a standard deviation of 11.2. Although RST JPI's have been well correlated over many years to adult female spawner estimates, the line of best fit visually demonstrates how the actual observations of juvenile winter Chinook production during the most recent years of drought conditions (i.e., BY2013 - BY2015) were less than would be predicted (Figure 7).

Water temperatures affect Chinook spawning success indirectly (e.g., reduced pathogen resistance; see Schreck 1996 and Karvonen et al. 2010) and egg survival directly (USFWS 1999) and indirectly (Martin et al. 2016). In 2015, sub-optimal high water temperatures during upstream adult migration and prior to spawning led to increased pathogen prevalence in winter Chinook adult broodstock held at Livingston Stone National Fish Hatchery. This increased prevalence was determined to have contributed to much higher pre-spawn mortality rates than previous years (Voss and True 2015).

Pathogen monitoring of naturally produced BY2015 winter Chinook juveniles was also studied via histological analyses (Foott 2016) and genomic pathogen profiles (Hasenbein et al. 2016) from samples collected (*N*=80) at RBDD. Foott (2016) determined prevalence of infection for the parasites *Ceratonova shasta* and *Parvocapsula minibicornis* were 15% and 81%, respectively. Additionally, Foott (2016) exposed CNFH late-fall Chinook sentinel fish to the Sacramento River for 5 days in late-September; histological analyses indicated a highly infective zone of the Sacramento River from Balls Ferry downstream to RBDD. RST collected winter Chinook samples analyzed by Hasenbein et al. (2016) indicated the presence of eight different pathogens, yet no viral infections were detected. Foott (2016) concluded that the results do not support a significant role for parasitic infection in the low ETF survival estimates but stated that disease could impair survival of out-migrant winter Chinook fry. Fish sampled at RBDD only account for the progeny that survived to pass through the RST transect and do not account for those individuals that succumbed to mortality prior to reaching RBDD.

Research by Martin et al. (2016) focused on mechanisms by which oxygen-limitation affects thermal tolerance in aquatic eggs. Martin et al. (2016) found strong support for the interaction between oxygen limitation and survival of embryos when coupled with water temperature, flow velocity, and egg size. Lab-derived modeling results between temperature and egg survival grossly under represented field-based monitoring observations of fish survival at RBDD in all years (including 2015) due to discrepancies between water flow velocities in the lab versus the field. Critics have argued that the RBDD juvenile winter Chinook abundance and ETF survival field-based estimates in recent years were erroneous and well below simple temperature-based egg survival models (Vogel 2016). It appears that flow velocities have significant interactions with egg survival not explained using earlier temperature-based models such as those produced by USBR (1992), Zeug et al. (2012), or Bedore et al. (2015). These simplistic temperature-based models were unsuccessful in explaining the low values of abundance and ETF survival estimates for winter Chinook found at RBDD in 2015 (Table 7). In light of the work by Martin et al. (2016), it appears flow management of the Sacramento River via CVP-Shasta operations will likely need greater focus commensurate with the extensive annual temperature management plans.

Differential impacts to salmonids between 2015 and 2014 water management plans.—The BY2015 fall Chinook fry-equivalent JPI value of 30,728,228 represented a seven-fold increase as compared to BY2014; which was the lowest estimate on record for the RBDD Juvenile Fish Monitoring Program. For BY2015, fall Chinook fry-equivalent based ETF survival was estimated to be 32.1% (Table 8). In contrast to the winter Chinook fry-equivalent estimate, fall Chinook ETF survival was the highest since estimates were calculated beginning in 2002 and nearly 14 times greater than BY2014 (Table 8). The disparity in ETF survival estimates between winter and fall Chinook in BY2015 is likely due to vastly different in-river conditions experienced by the two runs. Fall Chinook experienced more favorable water temperatures that decreased through their spawning, egg incubation and fry emergence periods (Figure 12). Water temperatures remained <57°F throughout the fall Chinook spawning and rearing period (CDFW memo dated April 25, 2016).

The 2015 CVP-Shasta temperature management plan, in effect, favored fall over winter Chinook Salmon production. The effects in 2015 were in stark contrast to 2014 whereby winter and fall Chinook production was equally dismal (Table 7 & 8) in response to the 2014 CVP-Shasta temperature management plan implemented by the USBR. The BY2015 winter ETF survival estimate of 4.5% was the lowest on record following the prior record low BY2014 value of 5.9%. Overall, BY2015 winter Chinook, BY2015 late-fall Chinook and calendar year 2015 *O. mykiss* passage estimates were the lowest in the history of the 18-year monitoring program.

Prolonged drought conditions and management of the available cold-water resources within Shasta Lake had considerable impacts to juvenile salmonid survival during the reporting period. In future years, it will be important to reflect on the outcomes of past water resource management strategies and learn from the effects the multi-year drought operations had on salmonids in the Sacramento River. W operations had some potentially far-reaching effects on endangered winter Chinook as well as the other listed and non-listed salmonid populations. In summary, an excerpt from the 2016 Sacramento River Temperature Management Plan (USBR letter dated June 27, 2016) appropriately characterized the CVP-Shasta operations in recent years:

"In WY 2015, a temperature management strategy to maintain suboptimal, yet stable temperature throughout the temperature control period was implemented and temperature dependent mortality appeared to be extremely high (85%; NMFS 2016). In WY 2014, a temperature management strategy to maintain optimal temperature as long as possible was implemented. Control of Shasta reservoir release temperatures was lost in September, which was a few weeks earlier than predicted by the model and temperature-dependent mortality appeared to also be very high (77%; NMFS 2016). Some lessons from these two recent years is that temperature management (especially in low storage years) should focus on a strategy that maintains suitable temperature throughout the period (potentially May 15 through October 31) when eggs are incubating, delays use of the full side gate configuration until later in the fall operations, and provides some adaptability if the actual operations and cold water pool characteristics do not reflect forecasted operations and reservoir characteristics."

Acknowledgments

The USBR provided financial support allowing the project to reach its goals and objectives (Interagency Agreement No. R15PG00067). Numerous individuals helped with development and implementation of this project including, but not limited to Samantha Adams, Leonard Cheskiewicz, Casey Collins, Josh Gruber, Robert Larson, Chad Praetorius, and David Ryan. Valerie Emge and Jim Smith provided programmatic support.

Literature Cited

Azat, J. 2017. GrandTab 2017.04.07. California Central Valley Chinook Population Database Report. California Department of Fish and Wildlife. http://www.dfg.ca.gov/fish/Resources/Chinook/CValleyAssessment.asp

Bedore, P., M. Bryan, P. Bratovich, J. Perez-Comas, M. Neal, C. Hammersmark, J. Barker, and C. Addley. 2015. Lower America River Chinook Salmon early life stage mortality model: updates and refinements. Prepared for Sacramento River Forum and U.S. Army Corps of Engineers, Sacramento District. November 2015. 84 p. plus appendix.

Borthwick, S. M. and R. R. Corwin. 2011. Fish entrainment by Archimedes lifts and an internal helical pump at Red Bluff Research Pumping Plant, Upper Sacramento River, California: February 1997 – May 2000. Red Bluff Research Pumping Plant Report Series, Volume 13. U.S. Bureau of Reclamation, Red Bluff, CA.

CDFW undated. Drought Monitoring of Water Quality for Sacramento River Winter-Run Chinook Salmon Spawning in the Sacramento River in 2015. State of California**.** California Department of Fish and Wildlife, Northern Region. Technical Report.

Foott, J.S. 2016. Memorandum on parasite infection of juvenile late-fall and winter run Chinook in the Sacramento River: September – November 2015 observations in the Balls Ferry to Red Bluff reach. U.S. Fish and Wildlife Service, California – Nevada Fish Health Center, Anderson, CA. January 15, 2016. 7 p.

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

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

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

Hansen, L.P., and Jonsson, B. 1985. Downstream migration of hatchery-reared smolts of Atlantic Salmon (*Salmo salar L*.) in the River Imsa, Norway. Aquaculture, 45: 237-248.

Hasenbein, M. K.M. Jeffries, J.A. Israel, D. Portz, T. Miller, W.R. Poytress, S. Foott, K. Nichols, G. Murphey, K. Kaukinen, K.M. Miller, B. Lehman, S.A. Hayes, D.V. Baxa, N.A. Fangue, and R. E. Connon. 2016. Monitoring for Pathogens and their Effects on Out-Migrating Chinook Salmon in the Delta. Poster for Bay-Delta Science Conference 2016. November 2016.

Hillman, T.W., and Mullan, J.W. 1989. Effect of hatchery releases on the abundance and behavior of wild juvenile salmonids. In summer and winter ecology of juvenile chinook salmon and steelhead trout in the Wenatchee River, Washington. Don Chapman Consultants, Boise, Idaho. pp. 266-285.

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

Karvonen, A., Rintamaki, P., Jokela, J., and E. T. Valtonen, E. T. 2010. Increasing water temperature and disease risks in aquatic systems: climate change increases the risk of some, but not all, diseases. International Journal for Parasitology, 40(13), 1483-1488.

Martin, B. T., A. Pike, S.N. John, N. Hamda, J. Roberts, S.T. Lindley, and E. M. Danner. 2016. Phenomenological vs. biophysical models of thermal stress in aquatic eggs. Ecology Letters. Doi:10.111/ele.12705

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

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

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

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

National Marine Fisheries Service (NMFS). 2016. Letter from Mrs. Maria Rea to Mr. Ron Milligan. Re:Response to March 15, 2016 Preliminary Sacramento River Temperature Modeling Results. March 18, 2016. West Coast Region, Sacramento, CA. 34 p.

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

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

Schreck, C. 1996. Immunomodulation: Endogenous Factors. In G. Iwama & T. Nakanishi (Eds.). The Fish Immune System: Organism, Pathogen, and Environment (pp. 311-327). San Diego, California: Academic Press.

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

U.S. Bureau of Reclamation. 1992. Biological assessment for the Long-Term Central Valley Project Operations Criteria and Plan. Mid-Pacific Region, Sacramento, CA. October 1992.

U.S. Bureau of Reclamation (USBR). 2015. Letter from Ron Milligan (USBR) to Maria Rea (NMFS) dated 3/24/2015. Contingency Plan for Water Year (WY) 2015 Pursuant to Reasonable and Prudent (RPA) Action I.2.3.C of the 2009 Coordinated Long-term Operation of the Central Valley Project (CVP) and State Water Project (SWP) Biological Opinion (NMFS 2009). 103 p.

U.S. Bureau of Reclamation (USBR). 2016. Letter from Ron Milligan (USBR) to Maria Rea (NMFS) dated 6/27/2016. Transmittal of Final Sacramento River Temperature Management Plan per Reasonable and Prudent (RPA) I.2.4 of the National Marine Fisheries Service 2009 Coordinated Long-term Operation of the Central Valley Project (CVP) and State Water Project (SWP) Biological Opinion (NMFS 2009 BiOp). 27 p.

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

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

United States Fish and Wildlife Service (USFWS). 1999. Effect of temperature on early-life survival of Sacramento River fall- and winter-run chinook Salmon. USFWS, Red Bluff, CA: Northern Central Valley Fish and Wildlife Office. January 1999.

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

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

Vogel, D. A. 2016. Draft Preliminary Report: Evaluation of Annual Estimates of Winter-Run Chinook Salmon Early Life Stage Survival/Mortality with Particular Focus on 2014 and 2015. Natural Resource Scientists, Inc. Red Bluff, CA. March 31, 2016.

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

Voss, A. and True, K. 2015. Winter Chinook Salmon 2015 Annual Report. California-Nevada Fish Health Center. Anderson, CA.

Wales, J.H., and M. Coots. 1955. Efficiency of chinook Salmon spawning in Fall Creek, California. Transactions of American Fisheries Society. 84:137-149.

Zeug, S.C., P.S. Bergman, B.J. Cavallo, and K.S. Jones. 2012. Application of a life cycle simulation model to evaluate impacts of water management and conservation actions on an endangered population of Chinook Salmon. Environmental Modeling and Assessment. 13 p.

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, 2015 through June 30, 2016 (brood year 2015). 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-equivalent. 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).

		Fry		Pre-smolt/smolts		Total		
Week	Sampling Effort	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	Fry-equivalent JPI
27 (Jul)	1.00	168	33	0	-	168	33	168
28	1.00	359	34	0	-	359	34	359
29	1.00	880	34	0	-	880	34	880
30	1.00	827	35	0	-	827	35	827
31 (Aug)	1.00	1,023	35	0	-	1,023	35	1,023
32	0.86	1,501	35	0	-	1,501	35	1,501
33	1.00	2,570	35	0	-	2,570	35	2,570
34	0.89	4,379	35	0	-	4,379	35	4,379
35 (Sep)	1.00	3,141	36	0	-	3,141	36	3,141
36	1.00	9,956	36	0	-	9,956	36	9,956
37	1.00	26,020	35	163	50	26,183	35	26,297
38	1.00	42,920	35	1,460	51	44,380	35	45,402
39	1.00	32,774	35	2,125	53	34,899	35	36,386
40 (Oct)	1.00	35,188	35	5,048	54	40,236	35	43,769
41	1.00	22,720	35	8,274	55	30,994	36	36,786
42	1.00	6,949	36	9,043	56	15,992	48	22,322
43	1.00	1,353	37	6,398	57	7,751	56	12,229
44 (Nov)	1.00	258	42	10,725	60	10,983	60	18,490
45	1.00	76	43	9,843	64	9,919	64	16,809
46	0.96	26	44	6,509	66	6,536	66	11,093
47	1.00	25	45	5,893	71	5,918	71	10,044
48 (Dec)	0.86	0	-	10,792	73	10,792	73	18,347
49	0.96	0	-	1,652	72	1,652	72	2,809
50	1.00	0	-	40,998	74	40,998	74	69,697

Table 1 –(continued)

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolt/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
51	0.54	0	-	3,897	76.5	3,897	76.5	6,626
52	0.68	0	-	2,225	88	2,225	88	3,783
1 (Jan)	0.32	0	-	68	112	68	112	116
2	0.41	0	-	2,885	85	2,885	85	4,905
3	0.14	0	-	11,326	83	11,326	83	19,254
4	0.34	0	-	145	118	145	118	247
5 (Feb)	0.57	0	-	902	121.5	902	121.5	1,533
6	1.00	0	-	257	125	257	125	438
7	1.00	0	-	35	136	35	136	59
8	0.79	0	-	390	115	390	115	664
9 (Mar)	1.00	0	-	70	138	70	138	120
10	0.57	0	-	437	151	437	151	742
11	0.11	0	-	1,776	135	1,776	135	3,018
12	0.36	0	-	0	-	0	-	0
13	0.63	0	-	1,797	139	1,797	139	3,054
14 (Apr)	1.00	0	-	196	145	196	145	333
15	0.32	0	-	0	-	0	-	0
16	0.55	0	-	333	153	333	153	567
17	0.46	0	-	123	130.5	123	130.5	208
18 (May)	0.30	0	-	0	-	0	-	0
19	0.41	0	-	0	-	0	-	0
20	0.46	0	-	0	-	0	-	0
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	0	-	0	-	0	-	0
26	0.46	0	-	0	-	0	-	0
BY total		193,115		145,786		338,901		440,951
90% CI (low : high)		(147,323 : 238,907)		(80,032 : 211,540)		(229,316 : 448,486)		(288,911 : 592,992)

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, 2015 through October 15, 2016 (brood year 2015). 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-equivalent. 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).

		Fry		Pre-smolt/smolts		Total		
Week	Sampling Effort	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	Fry-equivalent JPI
42	1.00	1,577	33	0	-	1,577	33	1,577
43	1.00	1,422	34	0	-	1,422	34	1,422
44 (Nov)	1.00	320	34.5	0	-	320	34.5	320
45	1.00	152	34.5	0	-	152	34.5	152
46	0.96	394	34	0	-	394	34	394
47	1.00	1,634	34	0	-	1,634	34	1,634
48 (Dec)	0.86	3,274	35	0	-	3,274	35	3,274
49	0.96	2,810	36	0	-	2,810	36	2,810
50	1.00	48,203	37	282	47.5	48,485	37	48,682
51	0.54	9,186	39	0	-	9,186	39	9,186
52	0.68	3,141	39.5	74	49	3,216	40	3,268
1 (Jan)	0.32	129	44	0	-	129	44	129
2	0.41	3,494	44	1,008	47	4,502	46	5,208
3	0.14	0	-	8,793	46	8,793	46	14,947
4	0.34	0	-	1,579	56	1,579	56	2,684
5 (Feb)	0.57	0	-	999	54	999	54	1,699
6	1.00	0	-	230	53	230	53	391
7	1.00	0	-	66	61	66	61	112
8	0.79	0	-	131	62	131	62	223
9 (Mar)	1.00	0	-	425	63	425	63	722
10	0.57	0	-	1,513	69	1,513	66	2,572
11	0.57	0	-	157,525	72	157,525	69	267,793
12	0.55	0	-	741,742	76	741,742	72	1,260,962
13	0.63	0	-	74,785	76	74,785	76	127,134

Table 2—(continued)

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolt/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
14 (Apr)	1.00	0	-	12,276	80	12,276	80	20,870
15	0.32	0	-	555,452	82	555,452	82	944,268
16	0.55	0	-	25,232	88	25,232	88	42,895
17	0.46	0	-	11,598	92	11,598	92	19,716
18 (May)	0.30	0	-	7,360	93.5	7,360	93.5	12,513
19	0.41	0	-	3,551	99	3,551	99	6,037
20	0.46	0	-	977	102	977	102	1,660
21	0.21	0	-	435	105	435	105	739
22 (Jun)	0.11	0	-	305	120	305	120	518
23	0.11	0	-	0	-	0	-	0
24	0.16	0	-	0	-	0	-	0
25	0.39	0	-	0	-	0	-	0
26	0.46	0	-	0	-	0	-	0
27 (Jul)	0.46	0	-	0	-	0	-	0
28	0.86	0	-	0	-	0	-	0
29	1.00	0	-	0	-	0	-	0
30	1.00	0	-	0	-	0	-	0
31 (Aug)	0.96	0	-	0	-	0	-	0
32	0.71	0	-	0	-	0	-	0
33	0.86	0	-	0	-	0	-	0
34	0.86	0	-	0	-	0	-	0
35 (Sep)	0.86	0	-	0	-	0	-	0
36	0.86	0	-	0	-	0	-	0
37	0.96	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		75,738		1,606,339		1,682,077		2,806,514
90% CI (low : high)		(42,025 : 109,451)		(-287,792 : 3,500,470)		(-244,730 : 3,608,883)		(-442,595 : 6,055,623)

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, 2015 through November 30, 2016 (brood year 2015). 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-equivalent. 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).

		Fry		Pre-smolt/smolts		Total		
Week	Sampling Effort	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	Fry-equivalent JPI
48 (Dec)	0.86	180	33	0	-	180	33	180
49	0.96	2,190	34	24	175	2,214	34	2,230
50	1.00	117,503	35	0	-	117,503	35	117,503
51	0.54	385,574	35	0	-	385,574	35	385,574
52	0.68	335,073	35	0	-	335,073	35	335,073
1 (Jan)	0.32	132,331	36	0	-	132,331	36	132,331
2	0.41	1,596,097	36	0	-	1,596,097	36	1,596,097
3	0.14	13,786,293	36	0	-	13,786,293	36	13,786,293
4	0.34	626,681	36	672	46	627,353	36	627,823
5 (Feb)	0.57	361,170	36	849	47	362,019	36	362,613
6	1.00	257,153	36	617	47.5	257,769	36	258,201
7	1.00	157,431	36	165	51	157,595	36	157,711
8	0.79	131,328	36	503	50	131,831	36	132,183
9 (Mar)	1.00	28,214	37	1,245	55	29,459	37	30,331
10	0.57	118,663	37	11,226	49	129,889	37	137,747
11	0.57	388,691	37	368,257	63	756,948	45	1,014,727
12	0.55	103,515	35	2,002,769	65	2,106,284	65	3,508,222
13	0.63	39,149	36	140,495	68	179,644	66	277,990
14 (Apr)	1.00	5,409	36	12,254	71	17,662	67	26,240
15	0.32	7,869	37	3,661,589	72	3,669,458	72	6,232,570
16	0.55	126	43	248,129	72	248,255	72	421,945
17	0.46	0	-	48,967	79	48,967	79	83,243
18 (May)	0.30	0	-	161,929	76	161,929	76	275,279
19	0.41	0	-	98,692	79	98,692	79	167,776

Table 3—(continued)

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolt/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
20	0.46	0	-	78,831	82	78,831	82	134,013
21	0.21	0	-	57,832	84	57,832	84	98,314
22 (Jun)	0.11	0	-	27,834	78	27,834	78	47,318
23	0.11	0	-	30,774	80	30,774	80	52,316
24	0.16	0	-	24,368	79	24,368	79	41,426
25	0.39	0	-	30,129	84	30,129	84	51,219
26	0.46	0	-	35,022	84	35,022	84	59,537
27 (Jul)	0.46	0	-	16,226	86	16,226	86	27,585
28	0.86	0	-	21,369	90	21,369	90	36,327
29	1.00	0	-	17,850	93	17,850	93	30,345
30	1.00	0	-	13,762	95	13,762	95	23,396
31 (Aug)	0.96	0	-	8,503	94	8,503	94	14,455
32	0.71	0	-	4,781	101.5	4,781	101.5	8,129
33	0.86	0	-	3,347	106	3,347	106	5,691
34	0.86	0	-	3,477	110	3,477	110	5,911
35 (Sep)	0.86	0	-	2,304	107	2,304	107	3,917
36	0.86	0	-	901	109	901	109	1,532
37	0.96	0	-	1,062	119.5	1,062	119.5	1,805
38	1.00	0	-	694	117	694	117	1,180
39	1.00	0	-	671	124	671	124	1,141
40 (Oct)	1.00	0	-	538	127	538	127	914
41	1.00	0	-	333	127	333	127	566
42	0.86	0	-	613	132	613	132	1,041
43	1.00	0	-	352	144	352	144	598
44 (Nov)	1.00	0	-	982	139	982	139	1,669
45	1.00	0	-	0	-	0	-	0
46	1.00	0	-	0	-	0	-	0
47	0.80	0	-	0	-	0	-	0
BY total		18,580,639		7,140,945		25,721,574		30,720,228
90% CI (low : high)		(-130,290 : 37,291,568)		(-345,212 : 14,627,082)		(-307,942 : 51,751,090)		(-533,520 : 61,973,977)

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, 2015 through March 31, 2016 (brood year 2015). 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-equivalent. 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		Pre-smolt/smolts		Total		Fry-equivalent JPI
		Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	
14 (Apr)	0.93	56	34	0	-	56	34	56
15	1.00	409	35	0	-	409	35	409
16	1.00	363	35.5	0	-	363	35.5	363
17	0.93	629	37	0	-	629	37	629
18 (May)	1.00	297	37	0	-	297	37	297
19	0.82	368	36.5	0	-	368	36.5	368
20	0.54	493	37	0	-	493	37	493
21	0.75	301	41.5	98	46.5	399	44.5	468
22 (Jun)	0.75	122	45	44	47	167	45	198
23	0.75	120	41	258	49.5	378	47	558
24	0.70	117	31	84	52.5	202	31	261
25	0.75	153	38	81	53	234	41.5	291
26	0.79	154	31	0	-	154	31	154
27 (Jul)	1.00	128	39	159	61	287	52	399
28	1.00	90	37	59	58.5	149	45	190
29	1.00	32	44	148	50	180	49.5	284
30	1.00	0	-	152	68	152	68	259
31 (Aug)	1.00	0	-	153	71	153	71	260
32	0.86	0	-	71	65.5	71	65.5	121
33	1.00	0	-	60	69.5	60	69.5	102
34	0.89	0	-	0	-	0	-	0
35 (Sep)	1.00	0	-	0	-	0	-	0
36	1.00	0	-	62	59.5	62	59.5	106
37	1.00	0	-	96	57	96	57	163

Table 4—(continued)

Week	Sampling Effort	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolt/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalent JPI
38	1.00	0	-	1,042	74	1,042	74	1,772
39	1.00	0	-	1,001	68	1,001	68	1,702
40 (Oct)	1.00	0	-	1,765	72	1,765	72	3,001
41	1.00	0	-	1,521	71	1,521	71	2,586
42	1.00	0	-	2,295	81	2,295	81	3,901
43	1.00	0	-	2,314	83	2,314	83	3,933
44 (Nov)	1.00	0	-	3,011	100	3,011	100	5,119
45	1.00	0	-	5,077	118	5,077	118	8,632
46	0.96	0	-	3,859	126	3,859	126	6,560
47	1.00	0	-	6,919	125	6,919	125	11,762
48 (Dec)	0.86	0	-	7,467	127	7,467	127	12,694
49	0.96	0	-	1,900	130	1,900	130	3,230
50	1.00	0	-	16,228	126	16,228	126	27,588
51	0.54	0	-	4,877	122	4,877	122	8,291
52	0.68	0	-	1,740	120.5	1,740	120.5	2,957
1 (Jan)	0.32	0	-	310	125	310	125	527
2	0.41	0	-	545	128	545	128	926
3	0.14	0	-	0	-	0	-	0
4	0.34	0	-	145	170	145	170	247
5 (Feb)	0.57	0	-	457	144	457	144	778
6	1.00	0	-	0	-	0	-	0
7	1.00	0	-	0	-	0	-	0
8	0.79	0	-	0	-	0	-	0
9 (Mar)	1.00	0	-	0	-	0	-	0
10	0.57	0	-	0	-	0	-	0
11	0.11	0	-	0	-	0	-	0
12	0.36	0	-	0	-	0	-	0
13	0.63	0	-	0	-	0	-	0
BY total		3,831		64,000		67,831		112,631
90% CI (low : high)		(933 : 6,728)		(39,899 : 88,102)		(41,392 : 94,269)		(72,046 : 153,216)

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, 2015 through December 31, 2015 (brood year 2015). 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).

		Total				Total	
Week	Sampling Effort	Est. passage	Med FL	Week	Sampling Effort	Est. passage	Med FL
1 (Jan)	0.21	0	-	27 (Jul)	1.00	199	62
2	0.38	0	-	28	1.00	179	57
3	0.32	0	-	29	1.00	319	53
4	0.43	46	260	30	1.00	153	57
5 (Feb)	0.61	35	250	31 (Aug)	1.00	256	62
6	0.14	0	-	32	0.86	273	54
7	0.43	127	159.5	33	1.00	183	69.5
8	0.57	42	236	34	0.89	96	66
9 (Mar)	0.71	0	-	35 (Sep)	1.00	256	67
10	1.00	0	-	36	1.00	321	70.5
11	0.57	35	35	37	1.00	100	72.5
12	1.00	0	-	38	1.00	578	74
13	1.00	73	39.5	39	1.00	208	72
14 (Apr)	0.93	74	62	40 (Oct)	1.00	314	88
15	1.00	476	65	41	1.00	125	93.5
16	1.00	2,993	68	42	1.00	31	72
17	0.93	1,792	62	43	1.00	80	134
18 (May)	1.00	791	61	44 (Nov)	1.00	24	81
19	0.82	656	62	45	1.00	25	233
20	0.54	802	70	46	0.96	32	79
21	0.75	1,110	64	47	1.00	47	112.5
22 (Jun)	0.75	581	62	48 (Dec)	0.86	85	121
23	0.75	510	56.5	49	0.96	69	99
24	0.70	1,465	62.5	50	1.00	207	218
25	0.75	316	59	51	0.54	40	88
26	0.79	120	59.5	52	0.68	268	110
					BY total	16,511	
					90% CI (low : high)	(7,134 : 25,888)	

Table 6.—Summary of results from mark-recapture trials conducted in 2016 (*N* = 3) to evaluate rotary-screw trap efficiency at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Results include the number of fish released, mean fork length at release (Release FL), number recaptured, mean fork length at recapture (Recapture FL), combined trap efficiency (TE%), percent river volume sampled by rotary-screw traps (%Q), number of traps sampling during trials, and modification status as to whether or not traps were structurally modified to reduce volume sampled by 50% (Traps modified).

Trial#	Year	Number Released	Release FL (mm)	Number Recaptured	Recapture FL (mm)	TE (%)	%Q	Number of traps sampling	Traps modified
1	2016	1,306	35.7	53	36.0	4.06	4.32	4	No
2	2016	1,442	35.8	66	35.7	4.58	5.50	4	No
3	2016	1,155	36.3	73	35.3	6.32	5.78	4	No

Table 7.— Winter Chinook fry-equivalent juvenile production indices (JPI), lower and upper 90% confidence intervals (CI), estimated adult female spawners above RBDD (Estimated Females), estimates of female fecundity, calculated juveniles per estimated female (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)
					Average	1,148	22.6 (13.4 : 31.9)
					Standard Deviation	589	11.8 (7.8 : 16.4)

[1]Estimated females derived from carcass survey data; 2014 estimate includes 1% pre-spawn mortality and 2015 estimate includes 2% pre-spawn mortality.
[2]Female fecundity estimates based on annual average values from LSNFH winter Chinook spawning data collected between 2002 and 2015.

Table 8.— Fall Chinook fry-equivalent juvenile production indices (JPI), lower and upper 90% confidence intervals (CI), estimated adult female spawners above RBDD (Estimated Females), estimates of female fecundity, calculated juveniles per estimated female (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 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	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	5,407	650	12.0 (5.7 : 18.4)
2009	9,674,829	3,678,373	15,723,368	6,531	5,407	1,481	27.4 (10.4 : 44.5)
2010	10,620,144	5,637,617	15,895,197	7,008	5,407	1,493	28.9 (15.3 : 43.2)
2011	7,554,574	4,171,332	10,960,125	9,260	5,407	816	13.7 (8.3 : 21.9)
2012	26,567,379	17,219,525	36,197,837	32,635	5,407	814	15.1 (9.8 : 20.5)
2013	34,163,943	6,247,962	62,079,924	39,422	5,407	867	16.0 (2.9 : 29.1)
2014	4,387,348	2,407,113	6,367,583	35,345	5,407	124	2.3 (1.3 : 3.3)
2015	30,728,228	-533,520	61,973,977	17,707	5,407	1,735	32.1 (-0.6 : 64.7)
					Average	782	14.5 (5.2 : 24.4)
					Standard Deviation	493	9.1 (4.4 : 16.4)

[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 2015.

[2]Female fecundity estimates based on average values from CNFH fall Chinook spawning data collected between 2008 and 2015.

Table 9.— Week number, release dates, total number of fish released per group, mean fork length (FL) of Chinook at release (mm) with LAD (length-at-date) 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 (CNFH) brood year 2015 fall Chinook into Battle Creek from March 14, 2016 through April 29, 2016.

Week	Release Date(s)	# Released	Mean FL of release group	LAD Range (% captures) Fall	Spring
11	3/14/2016	864,486	61.5	0 - 66 (57.4%)	67 - 89 (39.7%)
12	3/22/2016	1,373,815	70.7	0 - 69 (70.5%)	70 - 95 (29.5%)
13	--	--	--	0 - 73 (59.7%)	72 - 99 (40.1%)
14	4/7-8/2016	5,570,928	75.0	36 - 77 (54.3%)	78 - 105 (45.0%)
15	4/12/2016	2,436,541	75.0	37 - 79 (85.9%)	80 - 107 (14.1%)
16	--	--	--	38 - 84 (90.4%)	82 - 114 (8.6%)
17	--	--	--	39 - 88 (79.0%)	86 - 119 (21.0%)
18	4/29/2016	1,879,786	75.0	41 - 89 (98.3%)	90 - 120 (1.7%)
	Total:	**12,125,556**		**76.7%**	**22.9%**

Figures

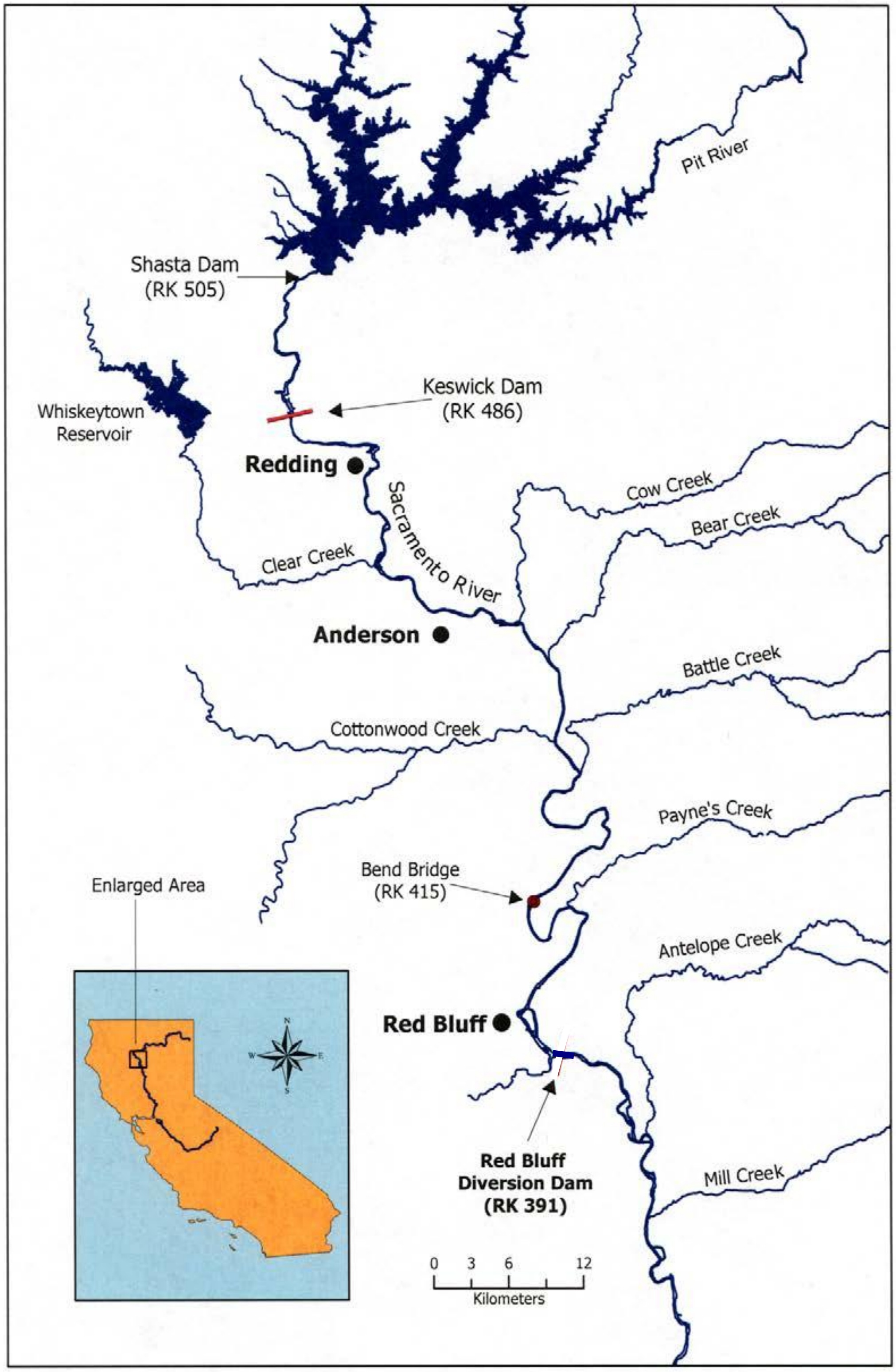


Figure 1. Location of Red Bluff Diversion Dam sample site on the Sacramento River, California at river kilometer 391 (RK 391).

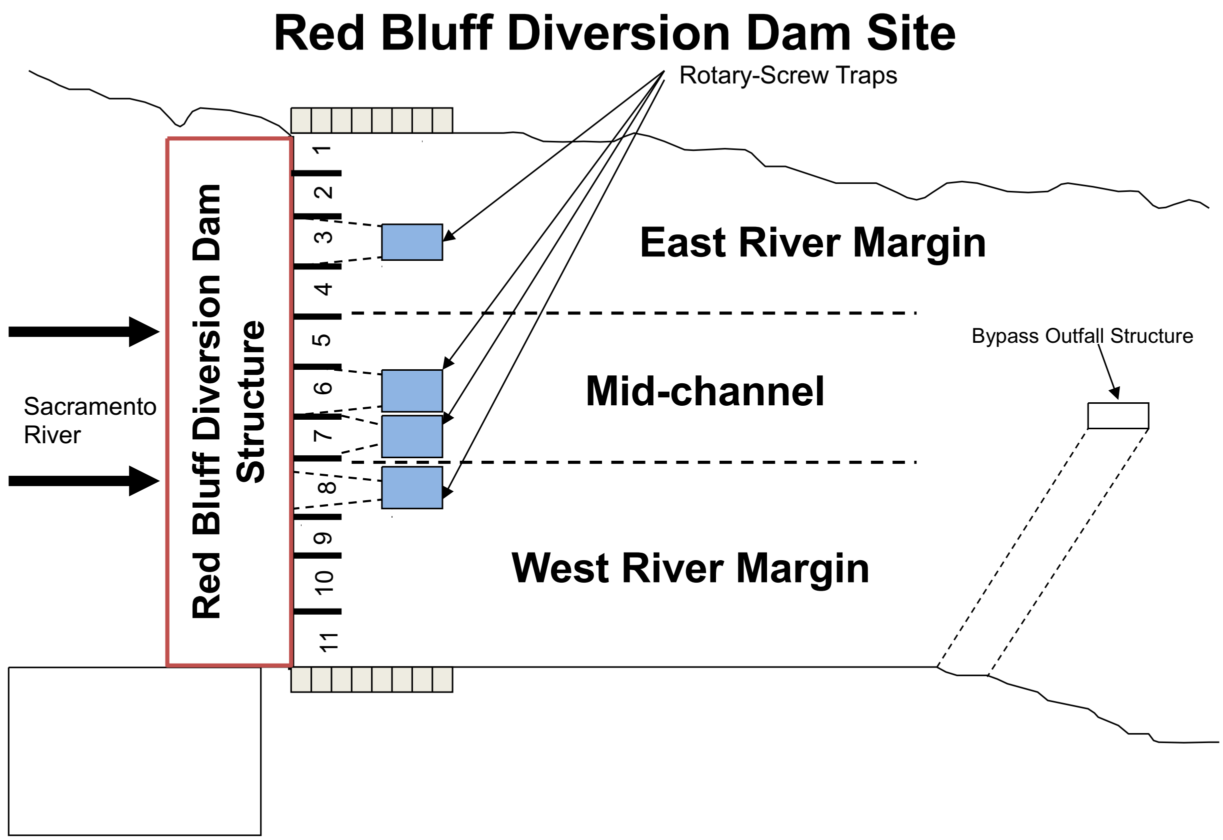


Figure 2. Rotary-screw trap sampling transect schematic of Red Bluff Diversion Dam site (RK 391) on the Sacramento River, CA.

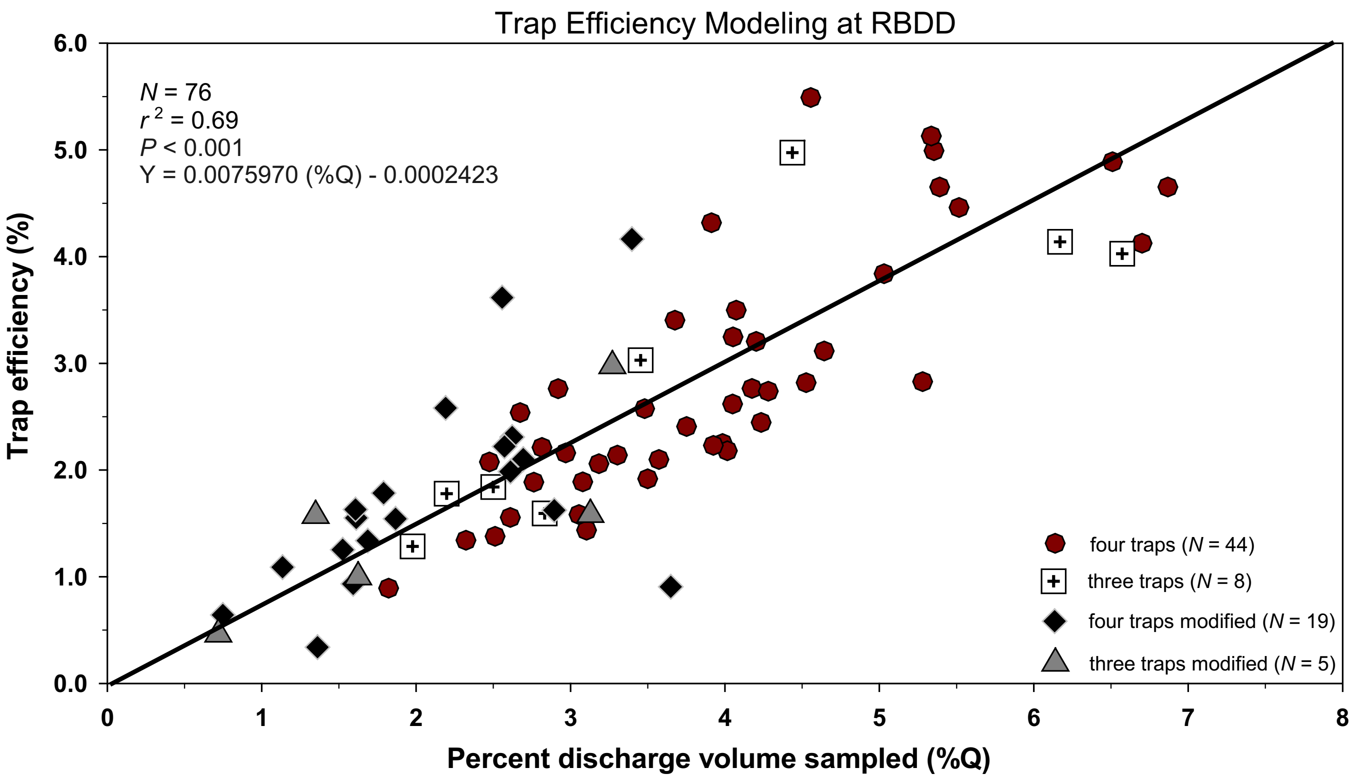


Figure 3. Trap efficiency model for combined 2.4 m diameter rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four traps (*N* = 44), three traps (*N* = 8), or with traps modified to sample one-half the normal volume of water (*N* = 24).

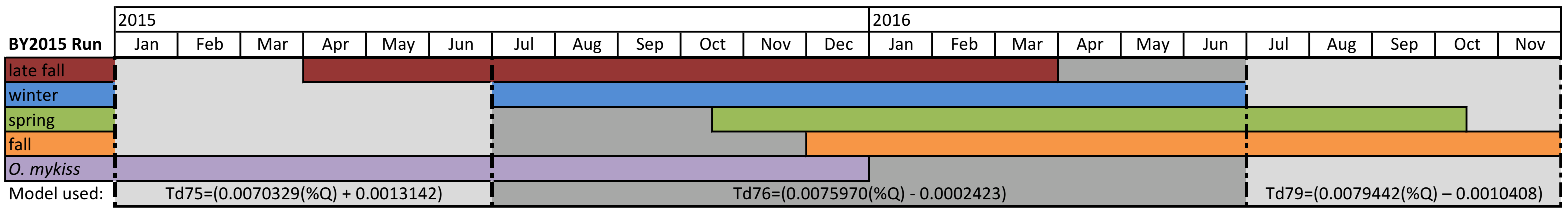


Figure 4.—Summary of trap efficiency models used for passage estimates during brood year 2015 for juvenile winter, spring, fall, late-fall Chinook Salmon and *O. mykiss* from January 1, 2015, the start of the *O. mykiss* 2015 brood year through November 30, 2016, the end of the 2015 fall Chinook brood year.

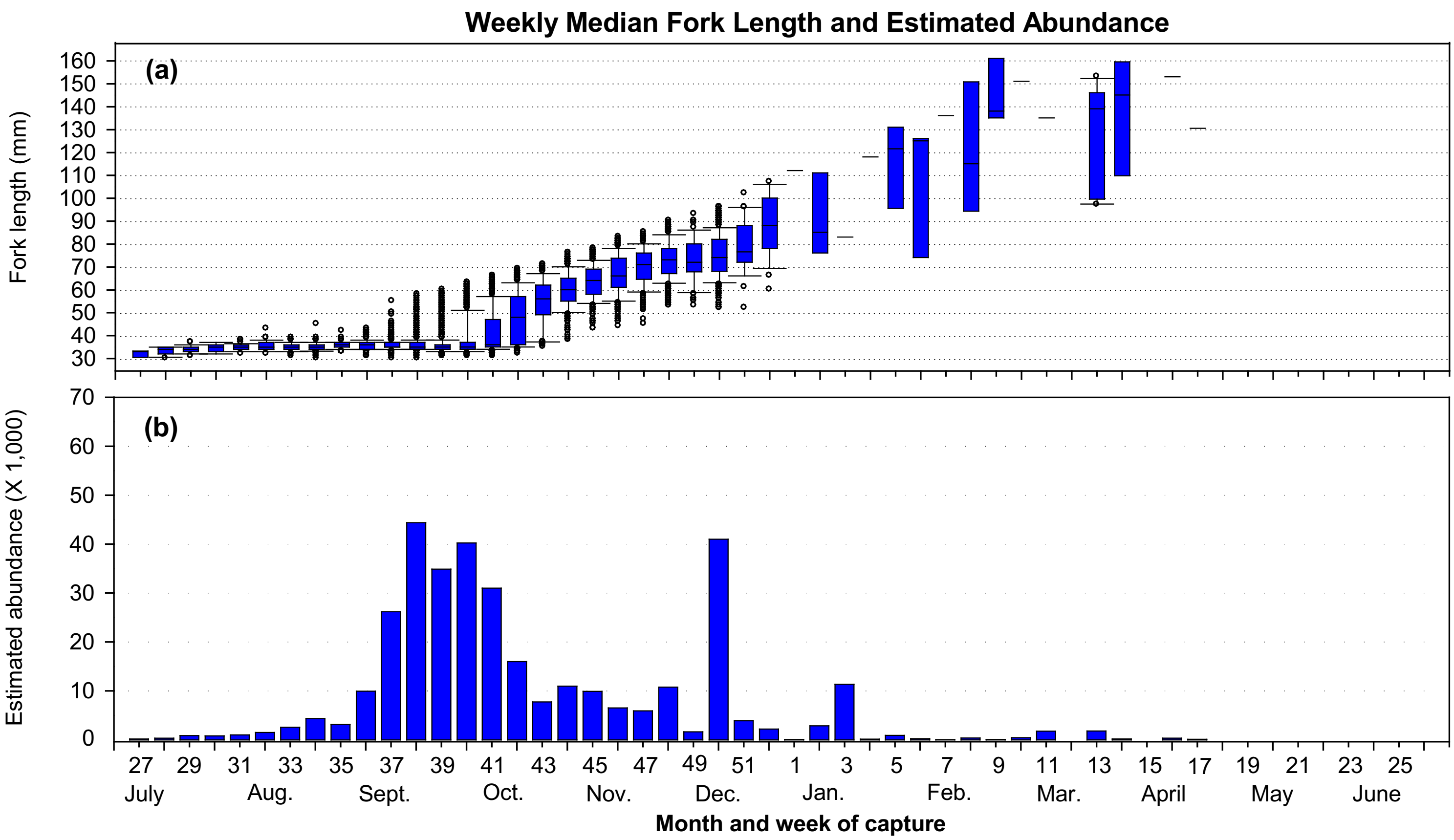


Figure 5. Weekly median fork length (a) and estimated abundance (b) of brood year 2015 juvenile winter Chinook Salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Winter Chinook Salmon were sampled by rotary-screw traps for the period July 1, 2015 through June 30, 2016. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

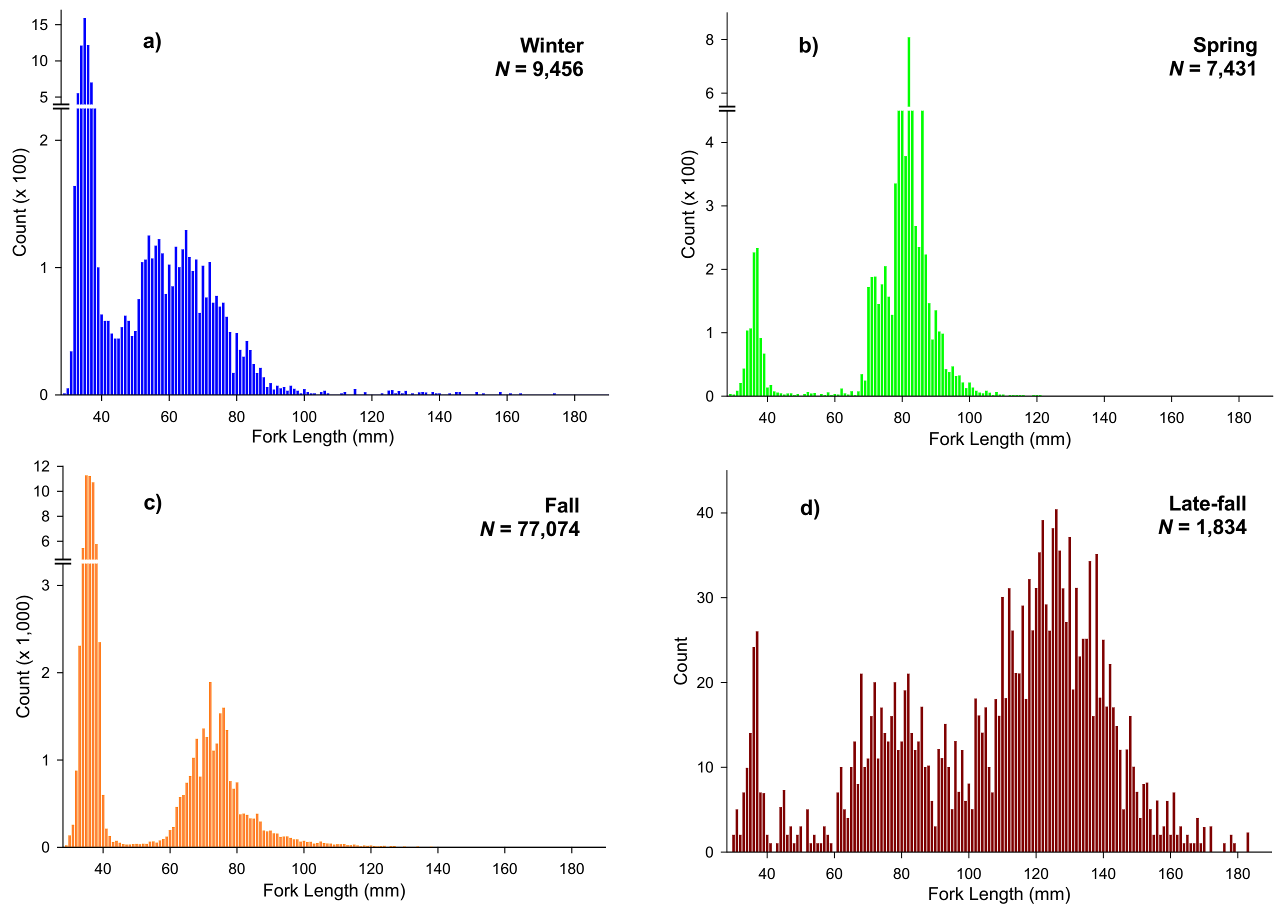


Figure 6. Fork length frequency distribution of brood year 2015 juvenile a) winter, b) spring, c) fall and d) late-fall Chinook Salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fork length data were expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from April 1, 2015 through November 30, 2016.

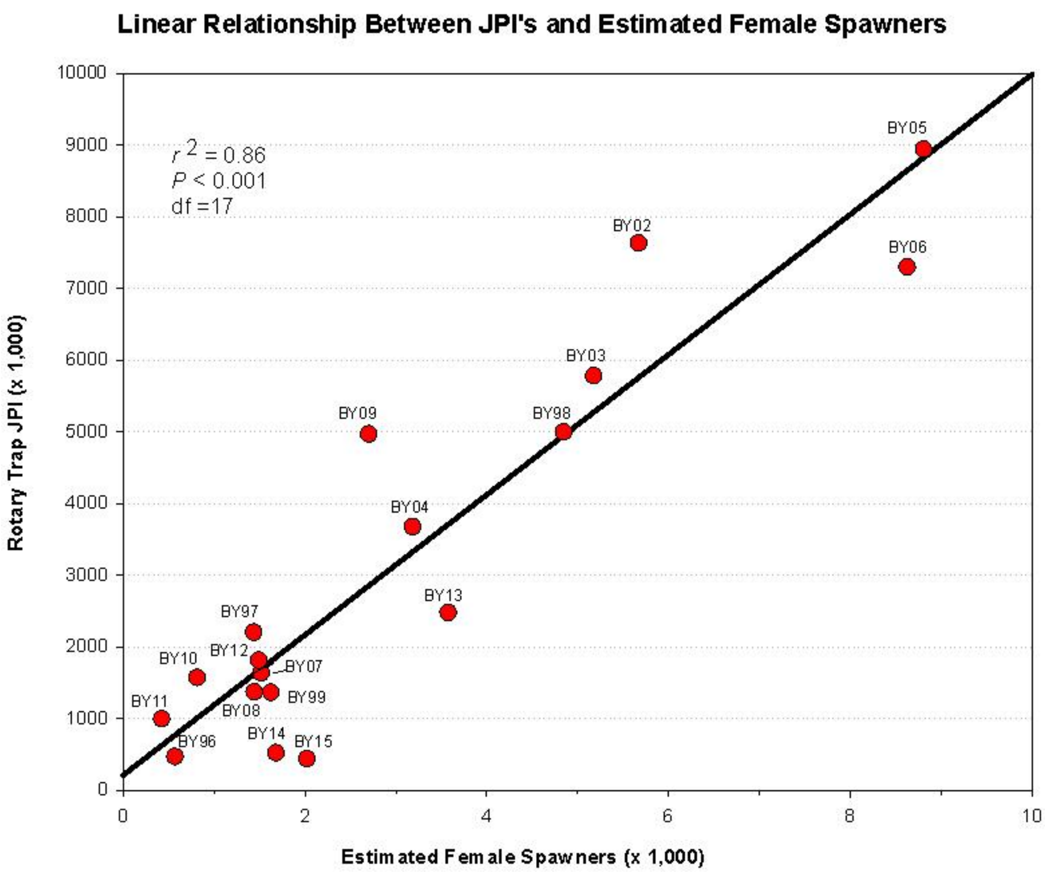


Figure 7. Linear relationship between rotary-screw trap juvenile winter Chinook fry-equivalent production indices (Rotary Trap JPI) and carcass survey derived estimated female spawners.

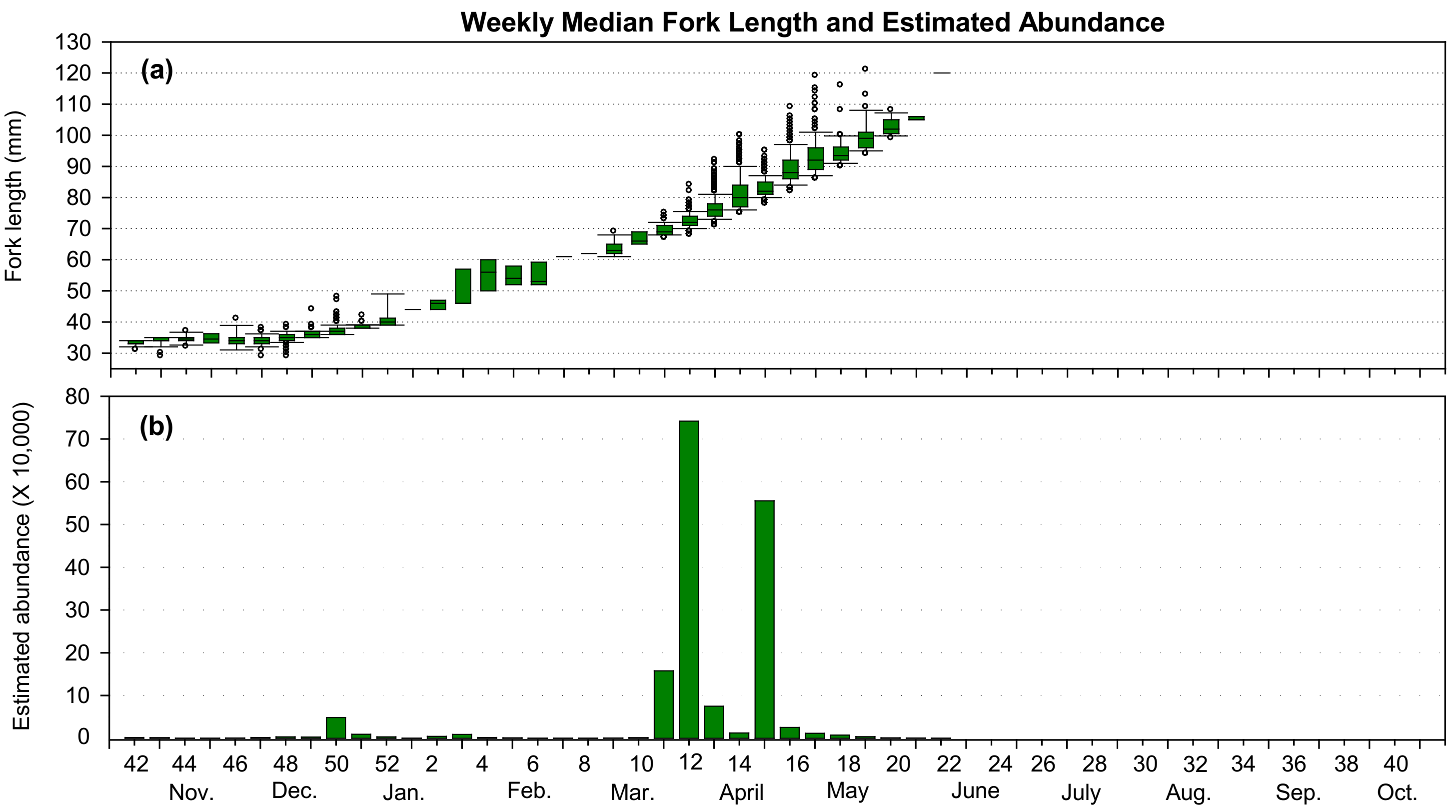


Figure 8. Weekly median fork length (a) and estimated abundance (b) of brood year 2015 juvenile spring Chinook Salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Spring Chinook Salmon were sampled by rotary-screw traps for the period October 16, 2015 through October 15, 2016. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

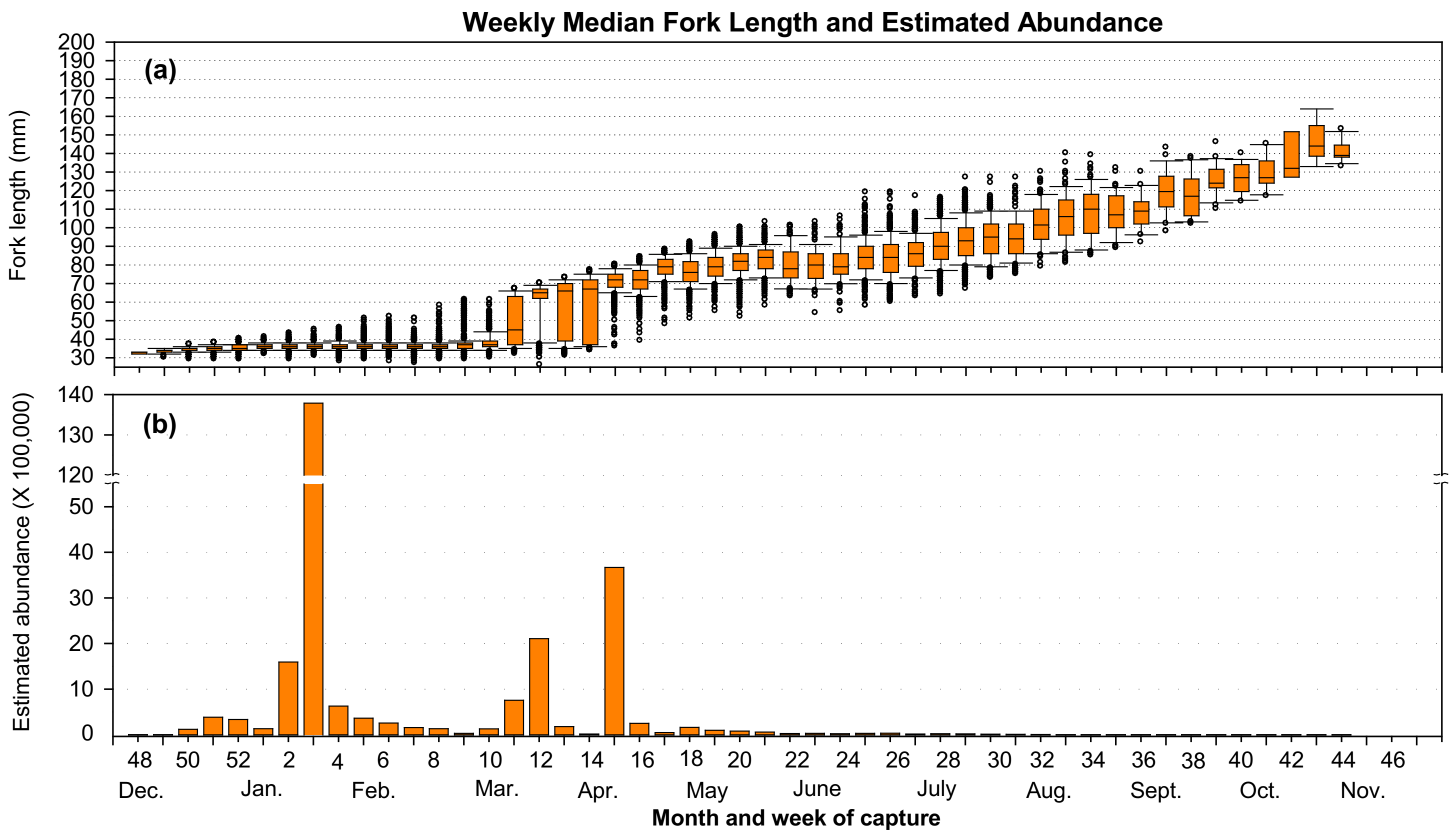


Figure 9. Weekly median fork length (a) and estimated abundance (b) of brood year 2015 juvenile fall Chinook Salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fall Chinook Salmon were sampled by rotary-screw traps for the period December 1, 2015 through November 30, 2016. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

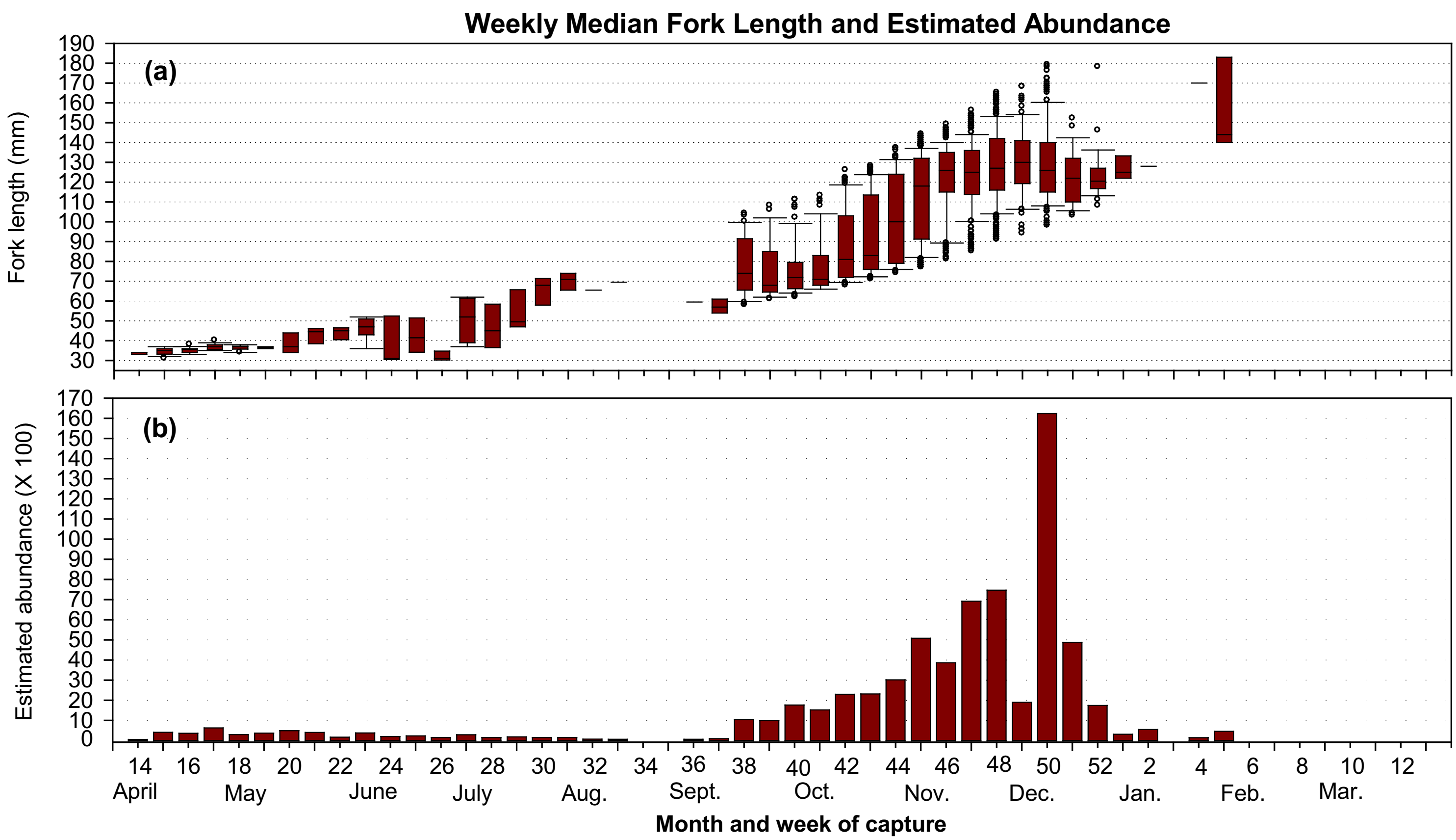


Figure 10. Weekly median fork length (a) and estimated abundance (b) of brood year 2015 juvenile late-fall Chinook Salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Late-fall Chinook Salmon were sampled by rotary-screw traps for the period April 1, 2015 through March 31, 2016. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

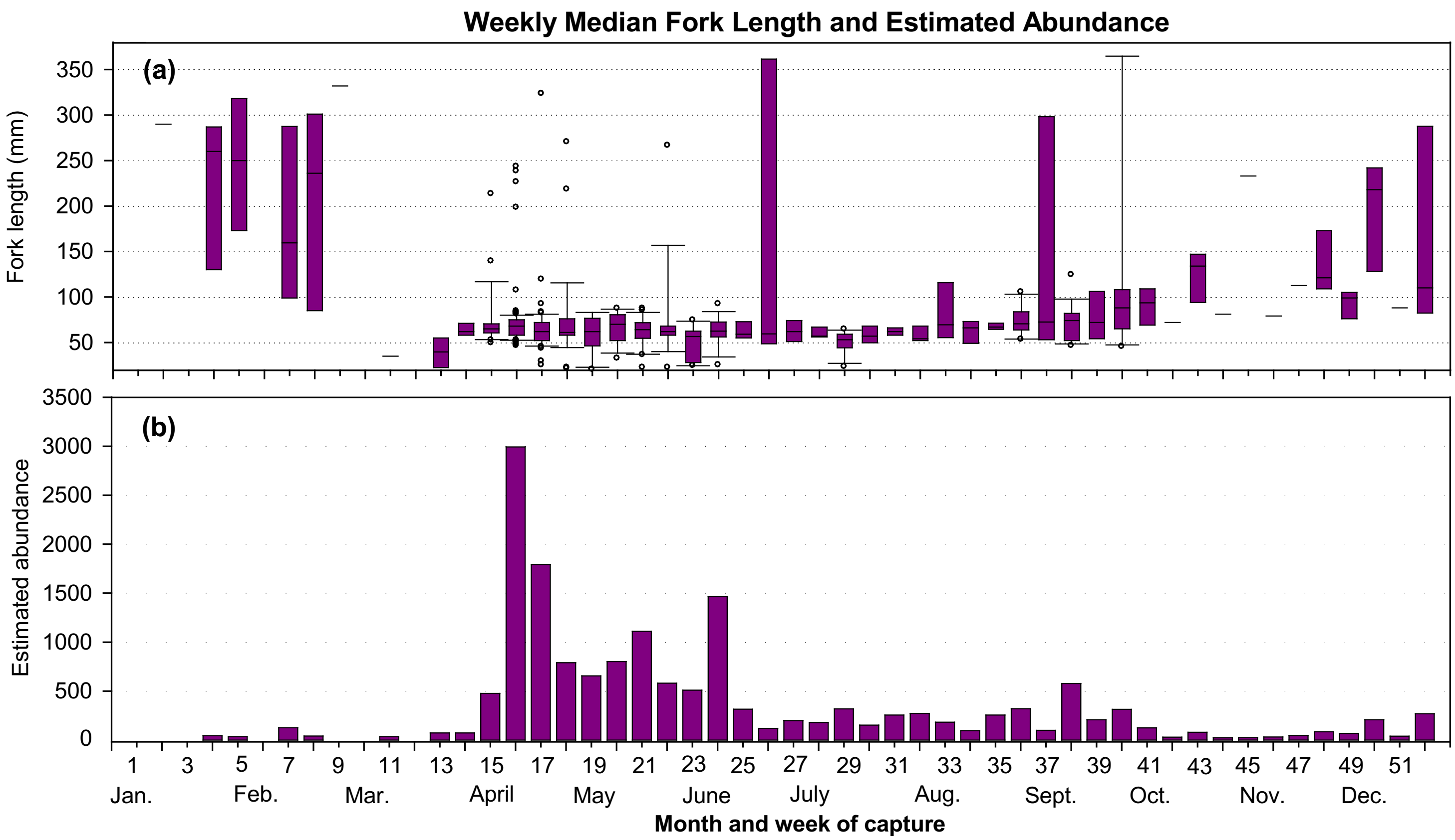


Figure 11. Weekly median fork length (a) and estimated abundance (b) of brood year 2015 juvenile *O. mykiss* passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. *O. mykiss* were sampled by rotary-screw traps for the period January 1, 2015 through December 31, 2015. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

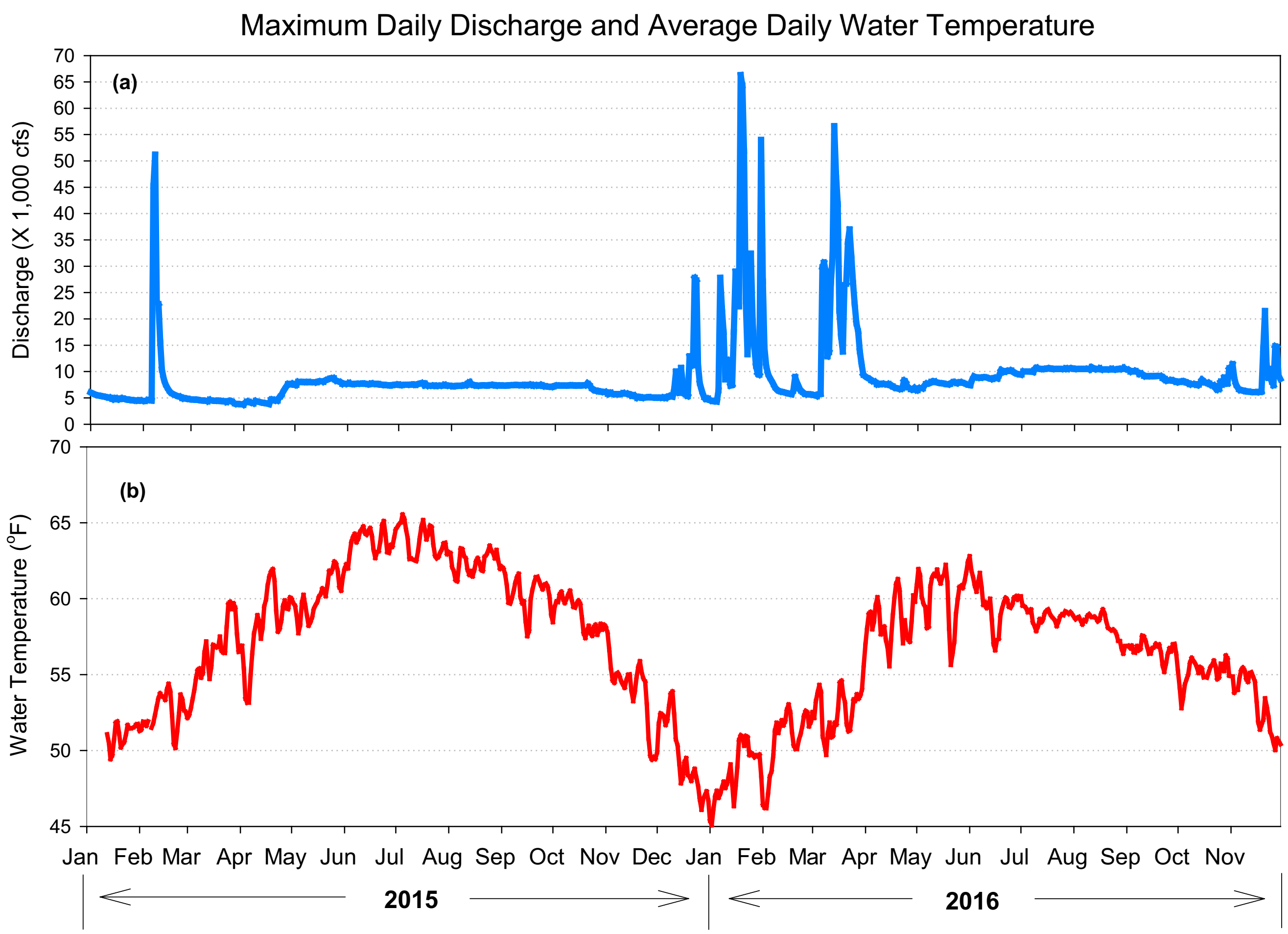


Figure 12. Maximum daily discharge (a) calculated from the California Data Exchange Center's Bend Bridge gauging station and average daily water temperatures (b) from rotary-screw traps at RBDD for the period January 1, 2015 through November 30, 2016.