BROOD-YEAR 2014 WINTER CHINOOK JUVENILE PRODUCTION INDICES WITH COMPARISONS TO JUVENILE PRODUCTION ESTIMATES DERIVED FROM ADULT ESCAPEMENT

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Brood-year 2014 winter Chinook juvenile production indices with comparisons to juvenile production estimates derived from adult escapement

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Abstract.— Brood-year 2014 juvenile winter-run Chinook salmon passage at Red Bluff Diversion Dam (RBDD) was estimated at 411,322 fry and pre-smolt/smolts combined. The fry-equivalent rotary trap juvenile production index was estimated at 523,872 with the lower and upper 90% confidence intervals ranging from 301,197 to 746,546 juveniles. BY2014 represented the lowest estimate of juvenile winter Chinook production since 1996. The estimated egg-to-fry survival rate, based on the brood-year 2014 winter Chinook fry-equivalent juvenile production index was 5.9%. This was the lowest estimated survival rate in 18 years of monitoring. The range of egg-to-fry survival rates based on 90% confidence intervals was 3.4% to 8.4%.

Rotary-screw trap fry-equivalent juvenile production indices (JPI's) were compared to juvenile production estimates (JPE's) derived from the National Oceanic and Atmospheric Administration's National Marine Fisheries Service carcass survey based JPE model. The brood-year 2014 Carcass JPE was calculated at 2,409,171 fry at RBDD. The Carcass JPE was considerably higher than the JPI, exceeding the upper 90% confidence intervals by 223% or 1,662,625 juveniles. When directly comparing the two estimates, the Carcass JPE was estimated to be 1,885,299 juveniles or 360% greater than the fry-equivalent rotary trap JPI.

Rotary trap JPI's were significantly correlated in trend to Carcass JPE's ($r^2 = 0.84$, $P < 0.001$, df = 16). The addition of the 2014 data decreased the correlation between the two estimates. In terms of the magnitude of the two estimates, a Mann-Whitney Rank Sum test detected no significant difference among rotary trap JPI's and Carcass JPE's ($U = 136.00$, $P = 0.78$). For the combined seventeen years of data, Carcass JPE's averaged 25.6% greater than rotary trap JPI's (range = -49% to +360%). Overall, the comparison between 2014 JPI's and JPE's resulted in the greatest disparity, by percentage, between estimates in seventeen years of comparisons.

Due to the disparity noted by preliminary JPI's estimated in real-time before December 2014, in corroboration with water temperature data collected during the winter Chinook spawning period, the collective fisheries agencies could not support the Carcass JPE value of 2,409,171 for BY 2014 fry production at RBDD. The USFWS fry-equivalent JPI value of 523,872 provided a more credible estimate that better reflected the effects of the high water temperatures experienced by eggs and alevins in the Sacramento River in 2014. As a result, the Carcass JPE model was changed in 2015 to incorporate the fry-equivalent JPI that accounts for annual variability in ETF survival rates based on actual observations of juvenile production.

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Introduction

Winter-run Chinook salmon is one of four distinct "runs" of Chinook salmon *(Oncorhynchus tshawytscha)* present in the Sacramento River, California. Distinguished by the season of the returning adult spawning migration, the winter-run Chinook salmon begin to return from the ocean to the Sacramento River in December (Vogel and Marine 1991).

Sacramento River winter-run Chinook salmon were federally listed as an endangered species under the Endangered Species Act (ESA) in 1994[1]. Numerous measures have, and continue to be implemented to protect and conserve winter-run Chinook salmon. One protective measure is adaptively managing water exports from the Central Valley Project's Tracy Pumping Plant and the State Water Project's Harvey Banks Delta Pumping Plant in the Sacramento-San Joaquin Delta (Delta). Exports are managed to limit entrainment of juvenile winter-run Chinook salmon (hereafter referred to as winter Chinook) annually migrating through the Delta seaward. The United States Bureau of Reclamation (USBR) and the California Department of Water Resources are authorized by the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) for incidental take of up to two percent of the annual winter Chinook population estimated to be entering the Delta and recovered at these facilities (CDFG 1996; McInnis 2002). NMFS uses a juvenile production estimate (JPE) model to determine the number of juvenile winter Chinook entering the Delta. Historically, the JPE model used adult escapement estimates derived from Red Bluff Diversion Dam (RBDD) fish ladder counts (Diaz-Soltero 1995, 1997; Lecky 1998, 1999, 2000). Since 1996, the winter Chinook carcass survey and the RBDD counts were used as the bases of the model (McInnis 2002). Since the fall of 2011, the RBDD gates have been left in the raised position to allow unobstructed upstream and downstream passage of adult and juvenile anadromous fish. As a result, current escapement estimates are derived solely from the winter Chinook carcass survey (NMFS 2009).

The NMFS JPE model uses estimated adult escapement as the primary variate that can introduce inaccuracies in resultant JPE's. One factor associated with inaccuracies of modeling juvenile production is the estimate of female spawners, the second variate of the JPE model. For data derived from the carcass survey, the size composition of fish sampled often leads to skewed sex ratios. Adult females are generally larger and may be more easily recognized and recovered than their male counterparts (Boydstun 1994; Zhou 2002). Additionally, females tend to remain within the spawning area to guard redds, whereas males have a tendency to disperse downstream and out of the survey area after spawning (Killam 2009). For example, in 1998, 1999, and 2000 the winter Chinook carcass survey male to female ratio was 1:8.9, 1:8.4, and 1:5.0, respectively (Snider et al 2001). The disparities in sex ratios related to survey techniques can have large net effects

[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). Critical habitat for winter Chinook salmon has been designated from Keswick Dam (RM 302) to the Golden Gate Bridge (58 FR 33212; June 16, 1993). Winter Chinook salmon have been listed as endangered under the CESA since September 22, 1989 (California Code of Regulations, Title XIV, Section 670.5). Federal endangered status was reaffirmed June 27, 2005 (70 FR 37160) and August 11, 2011 (76 FR 50447).

on the estimated number of spawning females, which in turn, can have considerable effects on the JPE. In light of the technical difficulties in estimating adult escapement described above, the use of the JPE model may be subject to considerable uncertainty.

Estimated escapement is just one factor affecting the accuracy of JPE's. Another factor, not addressed directly in the JPE model, is success on the spawning grounds. Many adult salmon may return to spawn, but spawning and rearing habitat conditions vary between years and, at times, may not be favorable for successful reproduction (Heming 1981; Reiser and White 1988; Botsford and Brittnacher 1998). For many years, the JPE model used a constant of 25% egg-to-fry survival rate (ETF) to estimate winter Chinook fry production which discounted how annual variability in escapement, or river and spawning habitat conditions might increase or decrease spawning success. In recent years, the ETF survival rate used in the JPE model has been adjusted annually based on juvenile monitoring data.

The United States Fish and Wildlife Service (USFWS) has conducted direct monitoring of juvenile winter Chinook passage at RBDD since 1994. Martin et al. (2001) developed quantitative methodologies for indexing juvenile passage using rotary-screw traps. The USFWS rotary trap juvenile production indices (JPI's) have been used in support of production estimates generated by the NMFS JPE 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), (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 purposes of measuring juvenile passage. Since 2012, the RBDD has not been in operation, yet sampling conditions have remained comparable due in part to the remaining dam structure that continues to confine and funnel the river through its concrete piers.

The objectives of this study were to (1) estimate the abundance of brood-year (BY) 2014 juvenile winter Chinook passing RBDD, (2) define temporal patterns of abundance, (3) determine if JPI's from rotary trapping support modeled JPE's generated from the carcass survey and (4) estimate ETF survival rates of winter Chinook based on fry–equivalent JPI's.

This annual report addresses, in detail, our juvenile winter Chinook monitoring activities at RBDD for the period July 1, 2014 through June 30, 2015. This report includes winter Chinook JPI's for the complete BY 2014 emigration period. Fall, late-fall and spring-run Chinook 2014 JPI's are located in the Appendix tables. This report is submitted to the USBR 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 is the largest river system in California, flowing south through 600 kilometers (km) of the state (Figure 1). It originates in northern California near Mt. Shasta as a mountain stream, widens as it drains adjacent slopes of the Coast, Klamath, Cascade, and Sierra Nevada mountain ranges, and reaches the ocean at the San Francisco Bay. Although agricultural and urban development have impacted the river, the upper river (below Keswick Dam) remains mostly unrestricted and supports areas of intact riparian vegetation. In contrast, urban and agricultural development has impacted much of the river between Red Bluff and the San Francisco Bay. Impacts include, but are not limited to: channelization, water diversion, agricultural and municipal run-off, and loss of associated riparian vegetation.

The Red Bluff Diversion Dam site is located at river-kilometer 391 (RK 391) on the Sacramento River, approximately 3-km southeast of Red Bluff, California (Figure 1). The dam is 226 meters (m) wide and has eleven, 18-m wide fixed-wheel gates that were lowered to impound and divert river flows into the Tehama-Colusa Canal. Since the fall of 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 and infrastructure were decommissioned in 2015.

Methods

Sampling gear.—Sampling was conducted along a transect using four 2.4-m diameter rotary-screw traps (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, but generally sampled in river-margin (east and west river-margins) and mid-channel habitats simultaneously (Figure 2). Rotary traps were positioned within these *spatial zones* unless sampling equipment failed, river depths were insufficient (< 1.2 m), or river hydrology restricted our ability to sample with all traps (water velocity < 0.6 m/s).

Sampling regimes.—In general, rotary traps sampled continuously throughout 24-hour periods and were serviced once daily. During periods of high winter Chinook abundance or elevated river flows with heavy debris loads, traps were serviced multiple times per day, continuously, or at randomly generated periods to reduce incidental mortality. When abundance of winter Chinook was very high for an extended period, sub-sampling protocols were implemented to reduce take and incidental mortality 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 winter Chinook captured or the probability of successfully sampling various river conditions. Typically, rotary traps were structurally modified to only sample one-half of the normal volume of water (Gaines and Poytress 2004). If further reductions in capture were needed, the number of traps sampling decreased from four to three. During storm events or elevated river discharge levels, the 24-hour sampling period was divided into four or six non-overlapping strata and stratum 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 were needed or river conditions were intolerable, sampling was 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 mean daily estimated values (i.e., interpolated).

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 criteria developed by Greene[2] (1992). 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 applicable.

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 where less than four traps were sampling, traps were structurally modified to sample only one-half the normal volume of water or when less than 7 days were sampled.

Trap efficiency trials.—Fish were marked with Bismarck brown staining solution (Mundie and Traber 1983) prepared at a concentration of 21.0 mg/L of water. Fish were stained for a period of 45-50 minutes, removed, and allowed to recover in fresh water. Marked fish were held for 6-30 hours before being released 4-km upstream from RBDD after 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.

Trap efficiency modeling.—Trap efficiency (i.e., the proportion of the juvenile population passing RBDD captured by traps) based on mark-recapture trials was plotted with %*Q* to develop a simple least-squares regression equation (Martin et al. 2001). The

[2] 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.

model-derived equation was then used to calculate predicted daily trap efficiencies based on estimates of daily river volume sampled.

The trap efficiency model was developed by conducting 142 mark-recapture trials at RBDD between 1998 and 2014 (Martin et al. 2001, Poytress and Gruber 2015). The 142-trial model was augmented starting in brood-year 2014 to remove pre-2002 trials that were conducted using CNFH hatchery fall run smolts and RBDD gates-in trials, as recommended in Poytress et al. (2014). The current model therefore relies on 75 wild fish based mark-recapture trials conducted only with the RBDD gates out between 2002 and 2014 ($r^2 = 0.68$, $P < 0.001$, df = 75; Figure 3).

Estimated daily passage ($\hat{P}_d$).—The following procedures and formulae were used to derive daily and weekly estimates of total numbers of winter Chinook salmon 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. $$\hat{T}_d = (0.0070329)(\%\hat{Q}_d) + 0.0013142$$

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

Weekly passage ($\hat{P}$).—Population totals for numbers of Chinook salmon 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 production estimates.—Winter Chinook fry (≤ 45 mm FL) and pre-smolt/smolt (≥ 46 mm FL) passage was estimated from JPI by size class. However, the ratio of fry to pre-smolt/smolts passing RBDD varies 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's and a weighted (1.7:1) pre-smolt/smolt JPI (59% fry-to-presmolt/smolt survival; Hallock undated). Rotary trap JPI's could then be directly compared to JPE's.

Egg-to-fry survival estimates.— Annual juvenile winter Chinook ETF survival rates were estimated by calculating fry-equivalent JPI's and dividing by the estimated number of eggs in-river based on carcass survey female estimates (D. Killam, CDFW, personal communication). Average female winter Chinook fecundity data was obtained from the Livingston Stone National Fish Hatchery annual spawning records.

Juvenile estimate comparisons.—The JPI is a direct measure of juvenile production and has been used to track the NMFS JPE model, an indirect measure of juvenile production since 2000 (Martin et al. 2001). A juvenile production estimate derived from in-river spawner populations based on carcass survey data (Carcass JPE) has been very comparable in trend and magnitude when compared with the fry-equivalent JPI since 2002 (Poytress et al. 2014).

As noted in the Introduction section, the NMFS JPE model historically has not accounted for the success of spawners on the spawning grounds. In 2014, NMFS based their JPE model on carcass survey data but relied upon USFWS fry-equivalent JPI's as an intermediate variate in their model representing survival (S1) to RBDD (NMFS 2015). Preliminary, real-time JPI's indicated significantly lower passage of winter Chinook juveniles through the end of the typical peak migration period (i.e., end of October) and Sacramento River water temperatures from Shasta Dam releases were not able to meet standards set for the thermal compliance point during the spawning season (NMFS 2009).

To demonstrate the difference between the estimates, we simulated what the fry-production JPE value at RBDD would have been using NMFS' traditional carcass-survey based model and an averaged ETF survival rate of 27%. As a result, we could not compare two official estimates directly but compare the fry-equivalent JPI with simulated NMFS Carcass JPE model fry production. Comparisons between all years' juveniles to adult returns (as noted above in egg-to-fry survival estimate section) were also conducted.

Results

Sampling effort.—Weekly sampling effort throughout the 2014 brood-year emigration period was moderate and ranged from 0.11 to 1.00 ($\bar{x}$ = 0.58; *N* = 52 weeks; Table 1). Weekly sampling effort ranged from 0.11 to 0.64 ($\bar{x}$ = 0.46; *N* = 26 weeks) between July and December, the period of greatest juvenile winter Chinook emigration, and 0.14 to 1.00 ($\bar{x}$ = 0.70; *N* = 26 weeks) during the latter half of the emigration period (Table 1).

The high variance in sampling effort throughout the year can be attributed to several sources. They included: (1) intentional reductions in effort resulting from sampling < 4 traps, cone modification(s), or unsampled 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) elevated aquatic debris loads in the late summer and fall coupled with lack of staff to perform multiple daily clearings. The maximum sampling effort was intentionally reduced to 0.75 effort (i.e., only three traps operating) between July and January to allow for public transit on the east side of the Sacramento River at RBDD and because of low staff levels. Four traps resumed sampling after decomissioning of the RBDD was complete and a new trap rigging system was employed in February 2015.

Trap efficiency trials.—Three mark-recapture trials were conducted using naturally produced fall-run Chinook between January and February of 2015 to estimate and validate rotary-screw trap efficiency (Table 2). Sacramento River discharge sampled during the trials ranged from 4,390 to 4,836 cfs. Estimated *%Q* during trap efficiency trials ranged from 5.24% to 6.83% ($\bar{x}$ = 5.83%; Table 2).

Trials were conducted using three traps (*N* = 2), and four traps (*N* = 1) with rotary traps sampling with unmodified cones. All trials were conducted using Chinook sampled from rotary traps, and trap efficiencies ranged from 1.99% to 7.64% ($\bar{x}$ = 4.06%). The number of marked fish released per trial ranged from 851 to 1,621 ($\bar{x}$ = 1,200) and the number of marked fish recaptured ranged from 21 to 65 ($\bar{x}$ = 43). All fish were released after sunset and 99.2% of recaptures occurred within the first 24 hours, and 100% within 48 hrs.

Fork lengths of fish marked and released ranged from 30 to 41 mm ($\bar{x}$ = 36.9 mm). Fork lengths of recaptured marked fish ranged from 31 to 42 mm ($\bar{x}$ = 36.3 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 rotary-screw traps and fish were considered fry size class.

The horizontal distribution of recaptured marked fish differed greatly in trials one and two compared to the distribution of unmarked fish. In fact, the highest rate of marked fish recapture occurred in the traps with the lowest rate of unmarked fish capture and vice-versa in the first two trials. The fourth trap was added for the third trial as it was suspected that efficiency might not have been accurate using three traps. This was determined to be incorrect. In the third trial, horizontal distributions were commensurate between marked and unmarked fish indicating marked fish distributed equally with unmarked fish in four of four traps.

The first two trials appeared to have violated the assumption of equal distribution with unmarked fish and were excluded from additional analyses. A group of recently released age-1 hatchery Steelhead, *Oncorhynchus mykiss*, from Coleman National Fish Hatchery was observed feeding in the marked fish release location and these data, in combination, indicate that predation of marked fish at the point of release during trials one and two affected the recapture results (Naman 2008). The third release occurred downstream slightly (~100 m) of a backwater where feeding was observed taking place at sunset. The results of this third trial compared well between marked and unmarked fish distributions indicating little to no impact by predators on trial number three's results.

Trap efficiency modeling.— Trials conducted during BY 2013 were subsequently included within the revised model (Poytress and Gruber 2015). The resultant linear regression model used for BY 2014 was a 75-trial model ($r^2 = 0.68$, $P < 0.001$, df = 75; Figure 3). The model used for BY 2015 will be updated to include only one of the three trials conducted during BY 2014 due to predation effects noted during the first two of three trials (i.e., $N = 76$).

Fork length evaluations.—Weekly median fork length of BY 2014 winter Chinook increased slowly from 34 mm in week 27 to 35 mm in week 40 (Table 3). Median fork lengths consistently increased from 42 mm in week 41 to 73 mm in week 48. Thereafter, an overall upward trend continued from week 50 to week 21 with slight variability in weekly median fork lengths. Median fork lengths peaked at 152 mm during week 18 and 19 (Figure 4a). One fish was sampled in late May that measured 237 mm.

Brood-year 2014 winter Chinook fry median fork lengths ranged from 34 mm in week 27 to 44 mm in week 44 and 47 (Figure 5a). Brood-year 2014 pre-smolt/smolt median fork length ranged from 46 to 73 mm, increasing by 2.1 mm per week, on average, from week 35 to week 48 (Figure 6a). From week 49 to 18, average weekly median fork length increase was 3.9 mm per week from 71 to 152 mm.

The length frequency distribution of brood-year 2014 juveniles captured at RBDD ranged from 28 mm to 237 mm (Figure 7). Fry sized individuals ranged from 28 to 45 mm and comprised 62.2% of all samples collected. Pre-smolt/smolt sized individuals ≥46 mm represented the remaining 37.8% of BY 2014 winter Chinook samples.

Patterns of abundance.—Brood-year 2014 winter Chinook juvenile estimated passage at RBDD was 411,322 fry and pre-smolt/smolts combined (Table 3). Winter Chinook juvenile passage increased from 67 in week 27 (July) to a peak of 65,127 during week 38 (late September). Thereafter, weekly juvenile passage fluctuated between 3,333 and 59,839 from weeks 39 to 51. Weeks 27 to 52 accounted for 95.1% of the total brood-year 2014 winter Chinook juvenile passage. Passage of brood-year 2014 winter Chinook ceased by the end of May (week 21: Table 3; Figure 4b).

Brood-year 2014 fry sized juveniles (≤45 mm FL) comprised 61% of total estimated winter Chinook passage (Table 3). Fry began to pass RBDD during week 27 (first week of July). Weekly fry passage increased slowly to 4,414 in week 33 (mid-August). Passage increased rapidly over the next five weeks peaking at 62,814 in week 38. Fry passage consistently declined through week 44; ultimately ending during the last week of November (week 47: Table 3; Figure 5b).

Brood-year 2014 pre-smolt/smolt sized juveniles (≥46 mm FL) comprised 39% of total passage and the first observed emigration past RBDD occurred in week 35 (first week of September; Table 3). Weekly pre-smolt/smolt passage increased to 6,174 by the end of September. Weekly passage peaked at 20,720 during week 43, late October (Table 3; Figure 6b). Peak passage in week 43 was coincident with the first storm and runoff event of the year (Figure 10). Weekly passage fluctuated between 20,720 and 3,333 with an overall declining trend from weeks 44 to 51. Pre-smolt/smolt passage was relatively low between week 51 and week 21 whereby it concluded in late-May (Table 3).

2014 Fry-equivalent JPI and egg-to-fry survival estimate.—The fry-equivalent rotary trap JPI for brood-year 2014 was 523,872 with the lower and upper 90% CI extending from 301,197 to 746,546 juveniles, respectively (Table 4). The estimated egg-to-fry survival rate based on the BY 2014 winter Chinook fry-equivalent JPI was estimated at 5.9%. The range of ETF survival based on 90% CI's was 3.4% to 8.4% (Table 5).

Comparisons of JPI's and JPE's.—The NMFS brood-year 2014 Carcass JPE had a simulated value of 2,409,171 fry at RBDD[3]. The value was considerably greater than the JPI, exceeding the upper 90% C.I. by 223% or 1,662,625 juveniles (Table 4). When directly comparing the two estimates, the simulated Carcass JPE was greater by 1,885,299 juveniles or 360% greater than the fry-equivalent rotary trap JPI (Figure 8).

We combined data from 1995 to 2013 with brood-year 2014 JPI's and Carcass JPE's to evaluate the linear relationship between the estimates. Seventeen 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 Carcass JPE's ($r^2 = 0.84$, $P < 0.001$, df = 16; Figure 9). The addition of the 2014 data, similar to 2013, decreased the correlation between the two estimates.

In terms of the magnitude of the two estimates, a Mann-Whitney Rank Sum test detected no significant difference among rotary trap JPI's and Carcass JPE's ($U = 136.00$, $P = 0.78$). For the combined seventeen years of data, Carcass JPE's averaged 25.6% greater than rotary trap JPI's (range = -49% to +360%). Overall, the comparison between 2014 JPI's and JPE's resulted in the greatest disparity, by percentage, between estimates in seventeen years of comparisons.

[3] This is a simulated JPE based on the previous method before being updated in 2015 by NMFS.

Discussion

*Sampling effort***.—**During the primary winter Chinook capture and passage period of July through December of 2014, sampling effort was moderate. The reasons varied, but the most significant impediment to sampling at full effort during the primary migration period was due to lack of adequate numbers of field staff to sample 7 days per week. Moreover, in 2013 and more so in 2014, very high levels of aquatic vegetation/debris accumulated in the traps beginning in August as compared to 2011 and 2012. Aquatic plant species encountered included native and non-native species such as Common elodea (*Elodea canadensis*)*,* Eurasian milfoil (*Myriopyllum spicatum*)*,* and Curlyleaf pondweed (*Potamogeton crispus*). Entrainment of large amounts of aquatic debris in traps can increase the incidental mortality of captured endangered winter Chinook. To mitigate for very high debris levels, traps were cleared twice per day which requires field staff to cover two shifts per day seven days weekly (i.e., 14 shifts per week). The program was not allowed to be staffed to this level due to agency hiring restrictions resulting from the 2013 Federal Budget Sequestration and subsequent limits imposed on hiring activities by National and Regional Managers.

Another method to reduce effort during periods of suboptimal staffing levels was to sample three traps to reduce impact and mortality concerns. The trap efficiency model employed by the project was designed to allow passage estimates to be accurately estimated based on sampling of three or four traps (Martin et al. 2001). The fourth trap, typically set in the east margin of the river, was idled during the salmon fishing season to allow public transit as noted in Poytress and Gruber (2015). Sampling with three traps has been incorporated into the trap efficiency model (Figure 3) and does not affect the accuracy of daily 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 3; Figure 4b) following a typical fry outmigration pattern (Poytress et al. 2014). Catch and passage soon dropped off after the peak as fry grew into the pre-smolt/smolt life stage and passage steadily decreased until late-October when a storm event resulted in elevated Sacramento River flows in excess of 8,000 cfs (Figure 10). This event resulted in a 38% increase in flow and greater than two orders of magnitude increase in turbidity as compared with ambient condition two days prior (i.e., 1.9 to 291.0 NTU). A small pulse of fry-sized winter Chinook and a substantial pulse of winter Chinook pre-smolt/smolts accounting for 37% of all smolts detected during the brood-year occurred during weeks 43-45 coinciding with the runoff event (Table 3; Figure 6b).

Fry outmigrants represented 61% of total winter Chinook passage with pre-smolt/smolts (>45 mm FL) representing the remaining 39%. These values were within one standard deviation of the 13-year mean ratio (in percent) of 76:24 seen at RBDD. The proportion interpolated in BY2014 due to incomplete sampling was valued at 31% and 39% for fry and pre-smolt/smolt passage, respectively. The fry interpolated values fell within one standard deviation of the 13-year mean while the pre-smolt/smolt interpolation value fell outside one standard deviation of the 13-year mean. Effort decreased during the pre-smolt/smolt migration period beginning in December due to staff attrition and hiring restrictions. As a result, storm events were randomly sub-sampled to the extent possible. By the end of November, passage data collected accounted for 93% of the total annual BY 2014 winter Chinook estimate (Table 3). Overall, interpolation between missed days of sampling accounted for 34% of the total BY 2014 estimate of 411,322 winter Chinook passing RBDD.

2014 Fry-equivalent JPI and egg-to-fry survival estimate.—The BY2014 winter Chinook fry-equivalent juvenile production index value of 523,872 represented the lowest estimate of winter Chinook production since 1996 (Table 4). Although the timing and size class of fish sampled during the brood-year were more or less normal, in comparison to previous years, the total abundance estimate was lower than expected based on adult returns and estimates of in-river female spawners. In the prior twelve years, egg-to-fry survival estimates averaged 25.4%. For BY 2014, winter Chinook fry-equivalent based egg-to-fry-survival was estimated at a mere 5.9%. This was the lowest estimated survival rate in 18 years of monitoring (Table 5).

Physical or biological factors that may contribute to low Chinook salmon egg-to-fry survival estimates at RBDD can occur during the adult upstream migration and spawning period through egg incubation, fry emergence as well as the rearing period. Below average precipitation in California during 2014 resulted in a third consecutive year of drought conditions. As a result, the 2014 water temperature compliance point for protection of winter Chinook spawners (NMFS 2009) was adjusted upstream by eight miles as compared to 2013 due to limited cold water pool reserves in Shasta Dam (Killam et al. 2015).

Water temperatures affect Chinook egg survival directly (USFWS 1999) and overall spawning success indirectly (e.g., reduced pathogen resistance; see Schreck 1996 and Karvonen et al. 2010). Little data exists on the indirect effects or mechanisms by which water temperatures affected spawning winter Chinook in 2014. For direct effects, Killam and Thompson (2015) determined that warm water temperatures in the Sacramento River resulted in poor survival of winter Chinook progeny. Killam et al. (2015) noted that greater than 80% of winter Chinook alevins were exposed to temperatures above 58°F and greater than 50% were exposed to temperatures above 60°F. From these data, they surmised that over 95% of the eggs and fry succumbed to mortality. The inverse of these results (i.e., mortality inversely related to survival) fell within the range of egg-to-fry survival estimates generated by 2014 juvenile winter Chinook monitoring results (Table 5).

Comparisons of JPI's and JPE's.—The 2014 winter Chinook fry-equivalent JPI was calculated at 523,872 juveniles. When compared to the Carcass JPE value of 2,409,171, the JPI was a mere 22% of what was predicted based on the simulated carcass-based JPE model. Differences in annual JPE and JPI values are common and the range of differences between the two estimates over the prior sixteen years has ranged from 49% less to 79% more (Figure 8). The 2014 JPI estimated value does fall *outside* of the range of differences detected over the last 17 years of comparisons and for the second consecutive year. Additionally, the 2014 Carcass JPE fell well outside of the confidence intervals around the JPI for a second year in a row, by nearly 1.9 million juveniles, and was 223% greater than the upper 90% confidence interval.

Comparing the mean values of the JPI and Carcass JPE over seventeen years of data did not indicate a significant statistical difference. Looking at the magnitude of the difference between estimates, a minimum of ~1.9 million juveniles, indicated a substantial numerical difference between the calculations. The fact that the carcass-survey based NMFS JPE model does not account for environmental conditions on the spawning grounds was clearly demonstrated by the substantial disparity between the two estimates using 2014 data.

Due to the disparity noted by preliminary JPI's by December of 2014, in corroboration with water temperature data collected during the winter Chinook spawning period (Killam and Thompson 2015; Killam et al. 2015), the collective fisheries agencies (NMFS, USFWS, CDFW) could not support the Carcass JPE value of 2,409,171 for BY 2014 fry production at RBDD. The USFWS fry-equivalent JPI value of 523,872 provided a more credible estimate that better reflected the effects of the high water temperatures experienced by eggs and alevins in the Sacramento River in 2014. As a result, the Carcass JPE model was changed in 2015 to incorporate the fry-equivalent JPI that accounts for annual variability in ETF survival rates based on actual observations of juvenile production.

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Table 1.— Summary of brood-year 2014 weekly rotary trap sampling effort. 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. A winter Chinook brood-year (BY) is identified as beginning on July 1 and ending on June 30.

Sampling effort			
Week	BY 2014	Week	BY 2014
27 (Jul)	0.55	1 (Jan)	0.21
28	0.54	2	0.38
29	0.54	3	0.32
30	0.46	4	0.43
31 (Aug)	0.54	5 (Feb)	0.61
32	0.54	6	0.14
33	0.54	7	0.43
34	0.43	8	0.57
35 (Sep)	0.43	9 (Mar)	0.71
36	0.54	10	1.00
37	0.54	11	0.57
38	0.54	12	1.00
39	0.46	13 (Apr)	1.00
40 (Oct)	0.54	14	0.93
41	0.43	15	1.00
42	0.54	16	1.00
43	0.54	17	0.93
44 (Nov)	0.43	18 (May)	1.00
45	0.54	19	0.82
46	0.54	20	0.54
47	0.64	21	0.75
48 (Dec)	0.32	22 (Jun)	0.75
49	0.11	23	0.75
50	0.21	24	0.70
51	0.11	25	0.75
52	0.32	26	0.79

Table 2.—Summary of results from mark-recapture trials conducted in 2015 (*N* = 3) to evaluate rotary-screw trap efficiency at Red Bluff Diversion Dam (RK391), 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	2015	1,691	37.0	44	35.9	2.60	5.24	3	No
2	2015	1,057	36.8	21	36.7	1.99	5.42	3	No
3	2015	851	36.9	65	36.3	7.64	6.83	4	No

Table 3.— 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, 2014 through June 30, 2015 (Brood-year 2014). 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).

Winter-run Chinook Brood-year 2014							
	Fry		Pre-smolt/smolts		Total		Fry-equivalent
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
27 (Jul)	67	34	0	-	67	34	67
28	198	34	0	-	198	34	198
29	476	33	0	-	476	33	476
30	471	32	0	-	471	32	471
31 (Aug)	1,134	34	0	-	1,134	34	1,134
32	973	35	0	-	973	35	973
33	4,414	34	0	-	4,414	34	4,414
34	12,012	35	0	-	12,012	35	12,012
35 (Sep)	26,204	35	67	46	26,271	35	26,318
36	19,026	35	0	-	19,026	35	19,026
37	25,903	35	318	50	26,221	35	26,443
38	62,814	35	2,312	51	65,127	35	66,745
39	53,665	35	6,174	52	59,839	35	64,161
40 (Oct)	23,496	35	7,118	52	30,614	35	35,597
41	10,402	35	8,485	54	18,887	42	24,826
42	3,566	37	10,660	56	14,225	53	21,687
43	2,595	42.5	20,720	58	23,315	57	37,819
44 (Nov)	1,465	44	17,866	60	19,331	59	31,837
45	1,295	43	20,171	62	21,466	61	35,586
46	254	43	10,554	64	10,808	64	18,196
47	104	44	10,436	70	10,540	70	17,845
48 (Dec)	0	-	15,603	73	15,603	73	26,526
49	0	-	3,333	71	3,333	71	5,666
50	0	-	6,788	73	6,788	73	11,539

Table 3.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalent
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
51	0	-	3,618	85	3,618	85	6,151
52	0	-	1,968	80.5	1,968	80.5	3,346
1 (Jan)	0	-	4,014	94	4,014	94	6,823
2	0	-	1,783	105	1,783	105	3,031
3	0	-	1,883	111.5	1,883	111.5	3,201
4	0	-	1,034	116	1,034	116	1,758
5 (Feb)	0	-	1,113	122	1,113	122	1,892
6	0	-	288	120	288	120	489
7	0	-	901	119	901	119	1,532
8	0	-	563	123	563	123	956
9 (Mar)	0	-	305	120	305	120	518
10	0	-	97	124	97	124	165
11	0	-	143	137	143	137	243
12	0	-	327	126	327	126	556
13 (Apr)	0	-	287	125	287	125	489
14	0	-	326	116.5	326	116.5	554
15	0	-	658	136	658	136	1,119
16	0	-	145	140	145	140	246
17	0	-	486	146	486	146	826
18 (May)	0	-	157	152	157	152	267
19	0	-	40	152	40	152	68
20	0	-	0	-	0	-	0
21	0	-	46	237	46	237	79
22 (Jun)	0	-	0	-	0	-	0
23	0	-	0	-	0	-	0
24	0	-	0	-	0	-	0
25	0	-	0	-	0	-	0
26	0	-	0	-	0	-	0
BY total	250,536		160,786		411,322		523,872

Table 4.—Comparisons between juvenile production estimates (JPE) and rotary trapping juvenile production indices (JPI). Carcass survey JPE's were derived from the estimated adult female escapement from the upper Sacramento River winter Chinook carcass survey. From BY96 through BY99, assumptions used in the carcass survey based NMFS JPE model were as follows: (1) 5% pre-spawning mortality, (2) 3,859 ova per female, (3) 0% loss due to high water temperature, and (4) 25% egg-to-fry survival. From BY00 through BY14, assumptions 1-3 were estimated using carcass survey data gathered on the spawning grounds, from Livingston Stone National Fish Hatchery spawning records, and aerial redd surveys, respectively. Dashes (-) indicate no survey conducted.

	Rotary-trapping [a]			Carcass survey [b]	
		90% C.I.			
Brood-year	Fry-equivalent JPI	Lower	Upper	Fry-equivalent JPE	Female Spawners
1996	469,183	384,124	818,096	550,872	571
1997	2,205,163	1,876,018	3,555,314	1,386,346	1,437
1998	5,000,416	4,617,475	6,571,241	4,676,143	4,847
1999	1,366,161	1,052,620	2,652,305	1,490,249	1,626
2000	-	-	-	4,946,418	5,397
2001	-	-	-	5,643,635	4,827
2002	7,635,469	2,811,132	13,144,325	6,964,626	5,670
2003	5,781,519	3,525,098	8,073,129	6,181,925	5,179
2004	3,677,989	2,129,297	5,232,037	2,786,832	3,185
2005	8,943,194	4,791,726	13,277,637	12,109,474	8,807
2006	7,298,838	4,150,323	10,453,765	11,818,006	8,626
2007	1,637,804	1,062,780	2,218,745	1,864,521	1,517
2008	1,371,739	858,933	1,885,141	1,952,614	1,443
2009	4,972,954	2,790,092	7,160,098	3,728,444	2,702
2010	1,572,628	969,016	2,181,572	1,049,385	813
2011	996,621	671,779	1,321,708	512,192	424
2012	1,814,244	1,227,386	2,401,102	1,684,039	1,491
2013	2,481,324	1,539,193	3,423,456	4,431,064	3,577
2014	523,872	301,197	746,546	*2,409,171* [c]	1,681

[a] Rotary trap fry equivalent JPI generated by summing fry passage at RBDD with a weighted pre-smolt/smolt passage estimate. Pre-smolt/smolts were weighted by approximately 1.7 (59% fry to pre-smolt/smolt survival; Hallock undated).

[b] Carcass survey derived estimated effective spawner population from Snider et al. (1996-2000) , Bruce Oppenheim (2000-2013), NMFS pers comm and Doug Killam (2014), CDFW, pers. comm..

[c] Simulated Fry-Equivalent JPE was estimated using carcass survey variables, but not used for official purposes due to large disparity between monitoring and modeling results. Value generated for comparison purposes only.

Table 5.—Summary of estimated egg-to-fry (ETF) survival rates derived from winter Chinook carcass survey female escapement estimates, average fecundity (number of eggs per spawning female), and the RBDD rotary trapping fry-equivalent JPI. Lower and upper 90% confidence intervals (L90 CI: U90 CI) and associated estimates of rates of egg-to-fry survival in parentheses. Dashes (-) indicate no survey was conducted.

Brood-year	Female Spawners [a]	Average Fecundity [b]	Fry-equivalent JPI [c] (L90 CI : U90 CI)	Estimated Recruits/Female	ETF Survival Rate (%) (L90 CI: U90 CI)
1996	571	3,859	469,183 (384,124 : 818,096)	822	21.3 (17.4 : 37.1)
1997	1,437	3,859	2,205,163 (1,876,018 : 3,555,314)	1,535	39.8 (33.8 : 64.1)
1998	4,847	3,859	5,000,416 (4,617,475 : 6,571,241)	1,032	26.7 (24.7 : 35.1)
1999	1,626	3,859	1,366,161 (1,052,620 : 2,652,305)	840	21.8 (16.8 : 42.3)
2000	-	-	-	-	-
2001	-	-	-	-	-
2002	5,670	4,923	7,635,469 (2,811,132 : 13,144,325)	1,347	27.4 (10.1 : 47.1)
2003	5,179	4,854	5,781,519 (3,525,098 : 8,073,129)	1,116	23.0 (14.0 : 32.1)
2004	3,185	5,515	3,677,989 (2,129,297 : 5,232,037)	1,155	20.9 (12.1 : 29.8)
2005	8,807	5,500	8,943,194 (4,791,726 : 13,277,637)	1,015	18.5 (9.9 : 27.4)
2006	8,626	5,484	7,298,838 (4,150,323 : 10,453,765)	846	15.4 (8.8 : 22.1)
2007	1,517	5,112	1,637,804 (1,062,780 : 2,218,745)	1,080	21.1 (13.7 : 28.6)
2008	1,443	5,424	1,371,739 (858,933 : 1,885,141)	951	17.5 (11.0 : 24.1)
2009	2,702	5,519	4,972,954 (2,790,092 : 7,160,098)	1,840	33.5 (18.7 : 48.0)
2010	813	5,161	1,572,628 (969,016 : 2,181,572)	1,934	37.5 (23.1 : 52.0)
2011	424	4,832	996,621 (671,779 : 1,321,708)	2,351	48.6 (32.8 : 64.5)
2012	1,491	4,518	1,814,244 (1,227,386 : 2,401,102)	1,217	26.9 (18.2 : 35.6)
2013	3,577	4,596	2,481,324 (1,539,193 : 3,423,456)	694	15.1 (9.4 : 20.8)
2014	1,681	5,308	523,872 (301,197 : 746,546)	312	5.9 (3.4 : 8.4)
			Average	1,181	24.8 (16.3 : 36.4)
			Standard Deviation	500	10.4 (8.4 : 15.2)

[a] Carcass survey derived estimated effective spawner population from Snider et al. (1996-2000) , Bruce Oppenheim (2000-2013), NMFS pers comm and Doug Killam (2014), CDFW, pers. comm..

[b] Egg estimates derived from Coleman National Fish Hatchery average of 76 females spawned in 1995, for the years 1996-1999. Data for 2002 – 2014 derived from annual average egg counts of winter-run brood stock spawned at the Livingston Stone National Fish Hatchery.

[c] Rotary trap fry equivalent JPI generated by summing fry passage at RBDD with a weighted pre-smolt/smolt passage estimate. Pre-smolt/smolts were weighted by approximately 1.7 (59% fry to presmolt/smolt survival; Hallock undated).

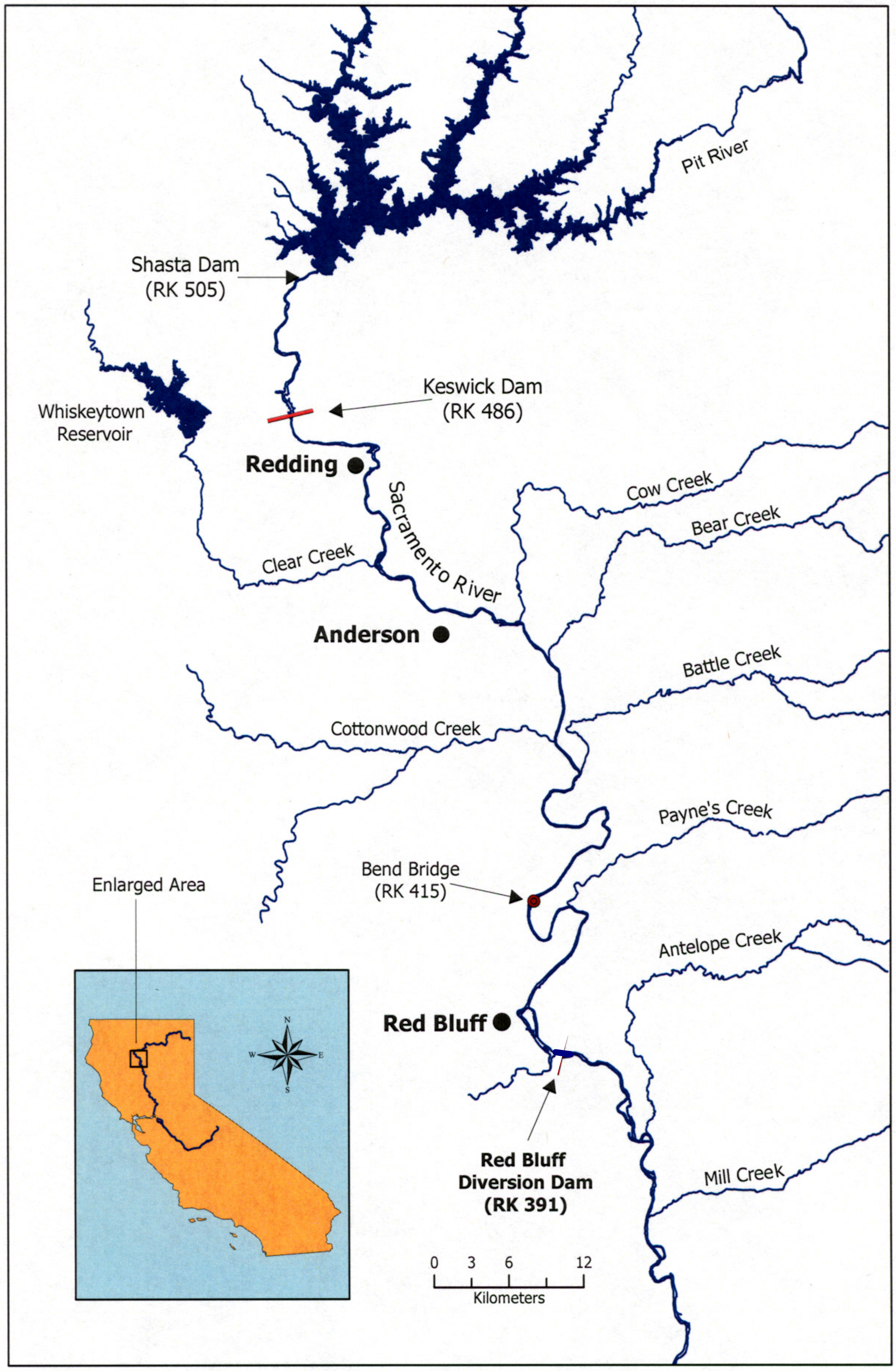

Figure 1. Location of Red Bluff Diversion Dam sample site on the Sacramento River, California at river kilometer 391 (RK 391).

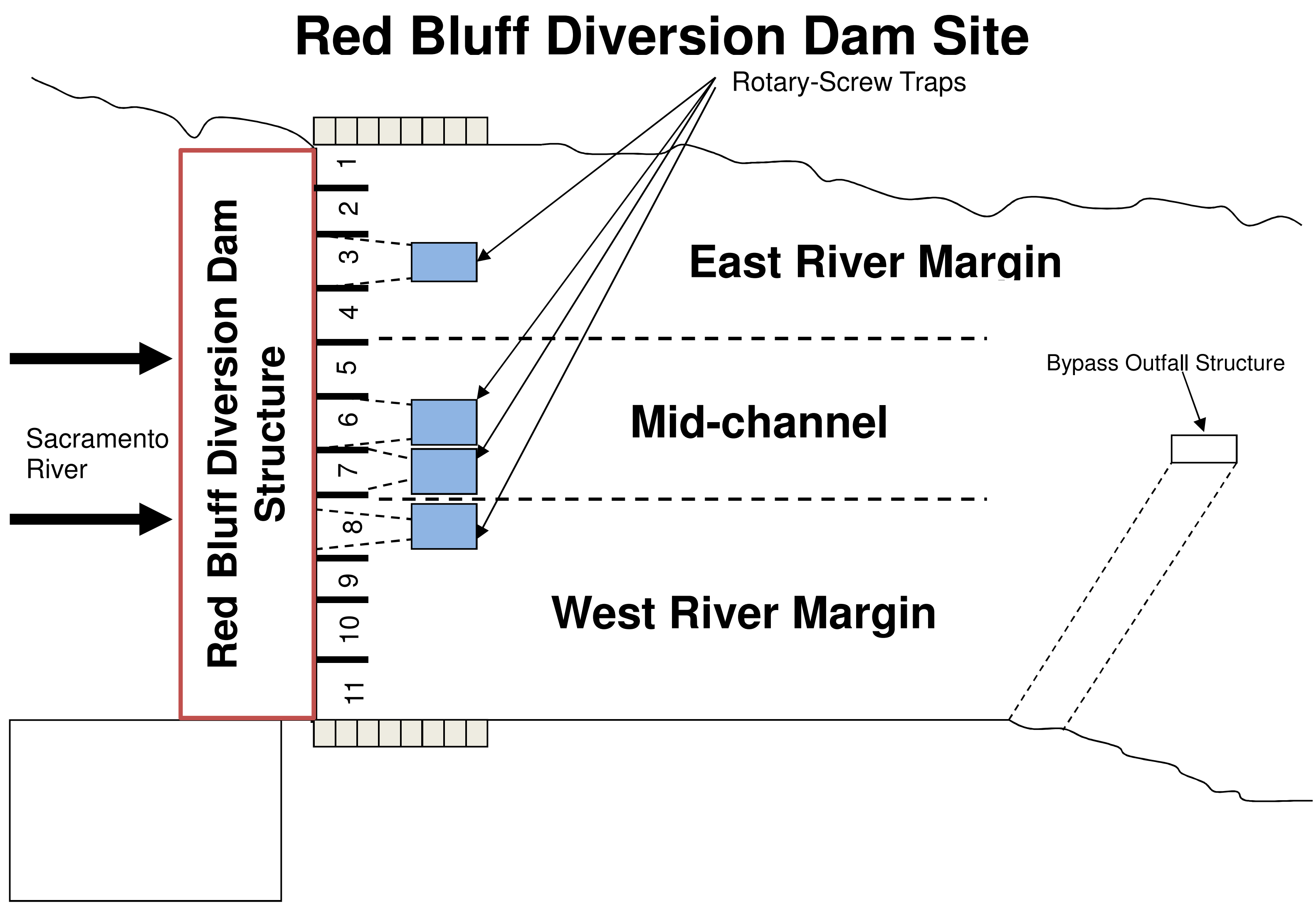

Figure 2. Rotary-screw trap sampling transect schematic of Red Bluff Diversion Dam site (RK 391) on the Sacramento River, CA.

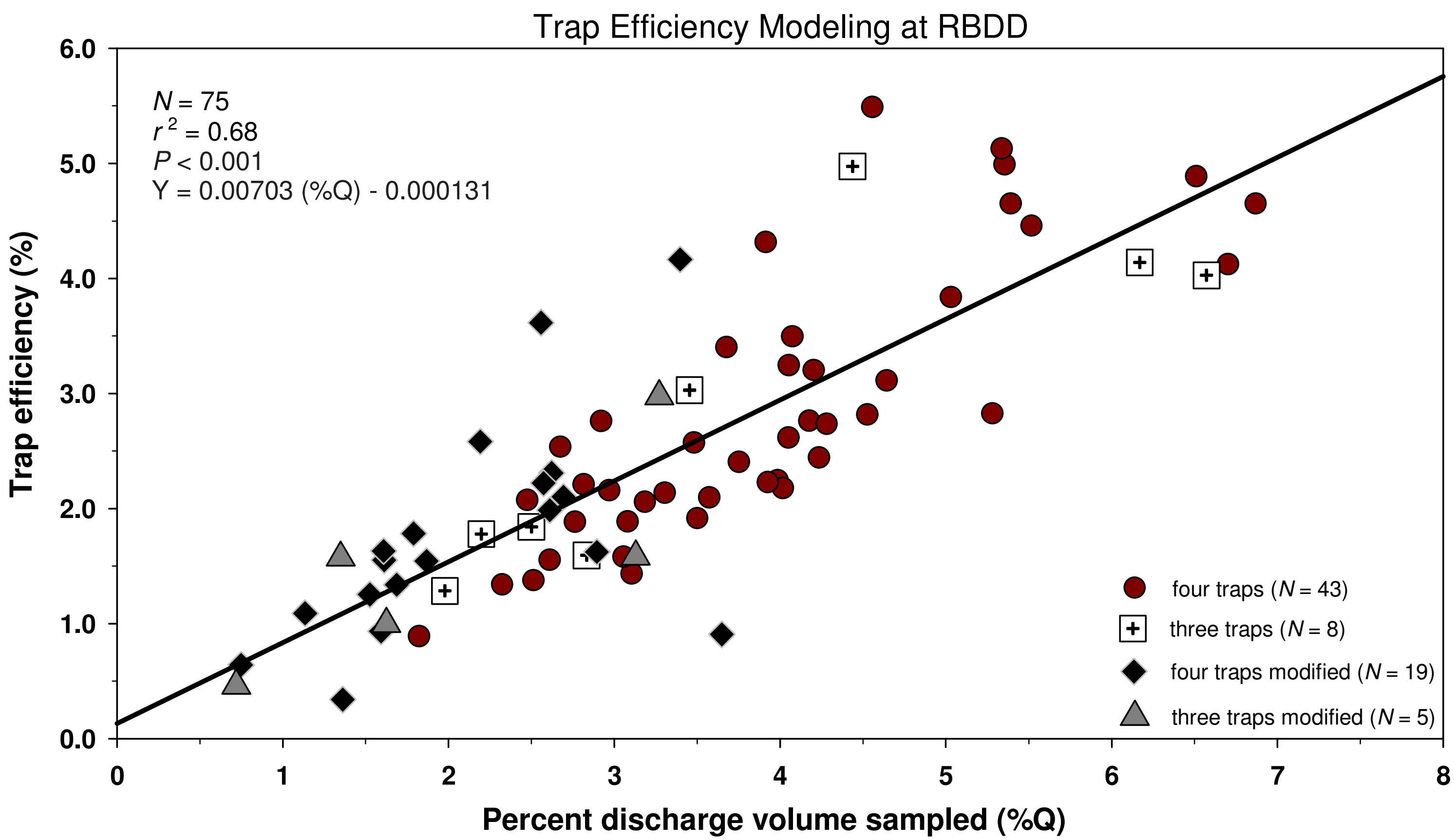

Figure 3. Trap efficiency model for combined 2.4 m diameter rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four traps (*N* = 43), three traps (*N* = 8), or with traps modified to sample one-half the normal volume of water (*N* = 24).

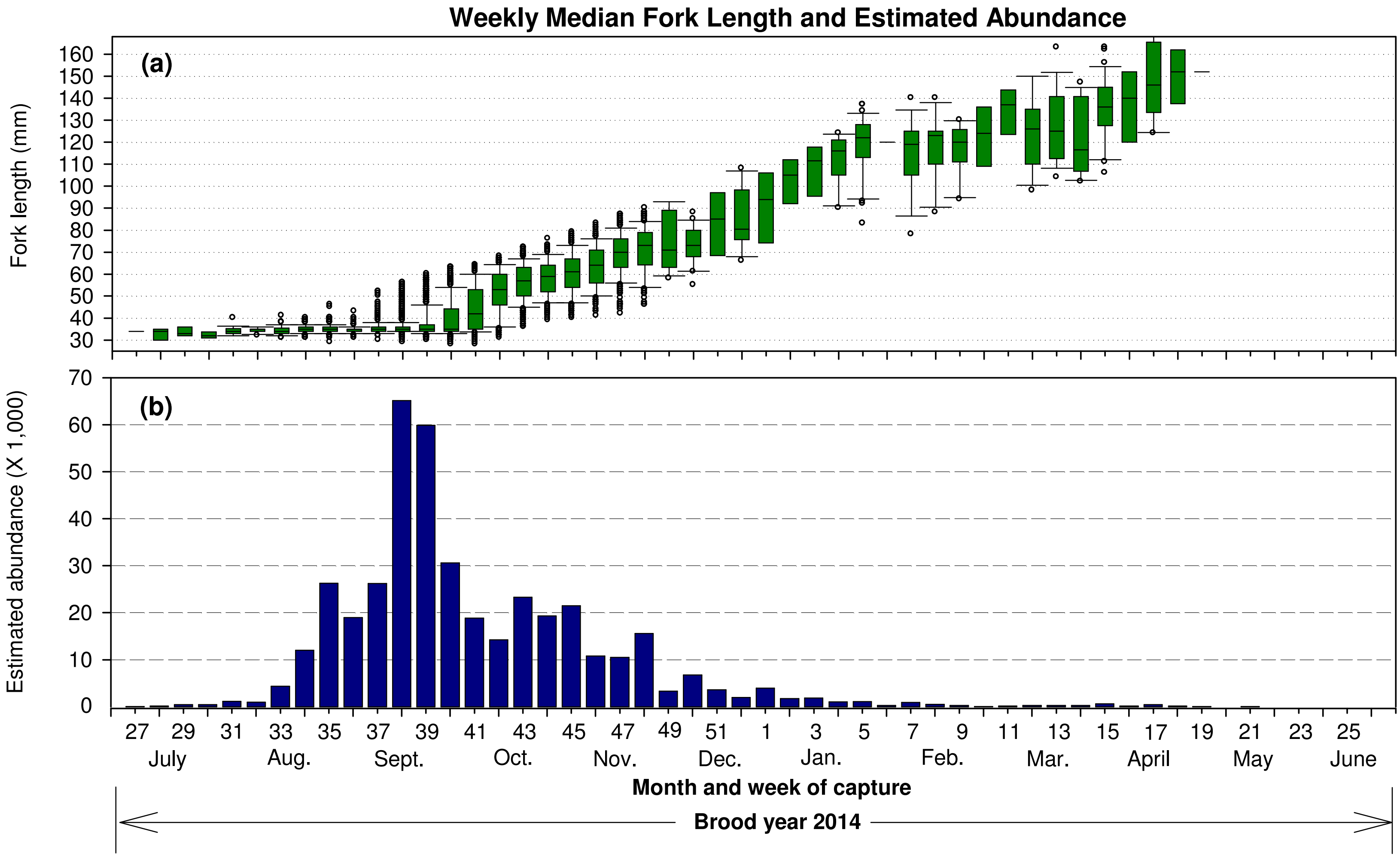

Figure 4. Weekly median fork length (a) and estimated abundance (b) of juvenile winter Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Winter Chinook salmon were sampled by rotary-screw traps for the period July 1, 2014 through June 30, 2015. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

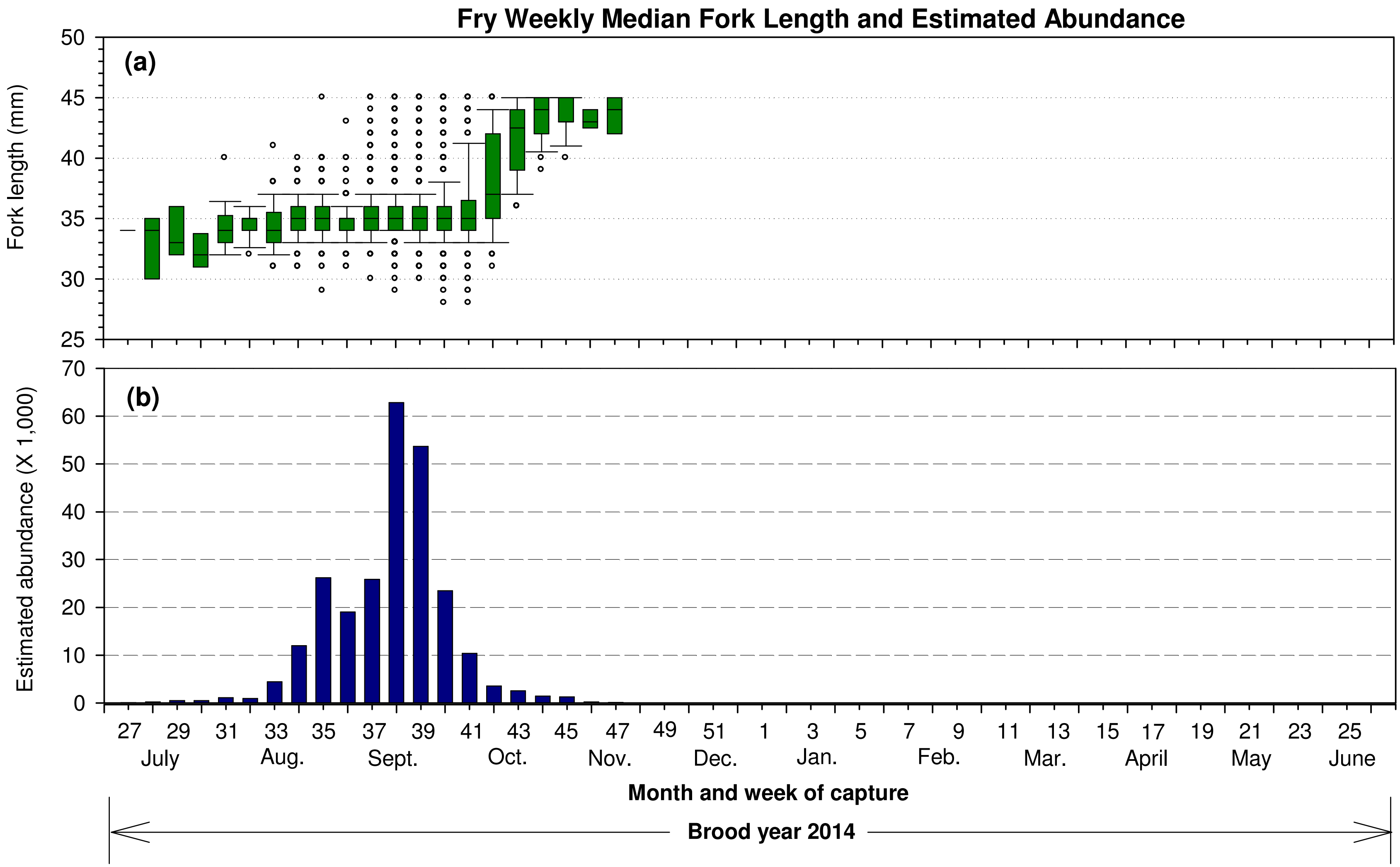

Figure 5. Weekly median fork length (a) and estimated abundance (b) of winter Chinook fry passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Winter Chinook juveniles were sampled by rotary-screw traps for the period July 1, 2014 through June 30, 2015. Box plots display weekly median fork length, 10^{th}, 25^{th}, 75^{th},and 90^{th} percentiles and outliers.

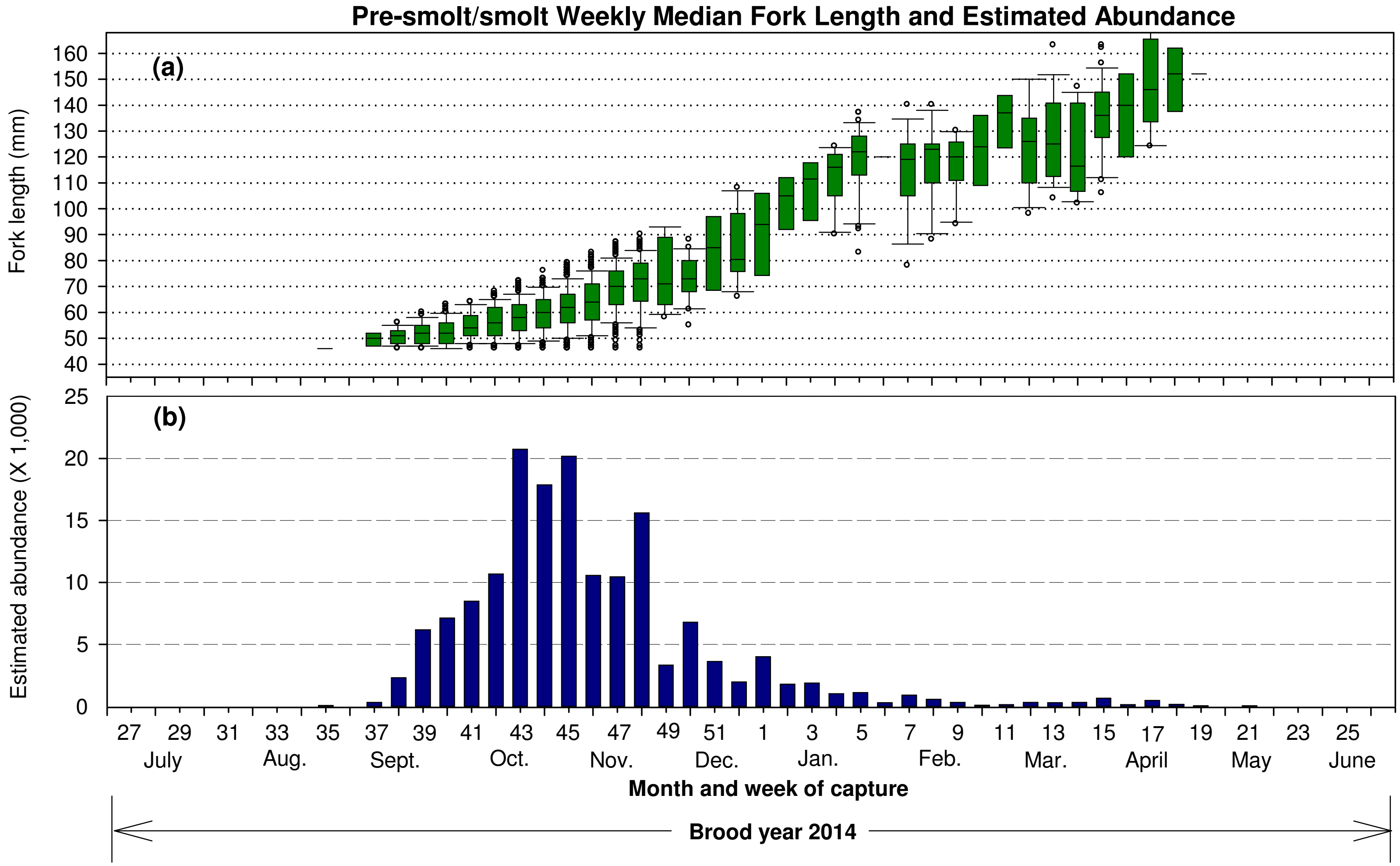

Figure 6. Weekly median fork length (a) and estimated abundance (b) of winter Chinook pre-smolt/smolts passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Winter Chinook juveniles were sampled by rotary-screw traps for the period July 1, 2014 through June 30, 2015. Box plots display weekly median fork length, 10^{th}, 25^{th}, 75^{th},and 90^{th} percentiles and outliers.

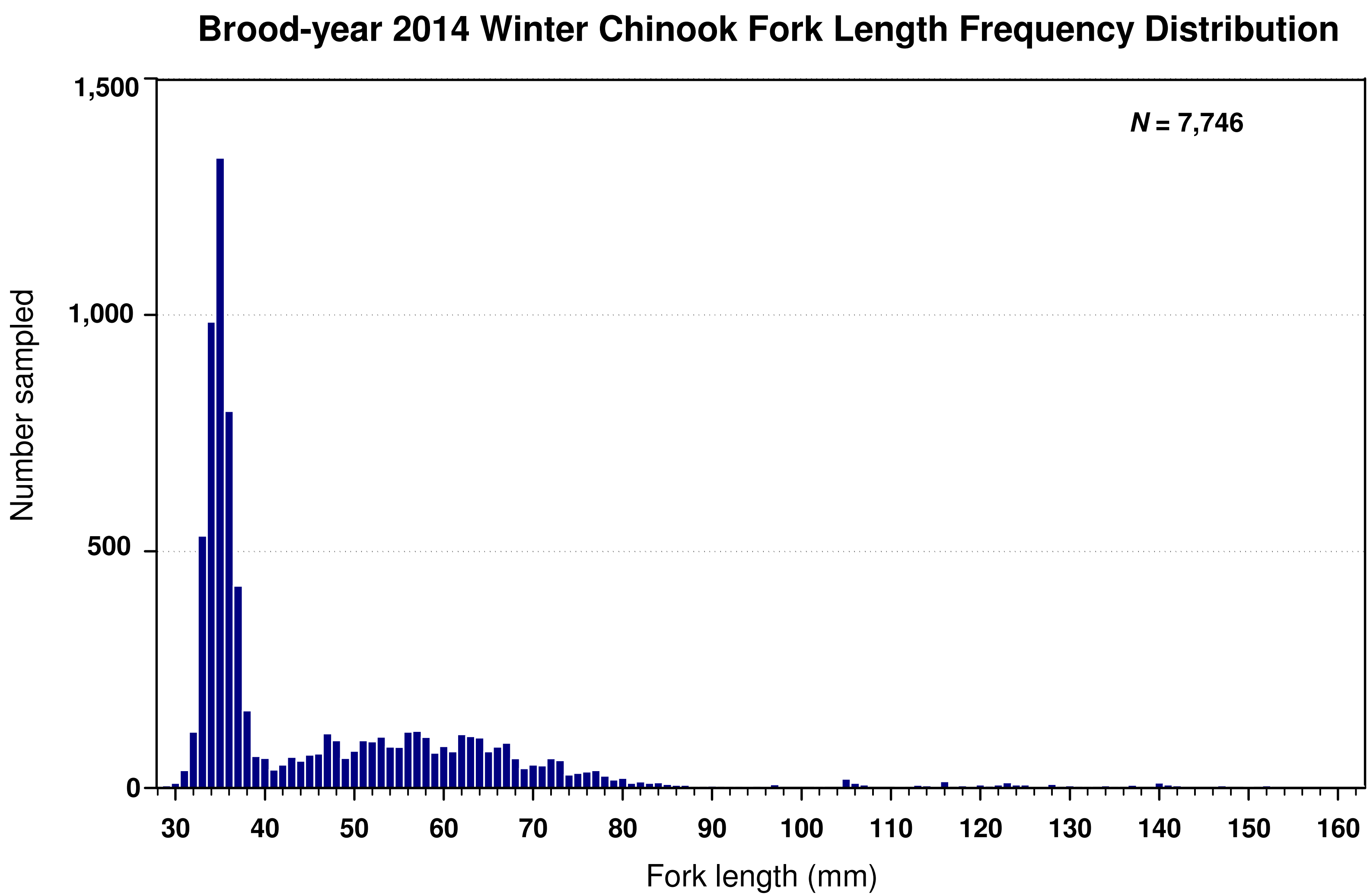

Figure 7. Fork length frequency distribution of brood-year 2014 juvenile winter Chinook salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fork length data was expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from July 1, 2014 through June 30, 2015.

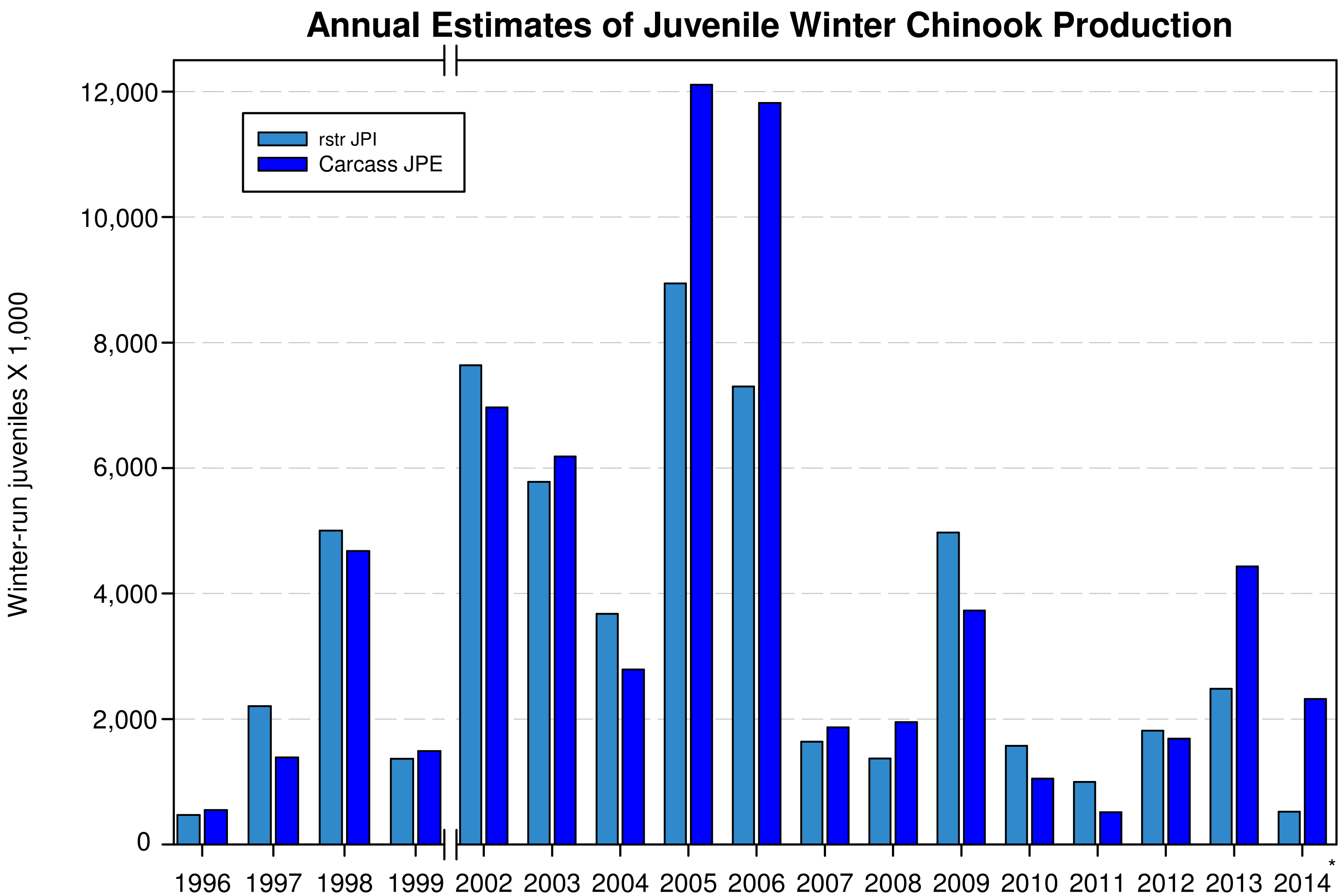

Figure 8. Time series comparison of annual estimates of juvenile winter-run production using rotary-screw trap fry-equivalent JPI's (light blue) and carcass survey JPE's (dark blue). Note (*) The 2014 Carcass JPE value simulated using traditional NMFS JPE model for comparison only.

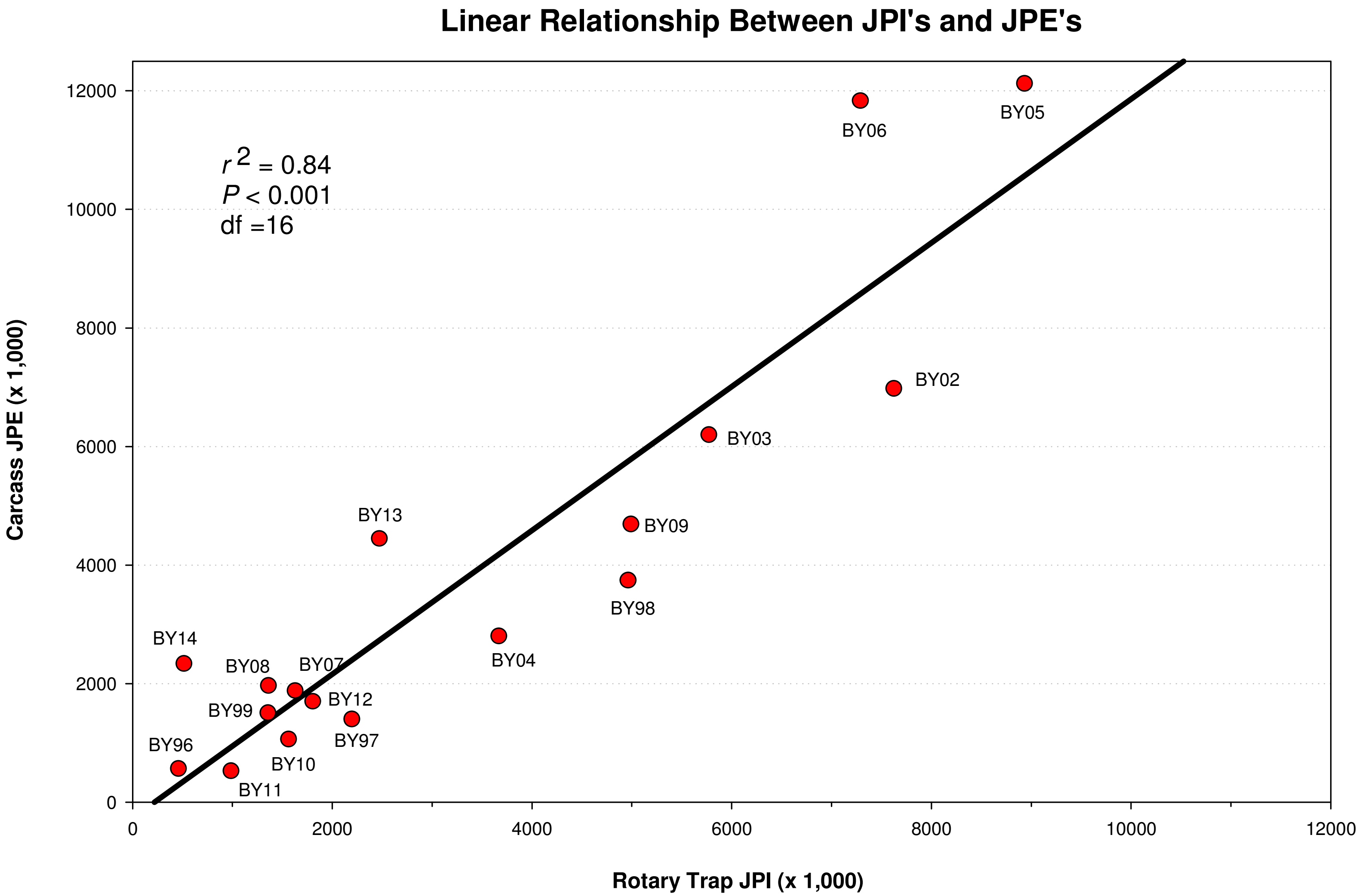

Figure 9. Linear relationship between rotary-screw trap fry-equivalent juvenile production indices (Rotary Trap JPI) and carcass survey derived juvenile production estimates (Carcass JPE).

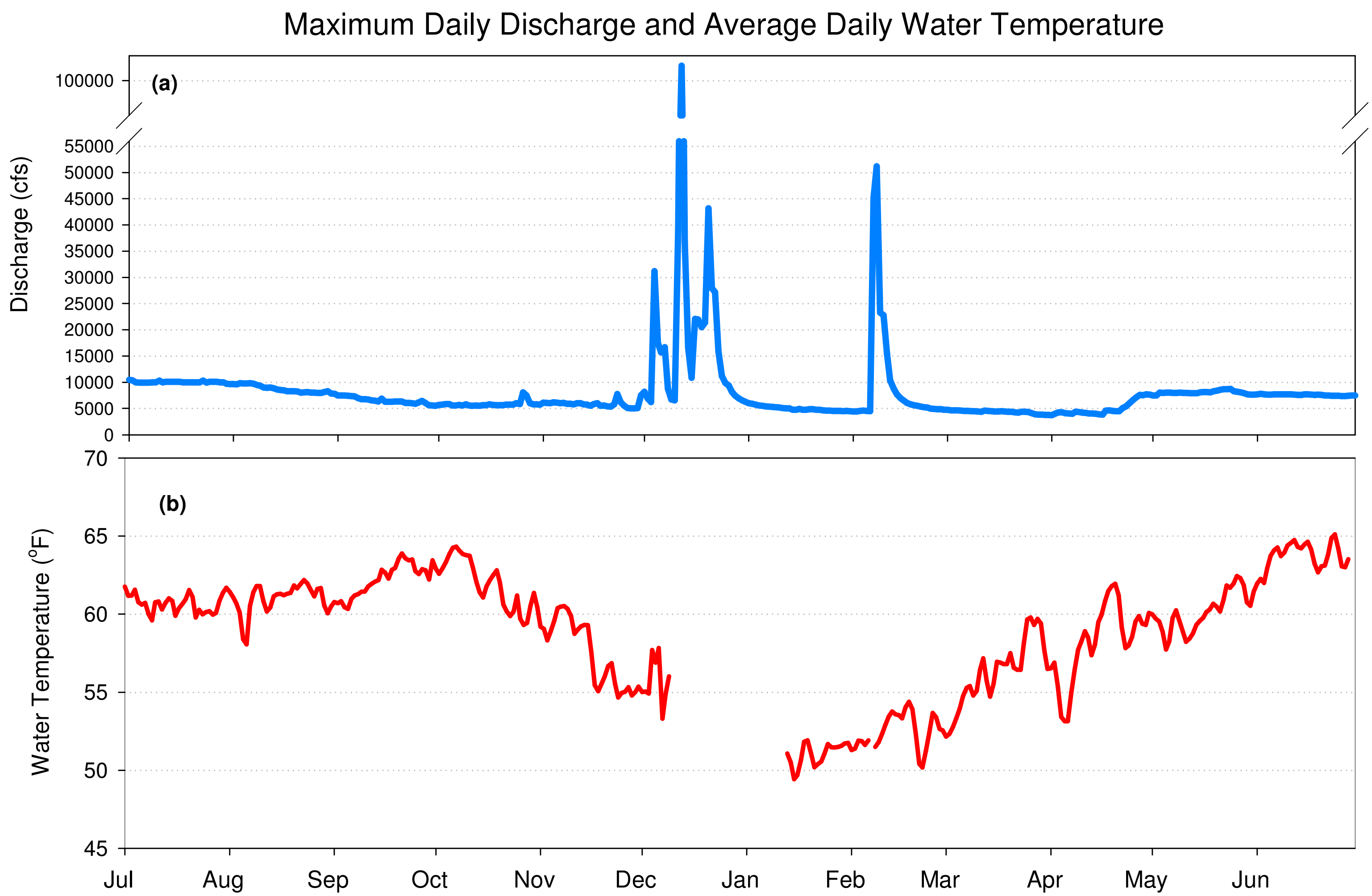

Figure 10. Maximum daily discharge (a) calculated from the California Data Exchange Center's Bend Bridge gauging station and average daily water temperatures (b) from rotary-screw traps at RBDD for the period July 1, 2014 through June 30, 2015.

Appendix 1

Appendix 1: List of Tables

Table **Page**

Table A1.— Weekly passage estimates, median fork length and juvenile production indices (JPI's) for fall Chinook salmon passing Red Bluff Diversion Dam (RK 391) for the period December 1, 2014 through November 30, 2015 (Brood-year 2014). 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).

Fall-run Chinook Brood-year 2014

	Fry		Pre-smolt/smolts		Total		Fry-equivalent
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
48 (Dec)	891	33	0	-	891	33	891
49	14,146	34	0	-	14,146	34	14,146
50	41,571	34	0	-	41,571	34	41,571
51	451,795	36	0	-	451,795	36	451,795
52	478,019	36	0	-	478,309	36	478,019
1 (Jan)	615,453	36	0	-	615,453	36	615,453
2	692,411	36	0	-	692,411	36	692,411
3	524,004	37	0	-	524,004	37	524,004
4	271,541	37	0	-	271,541	37	271,541
5 (Feb)	90,893	37	131	47	91,024	37	91,116
6	53,322	37	144	46	53,466	37	53,567
7	65,666	37	2,336	47	68,002	37	69,637
8	24,880	37	355	48.5	25,235	37	25,483
9 (Mar)	15,782	37	186	52	15,968	37	16,098
10	5,754	37	205	56	5,959	37	6,102
11	1,171	37	310	58	1,482	37	1,699
12	757	37	731	64	1,487	40	1,999
13 (Apr)	594	37	2,080	68	2,675	67	4,131
14	194	37.5	3,786	72	3,979	72	6,630
15	380	38	13,932	74	14,311	74	24,064
16	188	41	21,600	78	21,789	78	36,909
17	169	43	75,330	78	75,499	78	128,229
18 (May)	86	44	78,991	77	79,078	77	134,372
19	46	44	99,305	75	99,352	75	168,865
20	0	-	48,011	76	48,011	76	81,618

Table A1.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalent
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
21	0	-	83,963	74	83,963	74	142,738
22 (Jun)	0	-	59,907	77	59,907	77	101,842
23	0	-	46,147	76	46,147	76	78,450
24	0	-	26,149	77	26,149	77	44,453
25	0	-	11,407	82	11,407	82	19,393
26	0	-	9,449	86	9,449	86	16,063
27 (Jul)	0	-	7,183	87	7,183	87	12,211
28	0	-	2,529	92	2,529	92	4,299
29	0	-	1,182	95	1,182	95	2,009
30	0	-	1,727	96	1,727	96	2,936
31 (Aug)	0	-	1,606	98.5	1,606	98.5	2,730
32	0	-	306	106.5	306	106.5	520
33	0	-	536	100	536	100	911
34	0	-	488	104	488	104	829
35 (Sep)	0	-	709	106	709	106	1,206
36	0	-	253	110	253	110	430
37	0	-	230	125	230	125	391
38	0	-	1,012	120	1,012	120	1,721
39	0	-	952	129	952	129	1,618
40 (Oct)	0	-	790	125	790	125	1,342
41	0	-	599	134	599	134	1,019
42	0	-	1,238	135	1,238	135	2,105
43	0	-	1,003	138	1,003	138	1,705
44 (Nov)	0	-	709	145	709	145	1,205
45	0	-	892	152	892	152	1,517
46	0	-	422	157	422	157	717
47	0	-	451	162	451	162	767
BY total	3,349,715		609,272		3,958,987		4,385,477

Table A2.— Weekly passage estimates, median fork length and juvenile production indices (JPI's) for late-fall Chinook salmon passing Red Bluff Diversion Dam (RK 391) for the period April 1, 2014 through March 31, 2015 (Brood-year 2014). 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).

Late-fall-run Chinook Brood-year 2014

	Fry		Pre-smolt/smolts		Total		Fry-equivalent
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
13 (Apr)	0	-	0	-	0	-	0
14	12,398	34	0	-	12,398	34	12,398
15	6,545	35	0	-	6,545	35	6,545
16	2,854	35	0	-	2,854	35	2,854
17	421	35.5	0	-	421	35.5	421
18 (May)	807	38	0	-	807	38	807
19	1,037	38.5	0	-	1,037	38.5	1,037
20	1,022	41	67	46	1,089	42	1,136
21	273	45	217	47	490	45	641
22 (Jun)	436	43.5	591	49	1,027	47	1,441
23	280	42	1,145	49	1,425	48.5	2,226
24	105	40	1,431	52	1,535	52	2,537
25	297	43	3,278	56	3,575	56	5,870
26	81	32	2,966	57	3,047	56.5	5,123
27 (Jul)	0	-	1,113	60	1,113	60	1,892
28	0	-	2,001	64	2,001	64	3,402
29	0	-	674	65.5	674	65.5	1,145
30	0	-	910	65	910	65	1,547
31 (Aug)	0	-	504	70	504	70	857
32	0	-	444	71	444	71	755
33	0	-	634	76	634	76	1,077
34	0	-	67	47	67	47	114
35 (Sep)	0	-	137	71	137	71	233
36	0	-	203	81	203	81	346
37	0	-	332	78	332	78	564

Table A2.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalent
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
38	0	-	1,202	63	1,202	63	2,043
39	0	-	1,693	64.5	1,693	64.5	2,878
40 (Oct)	0	-	2,390	68.5	2,390	68.5	4,063
41	0	-	1,774	72	1,774	72	3,016
42	0	-	2,822	73.5	2,822	73.5	4,798
43	0	-	6,162	83	6,162	83	10,475
44 (Nov)	0	-	3,424	94.5	3,424	94.5	5,822
45	0	-	6,502	114	6,502	114	11,054
46	0	-	6,135	116	6,135	116	10,429
47	0	-	7,110	116	7,110	116	12,086
48 (Dec)	0	-	7,553	118	7,553	118	12,840
49	0	-	4,776	123	4,776	123	8,119
50	0	-	2,889	113	2,889	113	4,911
51	0	-	5,543	112	5,543	112	9,424
52	0	-	2,082	120	2,082	120	3,540
1 (Jan)	0	-	2,470	122.5	2,470	122.5	4,199
2	0	-	0	-	0	-	0
3	0	-	304	194	304	194	516
4	0	-	541	135	541	135	920
5 (Feb)	0	-	71	143	71	143	121
6	0	-	144	203	144	203	245
7	0	-	78	149	78	149	132
8	0	-	0	-	0	-	0
9 (Mar)	0	-	0	-	0	-	0
10	0	-	21	221	21	221	36
11	0	-	0	-	0	-	0
12	0	-	0	-	0	-	0
BY total	26,556		82,399		108,955		166,634

Table A3.— Weekly passage estimates, median fork length and juvenile production indices (JPI's) for spring run Chinook salmon passing Red Bluff Diversion Dam (RK 391) for the period October 16, 2014 through October 15, 2015 (Brood-year 2014). 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).

Spring-run Chinook Brood-year 2014							
	Fry		Pre-smolt/smolts		Total		Fry-equivalent
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
42	1,038	33	0	-	1,038	33	1,038
43	901	34	0	-	901	34	901
44 (Nov)	365	33.5	0	-	365	33.5	365
45	442	35.5	0	-	442	35.5	442
46	317	35	0	-	317	35	317
47	2,083	34	0	-	2,083	34	2,083
48 (Dec)	3,249	35	0	-	3,249	35	3,249
49	4,813	37	0	-	4,813	37	4,813
50	6,751	37	0	-	6,751	37	6,751
51	11,663	39	905	47	12,567	39	13,200
52	1,165	39.5	0	-	1,165	39.5	1,165
1 (Jan)	0	-	404	47	404	47	686
2	193	44	0	-	193	44	193
3	0	-	227	54	227	54	387
4	0	-	123	62	123	62	209
5 (Feb)	0	-	69	55.5	69	55.5	118
6	0	-	142	69	142	69	242
7	0	-	412	61	412	61	700
8	0	-	42	62	42	62	72
9 (Mar)	0	-	0	-	0	-	0
10	0	-	62	66	62	66	105
11	0	-	623	73	623	73	1,059
12	0	-	1,675	76	1,675	76	2,847
13 (Apr)	0	-	4,873	78	4,873	78	8,283
14	0	-	8,242	83	8,242	83	14,012

Table A3.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalent
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
15	0	-	20,770	86	20,770	86	35,309
16	0	-	20,670	90	20,670	90	35,140
17	0	-	22,663	92	22,663	92	38,527
18 (May)	0	-	6,011	95	6,011	95	10,218
19	0	-	1,868	97	1,868	97	3,176
20	0	-	419	104	419	104	712
21	0	-	333	106.5	333	106.5	566
22 (Jun)	0	-	84	111	84	111	143
23	0	-	0	-	0	-	0
24	0	-	0	-	0	-	0
25	0	-	0	-	0	-	0
26	0	-	0	-	0	-	0
27 (Jul)	0	-	0	-	0	-	0
28	0	-	0	-	0	-	0
29	0	-	0	-	0	-	0
30	0	-	0	-	0	-	0
31 (Aug)	0	-	0	-	0	-	0
32	0	-	0	-	0	-	0
33	0	-	0	-	0	-	0
34	0	-	0	-	0	-	0
35 (Sep)	0	-	0	-	0	-	0
36	0	-	0	-	0	-	0
37	0	-	0	-	0	-	0
38	0	-	0	-	0	-	0
39	0	-	0	-	0	-	0
40 (Oct)	0	-	0	-	0	-	0
41	0	-	0	-	0	-	0
BY total	32,978		90,617		123,595		187,027