BROOD-YEAR 2013 WINTER CHINOOK JUVENILE PRODUCTION INDICES WITH COMPARISONS TO JUVENILE PRODUCTION ESTIMATES DERIVED FROM ADULT ESCAPEMENT

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Brood-year 2013 winter Chinook juvenile production indices with comparisons to juvenile production estimates derived from adult escapement

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Abstract.— Brood-year 2013 juvenile winter-run Chinook salmon passage at Red Bluff Diversion Dam (RBDD) was estimated at 1,773,878 fry and pre-smolt/smolts combined. Fry-equivalent production was estimated at 2,481,324. Sample effort was lower than most years due to a Federal Government shutdown in October of 2013 and sampling of three traps for the year to conduct a river usage evaluation in the new post-RBDD operations era. The timing of the shutdown was unfortunate in that it occurred during typical peak migration of winter Chinook juveniles past RBDD. The result was reduced accuracy of weekly passage estimates during a critical emigration period and wider confidence intervals indicating greater uncertainty. The egg-to-fry survival rate for brood-year 2013 was estimated at 15.1%, with a range between 9.4% to 20.8% based on the 90% confidence intervals around the 2013 fry-equivalent juvenile production estimate.

We compared rotary-screw trap fry-equivalent juvenile production indices (JPI's) to fry-equivalent juvenile production estimates (JPE's) derived using the National Oceanic and Atmospheric Administration's National Marine Fisheries Service JPE model. The JPE model uses estimates of adult escapement from the winter-run Chinook salmon carcass survey as the primary variate. Despite considerable differences in numerical values, rotary-screw trap JPI's continued to be correlated strongly in trend when compared to carcass survey JPE's ($r^2 = 0.86$, $P < 0.001$, $df = 15$).

The 2013 JPE exceeded the 90% C.I. around the rotary trap JPI by 29%; the largest difference observed in sixteen years of comparison. Conversely, comparison of the magnitude of the two estimates detected no significant difference among rotary trap JPI's and carcass survey JPE's (Wilcoxon Signed-Rank test; $Z = -0.052$, $P = 0.98$). Overall, the relationship between the direct measure of juvenile abundance (JPI) and the indirect or modeled approach (JPE) using carcass survey data remains strong. The addition of the 2013 data continues to support this relationship, despite considerable uncertainty over the accuracy of the JPI due to a cessation of sampling during the typical peak outmigration period of winter run at RBDD.

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Introduction

Winter-run Chinook salmon is one of four distinct "runs" of Chinook salmon *(Oncorhynchus tshawytscha)* present in the upper 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).

Winter-run Chinook salmon have been federally listed as an endangered species since 1994[1]. Numerous measures have, and continue to be implemented to protect and conserve the endangered 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 (NOAA Fisheries) 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). NOAA Fisheries uses a juvenile production model to estimate the numbers of juvenile winter Chinook entering the Delta. Historically, the juvenile production estimate (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, therefore, current escapement estimates are derived solely from the winter Chinook carcass survey (NMFS 2009).

The NOAA Fisheries 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 the carcass survey, the size composition of fish sampled often leads to skewed sex ratios. Adult 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). Furthermore, females are generally larger and may be more easily recognized and recovered than their male counterparts (Boydstun 1994; Zhou 2002). 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

[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). Their federal endangered status was reaffirmed in June 2005 (70 FR 37160).

can have large net effects 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 has used a static 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 has been allowed to vary 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 from escapement data using the 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 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 passage. Since 2012, the RBDD has not been in operation, yet sampling conditions have remained similar 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) 2013 juvenile winter Chinook passing RBDD, (2) define temporal patterns of abundance, (3) determine if JPI's from rotary trapping support JPE's generated from the carcass survey and (4) estimate egg-to-fry 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, 2013 through June 30, 2014. This report includes winter Chinook JPI's for the complete 2013 brood-year emigration period. Fall, late-fall and spring run Chinook 2013 JPI's are located in Appendix tables. This report will be submitted to the US Bureau of Reclamation to comply with contractual reporting requirements for funds received under the Central Valley Project's Operations Criteria and Plan Biological Opinion (CVPIA OCAP BO; NMFS 2009).

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 the city of Red Bluff, California. The dam is 226 meters (m) wide and composed of 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 permanent pumping facility (NMFS 2009). Adult and juvenile anadromous fish now 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) as of spring 2012. Mothballing of the RBDD infrastructure occurred beginning in 2014.

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, elevated river flows or 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 of time, sub-sampling protocols were implemented to reduce take and incidental mortality in accordance with NOAA Fisheries Section 10 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, we decreased the number of traps sampling 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 estimate 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 winter Chinook juveniles exceeded approximately 200 fish/trap, a random sub-sample of the catch was taken 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 trap 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 by 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 RBDD/TCCA diversions, when applicable.

Sampling effort.—We quantified weekly rotary trap sampling effort by assigning a value of 1.00 to a sample consisting of four, 2.4-m diameter rotary-screw traps sampling 24 hours daily, 7 days per week. Weekly values <1.00 represent 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 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 6-30 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). This trap efficiency model was developed by conducting 142 mark-recapture trials at RBDD

[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.

between 1998 and 2012 (Figure 4; Martin et al. 2001, Poytress et al. 2014). The model-derived equation was then used to calculate predicted daily trap efficiencies based on estimates of daily river volume sampled.

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. $$\hat{T}_d = (0.0072552)(\%\hat{Q}_d) + 0.0015087$$

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. $$Cov(\hat{T}_i, \hat{T}_j) = Var(\hat{\alpha}) + x_i Cov(\hat{\alpha}, \hat{\beta}) + x_j Cov(\hat{\alpha}, \hat{\beta}) + x_i x_j Var(\hat{\beta})$$

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.—We estimated annual juvenile winter Chinook egg-to-fry (ETF) survival rates 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) and fecundity data from the Livingston Stone National Fish Hatchery spawning records.

Hypothesis testing.—The JPI is a direct measure of juvenile production and has been used to track the NOAA Fisheries JPE, an indirect measure of juvenile production (Martin et al., 2001). A juvenile production estimate derived from effective spawner populations based on carcass survey data (Carcass JPE) was compared with the fry-equivalent JPI. The hypothesis we tested was:

H_o: Carcass JPE does not differ from in-river estimates of juvenile abundance (JPI)
H_a: Carcass JPE differs from in-river estimates of juvenile abundance (JPI)

We used a Wilcoxon Signed-Rank test for testing significant differences using years as replicates. The BY 2013 fry-equivalent JPI was added to prior years' data, providing sixteen data points to compare with the Carcass JPE. Within-year evaluations were made by comparing Carcass JPE's with the JPI and determining whether the Carcass JPE's fall within the confidence intervals about the JPI.

Results

Sampling effort.—Weekly sampling effort throughout the 2013 brood-year emigration period was moderately low and ranged from 0.00 to 0.75 ($\bar{x}$ = 0.49; N = 52 weeks; Table 1). Weekly sampling effort ranged from 0.00 to 0.75 ($\bar{x}$ = 0.58; N = 26 weeks) between July and December, the period of greatest juvenile winter Chinook emigration, and 0.21 to 0.75 ($\bar{x}$ = 0.41; 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 as well as the 2013 Federal Government shutdown (i.e., Federal Government employee furlough period), (3) low staffing levels preventing 7 day a week sampling, and (4) hatchery fish releases from Coleman National Fish Hatchery (Figure 3). The maximum sampling effort was intentionally reduced to 0.75 effort (i.e., only three traps operating) throughout the entire sampling period to allow for public transit on the east side of the Sacramento River at RBDD and for evaluation of river usage in the new post-RBDD operations era. Twenty-three of the 52 weeks sampled had two or more additional reasons why sampling effort was reduced from the maximum value of 1.00 or 28 possible samples per week.

Trap efficiency trials.—Five mark-recapture trials were conducted using naturally produced winter (N = 1) and fall run (N = 4) Chinook between September 2013 and February 2014 to estimate and validate rotary-screw trap efficiency (Table 2). Sacramento River discharge sampled during the trials ranged from 4,099 to 6,858 cfs. Estimated $\%Q$ during trap efficiency trials ranged from 3.13% to 6.57% ($\bar{x}$ = 4.72%; Table 2).

Trials were conducted using three traps with the rotary traps modified to sample with half cones (N = 2), and unmodified (standard cone; N = 3). All trials were conducted using Chinook sampled from rotary traps, and trap efficiencies ranged from 1.58% to 4.97% ($\bar{x}$ = 3.54%). The number of marked fish released per trial ranged from 1,008 to 1,453 ($\bar{x}$ = 1,170) and the number of marked fish recaptured ranged from 23 to 59 ($\bar{x}$ = 40). All fish were released after sunset and 97.5% of recaptures occurred within the first 24 hours, and 100% within 48 hrs.

Fork lengths of fish marked and released ranged from 32 to 47 mm ($\bar{x}$ = 36.4 mm). Fork lengths of recaptured marked fish ranged from 34 to 40 mm ($\bar{x}$ = 36.0 mm). The distribution of fork lengths of fish marked and released in mark-recapture trials was commensurate with the distribution of fork lengths of fish recaptured by rotary-screw traps and were considered fry-size class fish.

Trap efficiency modeling.—The trap efficiency model used to produce weekly passage estimates covered by this report was left unchanged from that used in Poytress et al. (2014). Updating of the trap efficiency model by inclusion of the five trap efficiency trials conducted during this report period will be completed for the BY 2014 winter Chinook JPI report. Updates typically occur at the beginning of each winter Chinook brood-year (i.e., July 1 of each year, as applicable) due to consistency in model results over many years and for consistency with real-time bi-weekly report values.

Fork length evaluations.—Weekly median fork length of BY 2013 winter Chinook increased slowly from 32.5 mm in week 28 to 39.0 mm in week 42 (Table 3). Median fork lengths consistently increased from 49.0 mm in week 43 to 77.5 mm in week 2. Thereafter, an overall upward trend continued from week 3 to week 19 with slight variability in weekly median fork lengths. Median fork lengths peaked at 147.5 mm during week 16 (Figure 5a).

Brood-year 2013 winter Chinook fry median fork lengths ranged from 32.5 mm in week 28 to 45.0 mm in week 48, increasing 0.63 mm per week on average (Figure 6a). Brood-year 2013 pre-smolt/smolt median fork length ranged from 46.0 to 77.5 mm, increasing by 1.66 mm per week on average from week 35 to week 2 (Figure 7a). From week 2 to 16, average weekly median fork length increase was 5.0 mm per week from 77.5 to 147.5 mm.

The length frequency distribution of brood-year 2013 juveniles captured at RBDD ranged from 28.0 mm to 165.0 mm (Figure 8). Fry sized individuals ranged from 28.0 to 45.0 mm and comprised 40.5% of all samples collected. Pre-smolt/smolt sized individuals ≥46.0 mm represented the remaining 59.5% of BY 2013 winter Chinook samples.

Patterns of abundance.—Brood-year 2013 winter Chinook juvenile estimated passage at RBDD was 1,773,878 fry and pre-smolt/smolts combined (Table 3). Winter Chinook juvenile passage increased from 145 (week 28; July) to its peak of 296,463 during week 39 (last week of September). Weekly passage was interpolated at 104,907 for weeks 40 and 41 (Table 3), respectively, during the Federal Government shutdown period by calculating the mean daily passage value derived from samples collected between October 18 and 31 (i.e., mean daily passage value from latter part of the month of October summed weekly). Thereafter, weekly juvenile passage fluctuated between 28,118 and 133,203 from weeks 42 to 52. Weeks 28 to 52 accounted for 91.5% of the total brood-year 2013 winter Chinook juvenile passage. Passage of brood-year 2013 winter Chinook ceased by the middle of May (week 19; Table 3; Figure 5b).

Brood-year 2013 fry sized juveniles (≤45 mm FL) comprised 43.0% of total estimated winter Chinook passage (Table 3). Fry began to pass RBDD during week 28 (second week of July). Weekly fry passage increased slowly to 14,138 in week 35 (first week of September). Passage increased rapidly over the next four weeks to 289,951 in week 39. Fry passage was interpolated at 42,676 in weeks 40 and 41, respectively, during the Federal Government shutdown period. Fry passage remained stable through week 43 before passage began to decline, ultimately ending during the last week of November, week 48 (Table 3; Figure 6b).

Brood-year 2013 pre-smolt/smolt sized juveniles (≥46 mm FL) comprised 57.0% 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 6,513 by the end of September. During the Federal Government shutdown period weekly pre-smolt/smolt passage was interpolated at 62,231 in weeks 40 and 41, respectively. Weekly passage continued to increase to 107,862 where it peaked during week 45, early November (Table 3; Figure 7b). Weekly passage fluctuated between 28,118 and 99,583 with an overall declining trend from weeks 46 to 52. A pulse of pre-smolt/smolt passaged occurred during week 6 (N = 61,839) and 9 (N = 21,247) coincident with the first storm related runoff events (Figure 11). Pre-smolt/smolt passage concluded during the second week of May.

Fry-equivalent JPI and egg-to-fry survival estimate.—The fry-equivalent rotary trap JPI for brood-year 2013 was 2,481,324 with the lower and upper 90% CI extending from 1,539,139 to 3,423,456 juveniles, respectively (Table 4). The estimated egg-to-fry survival rate based on the BY 2013 winter Chinook fry-equivalent JPI was estimated at 15.1% (range based on 90% CI's was 9.4% to 20.8%; Table 5).

Comparisons of JPI and JPE.—The NOAA Fisheries brood-year 2013 carcass survey JPE was 4,431,064 and was considerably higher than the JPI, exceeding the upper 90% C.I. by 29% or 1,007,608 juveniles (Table 4). When directly comparing the two estimates, the carcass survey derived JPE was estimated to be 1,949,740 juveniles or 78.6% greater than the fry-equivalent rotary trap JPI (Figure 9).

We combined data from 1995 to 2012 with brood-year 2013 JPI's and JPE's to evaluate the linear relationship between the estimates. Sixteen 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 ($r^2 = 0.857$, $P < 0.001$, df = 15; Figure 10).

In terms of the magnitude of the two estimates, a Wilcoxon Signed-Rank test detected no significant difference among rotary trap JPI's and carcass survey JPE's ($Z = -0.052$, $P = 0.98$). For the combined sixteen years of data, Carcass JPE's averaged 4.7% greater than rotary trap JPI's (range = -48.6% to +78.6%). Overall, the comparison between 2013 JPI's and JPE's resulted in the greatest disparity, by percentage, between estimates in sixteen years of comparisons.

Discussion

*Sampling effort***.**—During the period July through December, the primary winter Chinook capture and passage period, sampling effort in BY 2013 was the lowest since 2002. The reasons varied, but the most significant impediment to sampling at full effort during a critical migration period was due to the Federal Government shutdown that occurred between October 1 and October 16, 2013. During this time, RBDD traps were removed from the river after a sample was collected on September 30 and redeployed October 17, 2013 the first day Federal employees could return to work. The result was two complete weeks and three days into a third week where sampling could not be conducted. Over the history of the project, sample effort has been low during consecutive weeks, but as noted in Poytress et al. (2014) lower sampling effort reduces the accuracy of passage estimates and increases the width of confidence intervals around estimates. The effects on BY 2013 winter-run passage estimates are likely a negative bias in interpolated passage estimates imputed for the first two weeks in October and increased width in confidence intervals. Specific information on the effects of the Federal Government shutdown on the BY 2013 winter Chinook passage estimates and comparisons to JPE's will be discussed in greater detail below.

During the entire BY 2013 winter Chinook emigration period, sampling effort was consistently reduced by 25% due to the program sampling only three of four traps. Trap efficiency trials validated the use of 3 traps to accurately estimate efficiency, in terms of percent river discharge sampled (%Q) and concern over negative or positive bias due to the number of traps sampling are not justified. 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). This reduced sampling effort occurred as plans and rigging equipment were formalized and tested to sample at the RBDD site in the absence of USBR operators who are no longer employed at the facility. In an effort to determine the magnitude of public use of the river through the RBDD gates throughout the year, we intentionally removed the trap in the east-margin spatial zone to allow greater utilization of this area by boaters. From the evaluation, it was determined that few boaters traveled upstream of the lower boat ramp at Sycamore Grove and even fewer went downstream through the dam gates from an upstream ramp location (e.g., Red Bluff City Park public boat ramp) throughout the year even during the annual salmon fishing season (mid-July to December).

Patterns of abundance and comparison of interpolation methods.—In 2013, the RBFWO's juvenile monitoring operation was halted mid-season due to the Federal Government shutdown, which resulted in 17 unsampled days between October 1 and October 17, 2013. The first half of October can be a period of substantial fry (<45mm) passage at RBDD, and on average, accounts for 23% of an annual Winter-run Chinook juvenile passage estimate (Poytress et al. 2014). This period is not usually associated with storm events or subsequent flow increases and flows are primarily the result of releases from the Shasta-Keswick Dam component of the Central Valley Project. Flows in 2013 remained stable around 7,000 cfs with slight variation (+/- 250 cfs) during the shutdown period (Figure 11).

The standard procedure for interpolating missed weeks of sampling are to impute a mean passage value for unsampled weeks based on the sample data collected throughout the month (i.e., impute a monthly mean daily value for each unsampled day of the month). In many instances these calculations are representative of fish passage in terms of magnitude and trend. In 2013, however, negative bias may have been introduced for the winter Chinook passage estimate since the first half of October was imputed based on the latter half of October, which typically is on the downslope of the annual emigration peak (Figure 12).

In an effort to more thoroughly evaluate what proportion of the winter Chinook juveniles may have passed RBDD during the 17 days that went unsampled in 2013 due to the Federal Government shutdown, one can begin by looking at recent trends in juvenile winter Chinook passage. During the period of October 1 through October 17, on average, 23% of the annual winter Chinook juvenile passage is estimated during this time frame (based on 11 prior years of sampling). By employing an 11-year annual average passage interpolation method accounting for 23% of the annual estimate, the resultant JPI would be estimated at 2,786,992 (Table 6). These data indicate that the 2013 JPI using standard monthly mean interpolation methods is negatively biased by ~ 9% when compared to the *average* annual passage during this 17 day period.

Alternately, on average, 1.36% of the annual passage of winter-run juveniles occurs *daily* during October 1 through 17 of each year. There is considerable variability around this average as maximum daily passage has ranged from 1.8% to 8.1% of annual daily passage ($\bar{x}_{max}$ = 3.1%). If maximum daily percentage of passage based on the prior 11 years was imputed for the 17 day period, the resultant 2013 JPI would be estimated at

3,595,220 juveniles (Table 6). The estimate would indicate that during the Federal Government shutdown, 40% of the juveniles passed by Red Bluff. Although possible, using a maximum average daily passage rate during the 17 day missed sample period would likely introduce positive bias to the estimate.

Potential negative bias due to use of length-at-date criteria.—Another possible scenario affecting the patterns of abundance seen in the 2013 winter run passage estimate is the potential for incorrect run assignment. Between 2011 and 2013, spawn timing of winter Chinook adults has been slightly later than the prior decade (USFWS 2012-2014). Emergence timing and peak migration have also shifted later into October in recent years (Poytress et al. 2014).

To investigate potential incorrect assignment of run to juveniles passing RBDD requires some assumptions to be made regarding juvenile passage data at RBDD. One assumption regarding fish run assignment is the accuracy of the length-at-date (LAD) criteria for identifying winter-run Chinook salmon. The length-at-date criteria were developed from data collected in Red Bluff and winter-run Chinook salmon misclassification at Red Bluff is quite low compared to other locations further from the natal reach.

On average, Poytress et al. (2014) found that 19% of fish annually classified as spring Chinook in RBDD traps occurred *prior* to capture of spring Chinook from upstream tributaries producing them (range 2.6% to 44.2%). Based on size and timing of capture, these fish are most likely winter Chinook. LAD criteria presume emergence of juveniles in the spring-run category by mid-October, but rarely have fish been detected in primary production areas as outmigrants before the end of November. Moreover, no significant correlation was detected between estimated spring Chinook females and JPI's over 11 years of data. Spring Chinook passage typically accounts for a small fraction ($\bar{x} = 2.1\%$) of annual Chinook passage at RBDD and does not significantly affect winter-run or fall and late-fall run JPI's (Appendix 1, Table A1-A2).

Assuming all 2013 juveniles categorized as spring Chinook based on LAD criteria (Appendix 1, Table A3) were late emerging winter Chinook juveniles would result in an increase of 426,325 juveniles to the 2013 winter Chinook fry-equivalent JPI (Table 6). This value incorporates the assumption that all fish outmigrating between mid-October and the end of March (prior to Coleman National Fish Hatchery fall Chinook production release of 4.5 million smolts into Battle Creek) were incorrectly assigned from the winter to the spring Chinook run category due to late emergence. Whether or not the LAD criteria properly identifies each run, especially in years where flows and temperatures are at the extremes, needs to assessed through genetic characterization, both at RBDD and further downstream at other monitoring locations.

To evaluate the effect of potential incorrect assignment of juveniles to the spring category from the presumed winter Chinook category we simply added the 426,325 juveniles to the previously discussed values derived from various winter Chinook JPI interpolation methods (Table 6). The results would indicate that the standard monthly mean interpolation with the inclusion of all potentially incorrectly assigned juveniles would raise the 2013 JPI to 2,907,649 winter juveniles passing RBDD. If included with the 11-year mean daily percentage passage estimate data, the JPI would be estimated at 3,213,317 juveniles. If included with the 11-year maximum daily percentage of passage the JPI would be estimated at 4,021,545 juveniles (Table 6).

Comparisons of JPI's and JPE's.—Using standard methods, the 2013 winter-run Chinook fry-equivalent JPI was calculated at 2,481,324 juveniles. When compared to the NOAA Fisheries JPE value of 4,431,064, the JPI was 44% less than what was predicted based on the JPE model. Differences in JPE and JPI values are common and the range of differences between the two estimates over the prior sixteen years has ranged from 15% less to 38% more (Figure 9). The 2013 JPI estimated value does fall *outside* of the range of differences detected over the last 16 years of comparisons. Additionally, the JPE falls outside of the confidence intervals around the JPI by over a million juveniles and was 29% greater than the upper 90% interval.

From analysis of additional interpolation methods that could have been employed to potentially more accurately represent the magnitude of winter Chinook juvenile emigration we still found large differences between the JPI and JPE in 2013 (Table 6). When compared to the JPE, the fry-equivalent JPI using the 11-year mean daily percentage interpolated value increased the JPI value by ~300,000 juveniles and resulted in a difference of 37% less than the JPE. When compared to 11-year maximum daily percentage estimated passage, the difference was 19% less, a more typical difference. To simulate what passage would have been to result in similar values between the JPE and JPI would have required passage during the Federal Government shutdown to have been 150% of the maximum daily percentage passage seen in the prior 11 years. In this scenario, the JPI would be estimated at 4,319,838 and would have indicated we missed 50% of the run during this period (Table 6). In light of the environmental conditions observed during this period, this seems highly improbable.

If all spring size class Chinook were included with winter Chinook fry-equivalent JPI's, the results would indicate that the standard monthly mean interpolation with the inclusion of all incorrectly assigned juveniles would raise the 2013 JPI to 2,907,649 winter juveniles passing RBDD (Table 6). If included with the 11-year mean daily percentage passage estimate data, the JPI would be estimated at 3,213,317 juveniles. If included with the 11-year maximum daily percentage passage data the JPI would be estimated at 4,021,545 juveniles. If included with the 150% of the maximum daily percentage of passage the JPI would be estimated at 4,746,163. In comparison to the JPE, the JPI estimates using the interpolation methods above would differ by, -34%, -27%, -9% and +7%, respectively (Table 6). Without any data to validate the estimates, our hypotheses over what may have occurred in the absence of sample data cannot be supported or discredited.

Statistically, the mean values of the JPI and JPE comparing sixteen years of data do not indicate a significant statistical difference. Looking at the magnitude of the difference, a minimum of one million juveniles between estimates appears to indicate substantial numerical differences between the calculations. With the uncertainties associated with interpolations during the 17-day Federal Government shutdown, we must conclude that there is no statistical difference between the JPI and JPE and therefore the estimates support each other.

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Table 1.— Summary of brood-year (BY) 2013 weekly rotary trap sampling effort. Full sampling effort was 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 2013	Week	BY 2013
27 (Jul)	0.64	1 (Jan)	0.32
28	0.64	2	0.27
29	0.54	3	0.21
30	0.64	4	0.32
31 (Aug)	0.64	5 (Feb)	0.32
32	0.64	6	0.38
33	0.64	7	0.27
34	0.75	8	0.52
35 (Sep)	0.64	9 (Mar)	0.27
36	0.64	10	0.38
37	0.64	11	0.52
38	0.75	12	0.75
39	0.71	13 (Apr)	0.43
*40 (Oct)**	-	14	0.21
*41**	-	15	0.21
*42**	*0.32*	16	0.39
43	0.66	17	0.50
44 (Nov)	0.63	18 (May)	0.41
45	0.64	19	0.43
46	0.64	20	0.50
47	0.75	21	0.43
48 (Dec)	0.64	22 (Jun)	0.43
49	0.54	23	0.61
50	0.43	24	0.59
51	0.71	25	0.43
52	0.56	26	0.50

* Traps were removed from the river and no work performed during Federal Government shutdown period between October 1 and October 17, 2013.

Table 2.—Summary of results from mark-recapture trials conducted in 2013 (*N* = 3) and 2014 (*N*= 2) to evaluate rotary-screw trap efficiency at Red Bluff Diversion Dam (RK391), Sacramento River, California. Results include the number of fish released, the mean fork length at release (Release FL), the number recaptured, the 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	2013	1,186	35.3	59	36.7	4.97	4.44	3	No
2	2013	1,018	36.3	41	35.3	4.03	6.57	3	No
3	2013	1,184	36.5	49	36.9	4.14	6.17	3	No
4	2014	1,008	37.0	30	36.5	2.98	3.27	3	Yes
5	2014	1,453	36.8	23	35.9	1.58	3.13	3	Yes

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, 2013 through June 30, 2014 (Brood-year 2013). Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry-equivalents. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry-to-pre-smolt/smolt survival rate (59% or approximately 1.7:1, Hallock undated).

Winter run Chinook Brood-year 2013

	Fry		Pre-smolt/smolts		Total		Fry-equivalent
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
27 (Jul)	0	-	0	-	0	-	0
28	145	32.5	0	-	145	32.5	145
29	0	-	0	-	0	-	0
30	1,747	34	0	-	1,747	34	1,747
31 (Aug)	3,177	34	0	-	3,177	34	3,177
32	3,917	35	0	-	3,917	35	3,917
33	5,924	34	0	-	5,924	34	5,924
34	8,639	35	0	-	8,639	35	8,639
35 (Sep)	14,138	35	168	46	14,306	35	14,423
36	45,311	35	75	48	45,386	35	45,439
37	86,490	35	302	50	86,792	35	87,003
38	84,129	35	1,755	49	85,884	35	87,113
39	289,951	35	6,513	51	296,463	36	301,022
*40 (Oct)**	*42,676*	-	*62,231*	-	*104,907*	-	*148,469*
*41**	*42,676*	-	*62,231*	-	*104,907*	-	*148,469*
42	52,053	36	31,740	54	83,792	39	106,010
43	49,161	38	84,041	55	133,203	49	192,032
44 (Nov)	14,176	42	58,558	55	72,734	53	113,724
45	15,322	43	107,862	55	123,184	54	198,688
46	2,490	44	70,994	59	73,484	59	123,179
47	829	45	88,433	61	89,262	61	151,165
48 (Dec)	290	45	56,556	63	56,846	63	96,435
49	0	-	99,583	65	99,583	65	169,292
50	0	-	72,512	66	72,512	66	123,271

* Passage interpolated using monthly mean data derived from the latter half of October’s daily passage during Federal Government shutdown period.

Table 3.— (continued)

Week	Fry		Pre-smolt/smolts		Total		Fry-equivalent
	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
51	0	-	28,118	69	28,118	69	47,801
52	0	-	28,747	71	28,747	71	48,869
1 (Jan)	0	-	6,054	75	6,054	75	10,292
2	0	-	7,628	77.5	7,628	77.5	12,968
3	0	-	10,708	73	10,708	73	18,204
4	0	-	7,607	79.5	7,607	79.5	12,933
5 (Feb)	0	-	2,963	93.5	2,963	93.5	5,037
6	0	-	61,839	89.5	61,839	89.5	105,126
7	0	-	11,252	97	11,252	97	19,128
8	0	-	4,802	102.5	4,802	102.5	8,163
9 (Mar)	0	-	21,247	122	21,247	122	36,120
10	0	-	4,385	109.5	4,385	109.5	7,454
11	0	-	1,417	126.5	1,417	126.5	2,409
12	0	-	1,109	118	1,109	118	1,885
13 (Apr)	0	-	2,203	135	2,203	135	3,746
14	0	-	1,812	133	1,812	133	3,081
15	0	-	4,087	141	4,087	141	6,948
16	0	-	789	147.5	789	147.5	1,342
17	0	-	247	142	247	142	420
18 (May)	0	-	0	-	0	-	0
19	0	-	67	140	67	140	114
20	0	-	0	-	0	-	0
21	0	-	0	-	0	-	0
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	763,240		1,010,638		1,773,878		2,481,324

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 BY95 through BY99, assumptions used in the carcass survey based NOAA Fisheries 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 BY13, 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
1995	1,816,984	1,658,967	2,465,169	-	-
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 [c]	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	1,419
2013	2,481,324	1,539,193	3,423,456	4,431,064	3,577

[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 JPE using estimated effective spawner population from Snider et al. (1996-2000) and Bruce Oppenheim (2000-2013), NOAA Fisheries pers comm.

[c] The 2004 JPE calculations used a standard value of fecundity of 3,500 eggs/female (Bruce Oppenheim 2006, NOAA Fisheries, pers. comm..).

Table 5.—Summary of estimated egg-to-fry (ETF) survival rates derived from winter Chinook carcass survey female escapement estimates, estimates of the number of eggs per female (potential egg deposition), 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]	Potential Egg Deposition [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)
				Average	1,236	25.9 (17.2 : 38.2)
				Standard Deviation	461	9.5 (7.9 : 13.8)

a Carcass survey derived estimated effective spawner population from Snider et al. (1996-2000) and Bruce Oppenheim (2000-2013), NOAA Fisheries 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 – 2013 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).

Table 6.—Comparisons between winter Chinook fry-equivalent JPI's using standard interpolation method (monthly mean), an 11-year daily mean percentage passage, an 11-year daily maximum percentage passage, and 150% of daily maximum percentage passage value estimates from data collected between 2002 and 2012 (Poytress et al. 2014). These JPI estimates are compared to NOAA Fisheries winter Chinook JPE (a) for brood-year 2013 and (b) a calculated JPI estimating all spring Chinook sampled at RBDD[1] were late-emerging winter Chinook incorrectly assigned to spring Chinook run using length-at-date criteria.

	Monthly Mean	11-Year Daily Mean	11-Year Daily Max	150% Daily Max
17-day Interpolation Proportion	14%	23%	40%	50%
Fry Equivalent JPI	2,481,324	2,786,992	3,595,220	4,319,838
JPE Difference (a)	-44%	-37%	-19%	-3%
Spring run JPI	426,325	426,325	426,325	426,325
Winter + Spring JPI Total	2,907,649	3,213,317	4,021,545	4,746,163
JPE Difference (b); Winter + spring run JPI's	-34%	-27%	-9%	+7%

[1] Sum of all spring Chinook passage prior to CNFH fall Chinook releases (i.e., < 4/5/2014; Appendix Table A3).

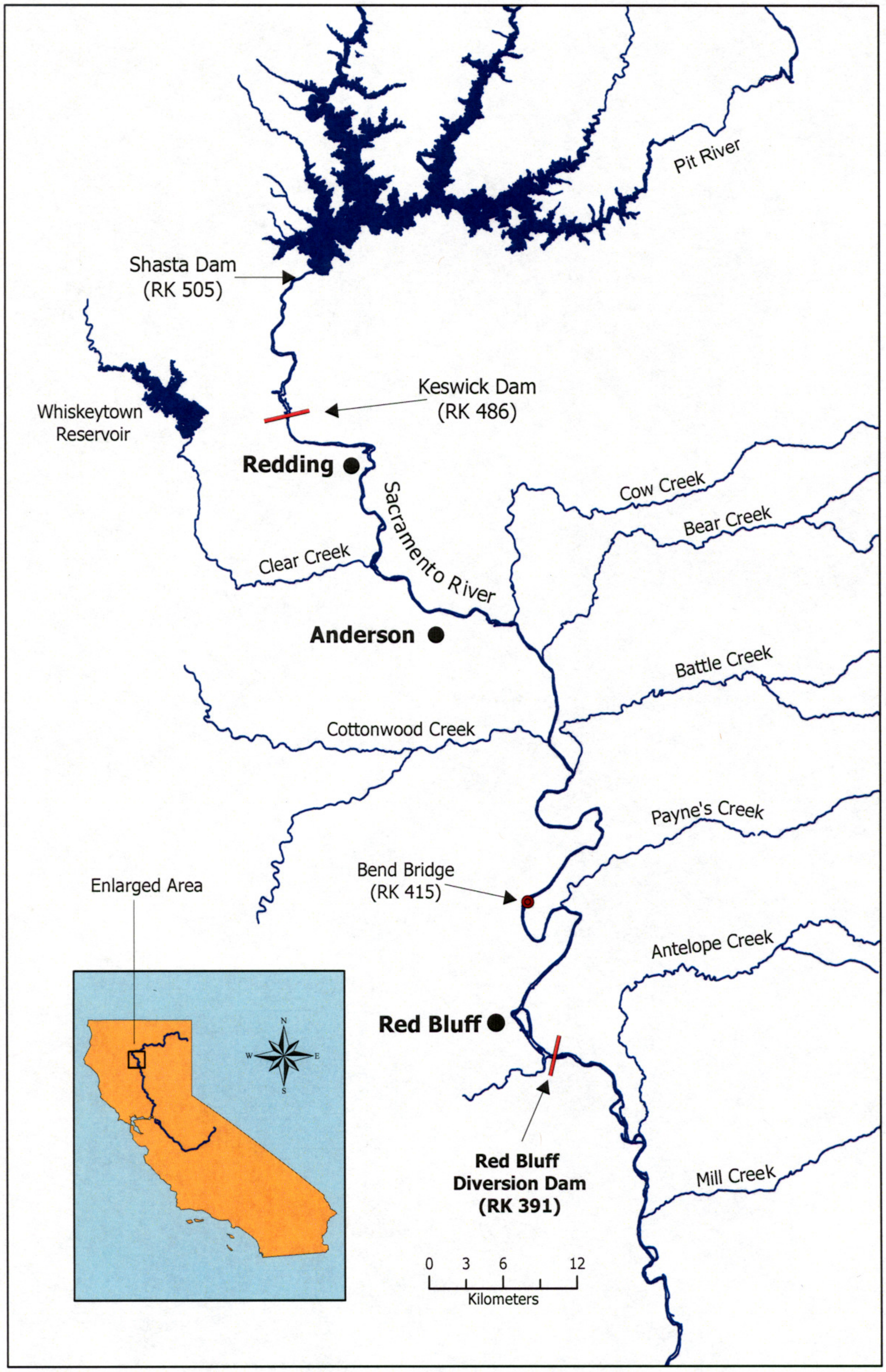

Figure 1. Location of Red Bluff Diversion Dam on the Sacramento River, California at river kilometer 391 (RK 391).

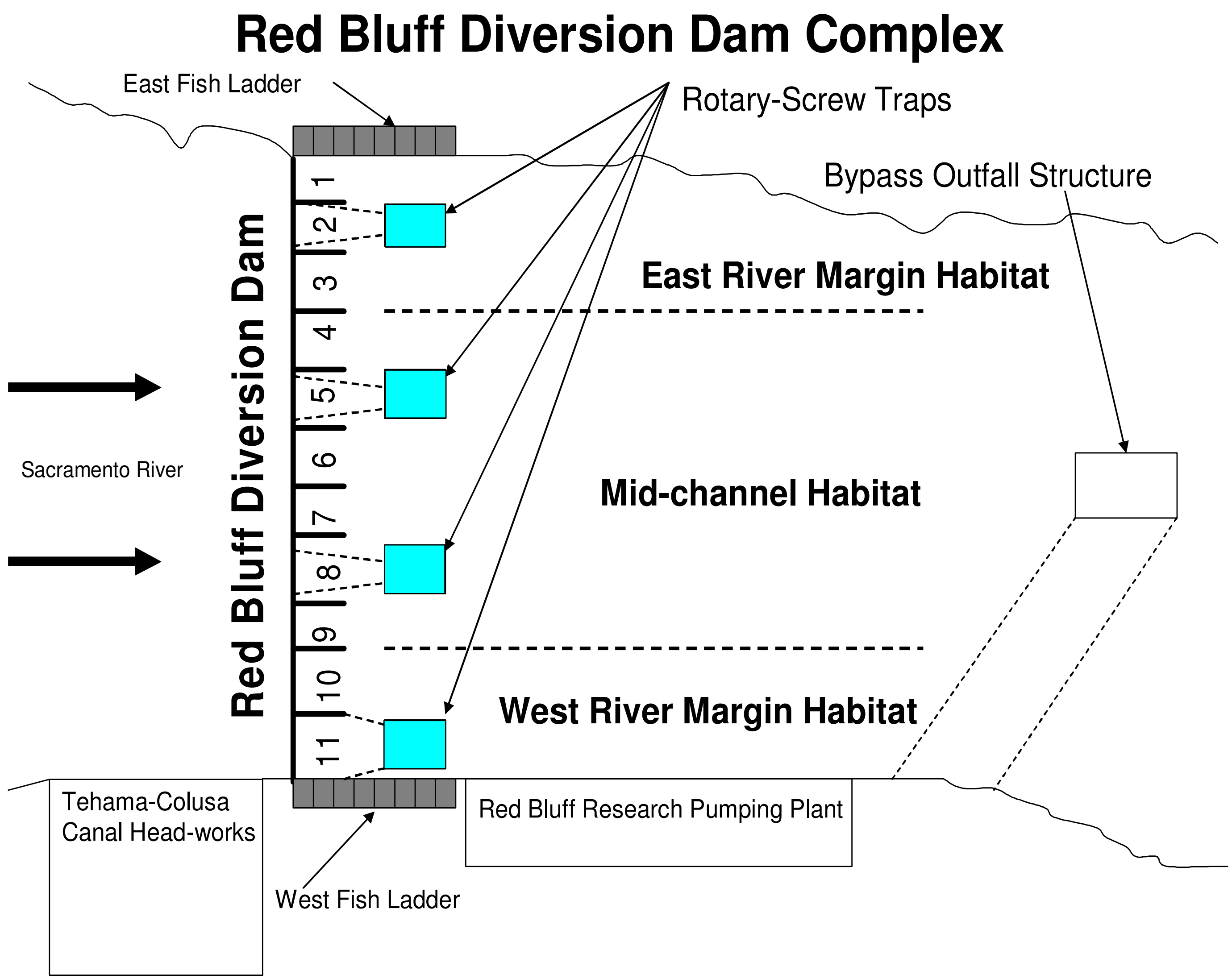

Figure 2. Rotary-screw trap sampling transect at Red Bluff Diversion Dam Complex (RK391) on the Sacramento River, California.

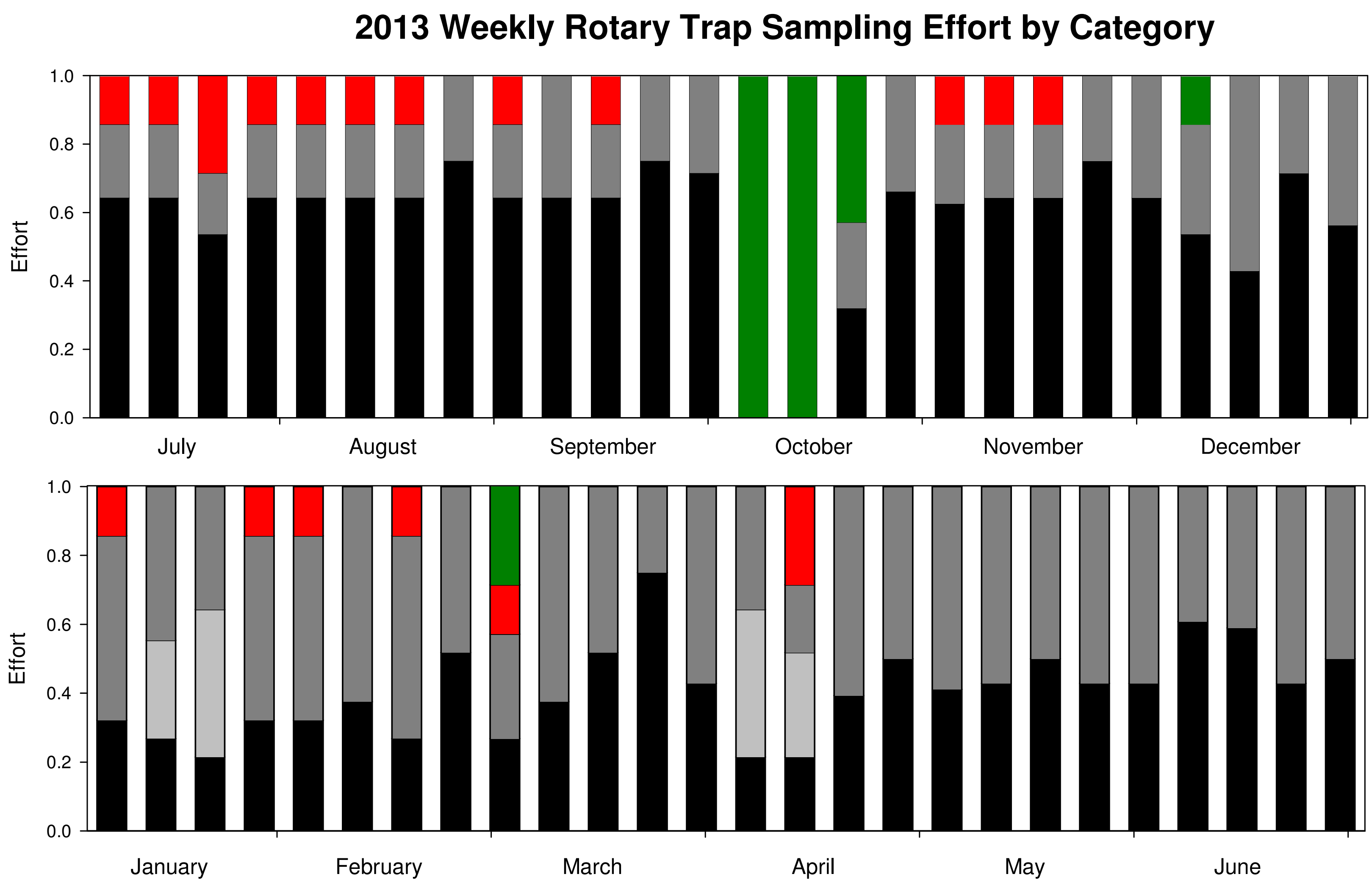

Figure 3. Weekly rotary trap sampling effort (stacked bars) for the period July 1, 2013 through June 30, 2014, by category. Sampled portions represented by black bars; unsampled portions (designated in descending order of frequency): intentional reductions in effort (dark grey), unintentional reductions (dark green), lack of staff (red), and hatchery releases (light grey).

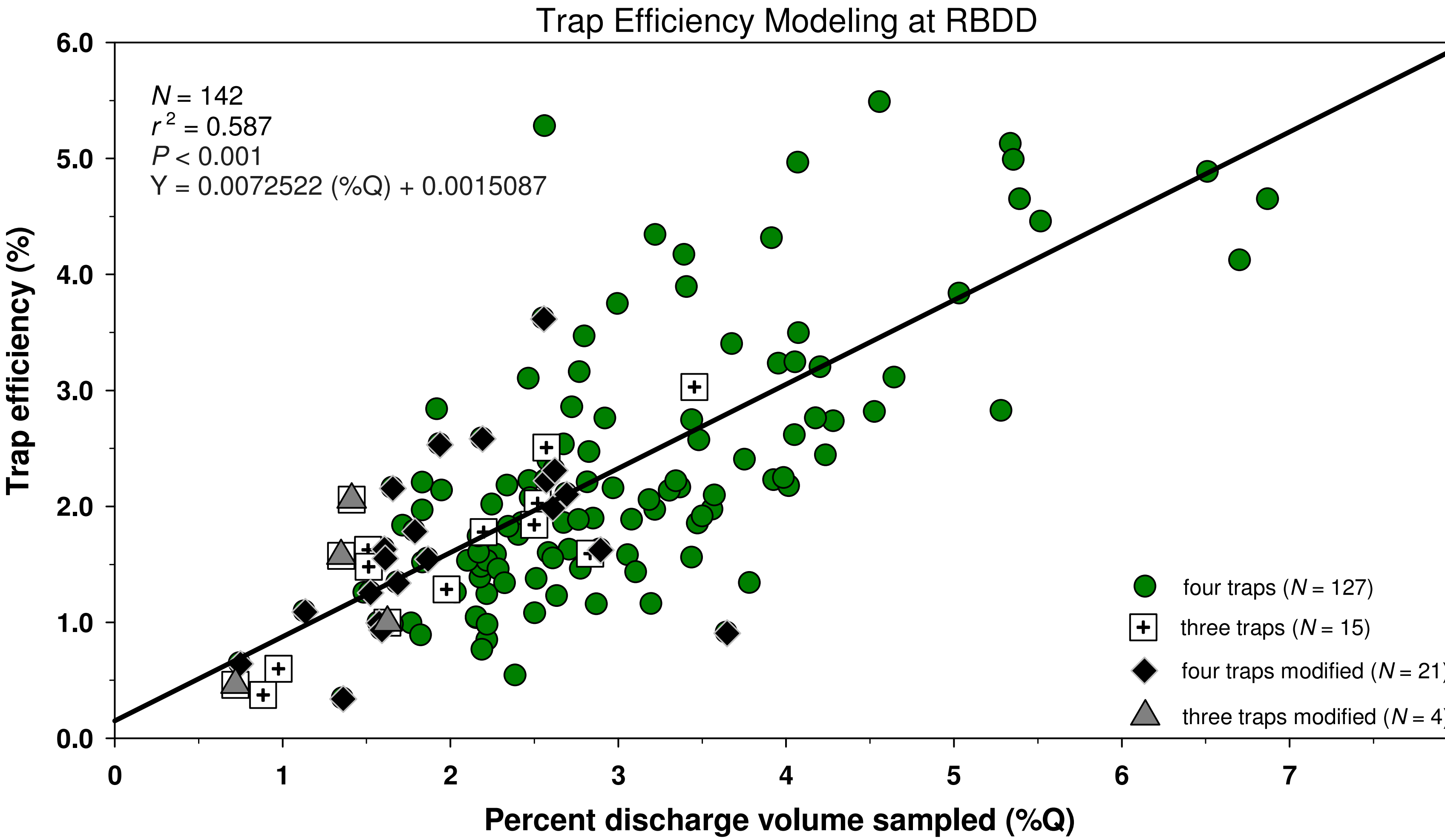

Figure 4. Trap efficiency model for combined 2.4 m diameter rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four traps (*N* = 127), three traps (*N* = 15), or with traps modified to sample one-half the normal volume of water (*N* = 25).

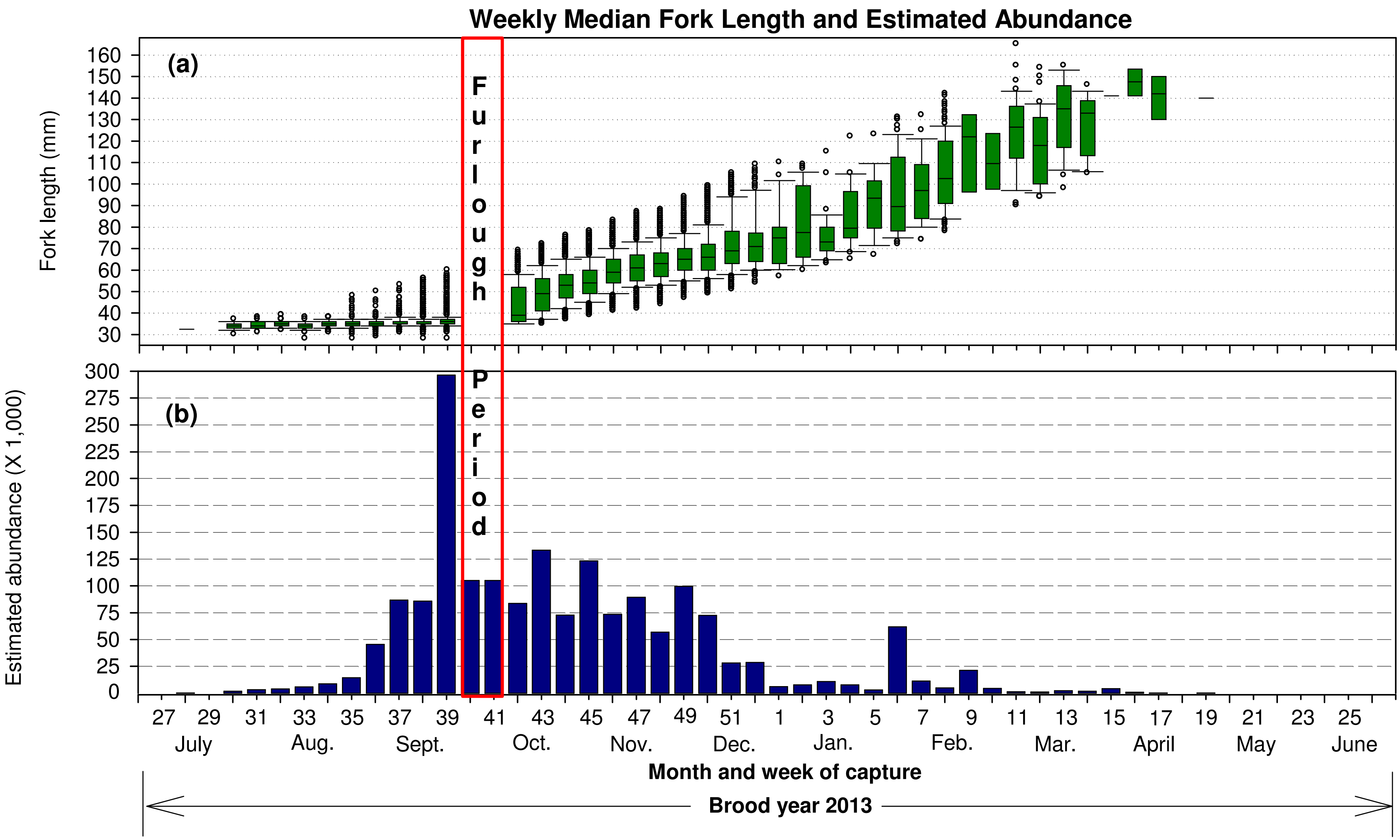

Figure 5. Weekly median fork length (a) and estimated abundance (b) of juvenile winter Chinook salmon passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Winter Chinook salmon were sampled by rotary-screw traps for the period July 1, 2013 through June 30, 2014. Box plots display weekly median fork length, 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles and outliers.

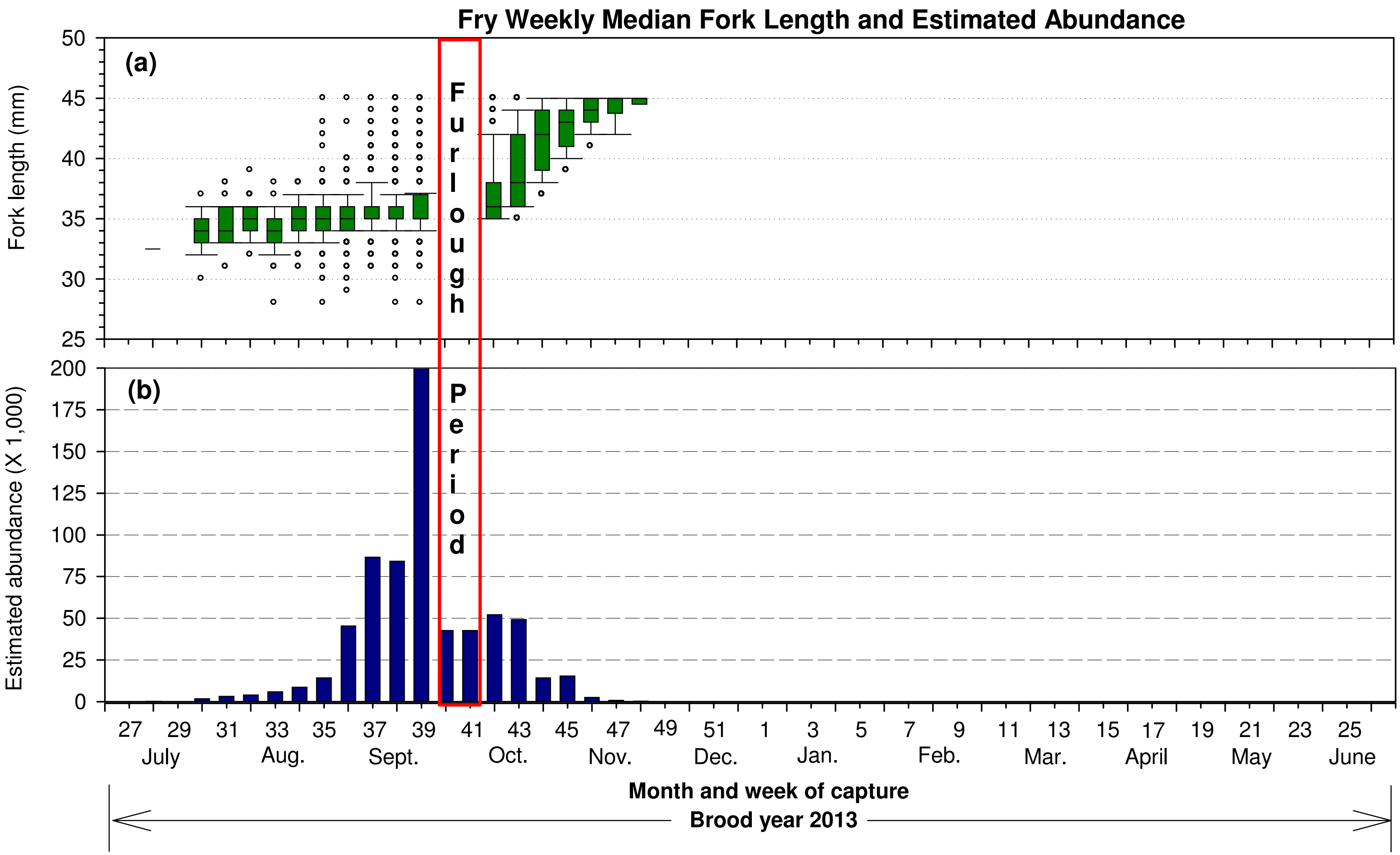

Figure 6. Weekly median fork length (a) and estimated abundance (b) of winter Chinook fry passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Winter Chinook juveniles were sampled by rotary-screw traps for the period July 1, 2013 through June 30, 2014. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

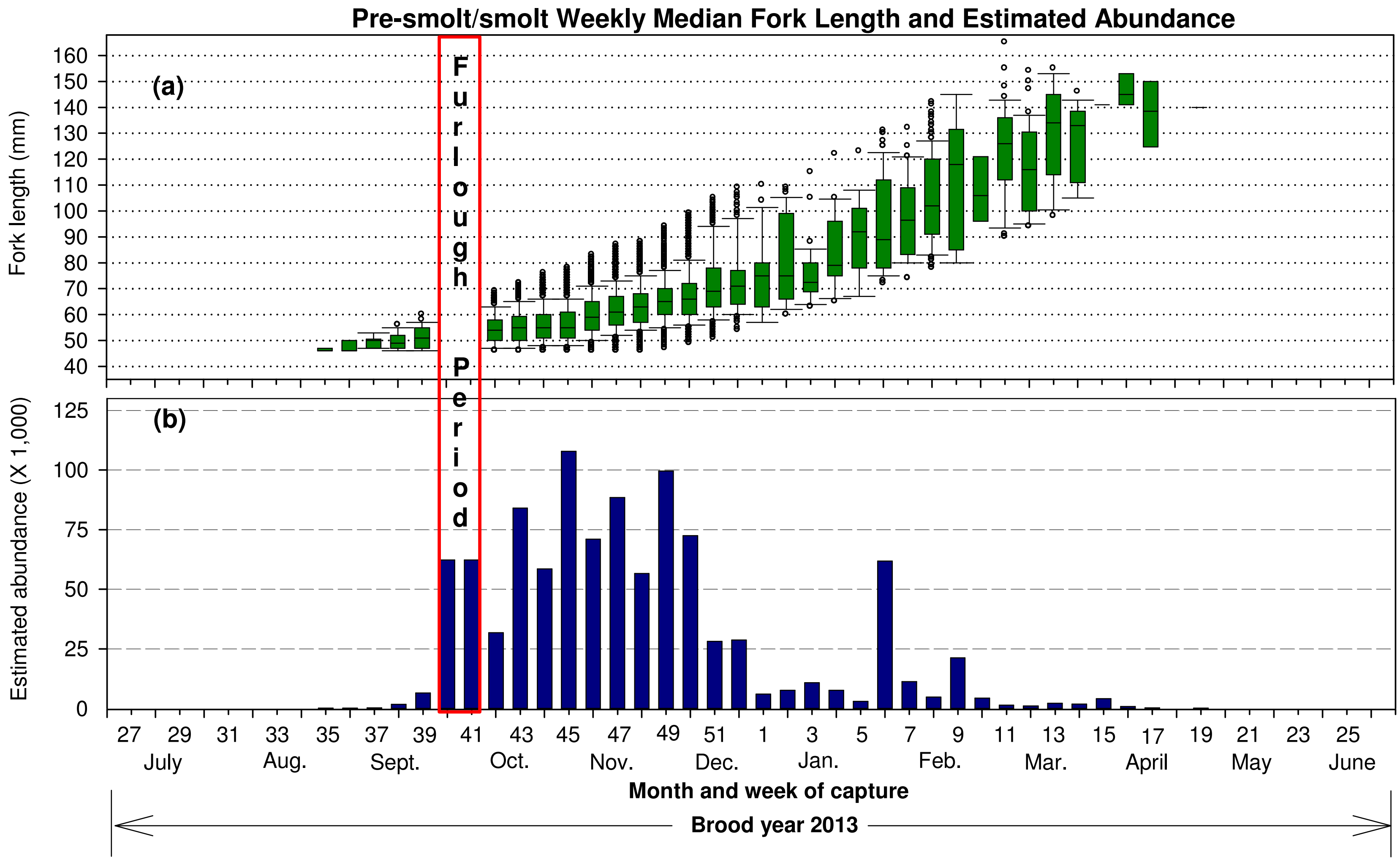

Figure 7. Weekly median fork length (a) and estimated abundance (b) of winter Chinook pre-smolt/smolts passing Red Bluff Diversion Dam (RK 391), Sacramento River, California. Winter Chinook juveniles were sampled by rotary-screw traps for the period July 1, 2013 through June 30, 2014. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

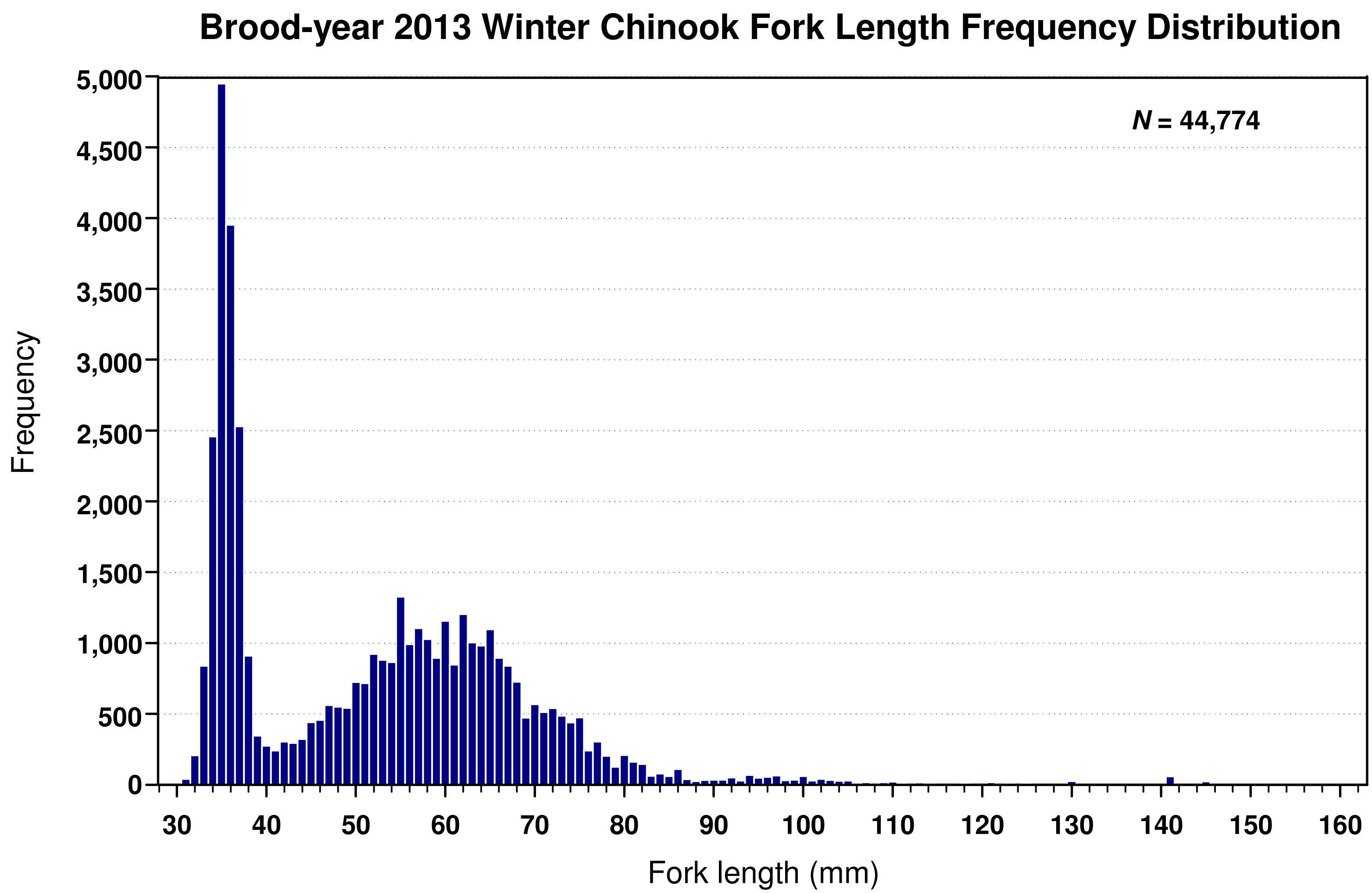

Figure 8. Fork length frequency distribution of brood-year 2013 juvenile winter Chinook salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fork length data was expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from July 1, 2013 through September 30, 2013 and October 17, 2013 through June 30, 2014.

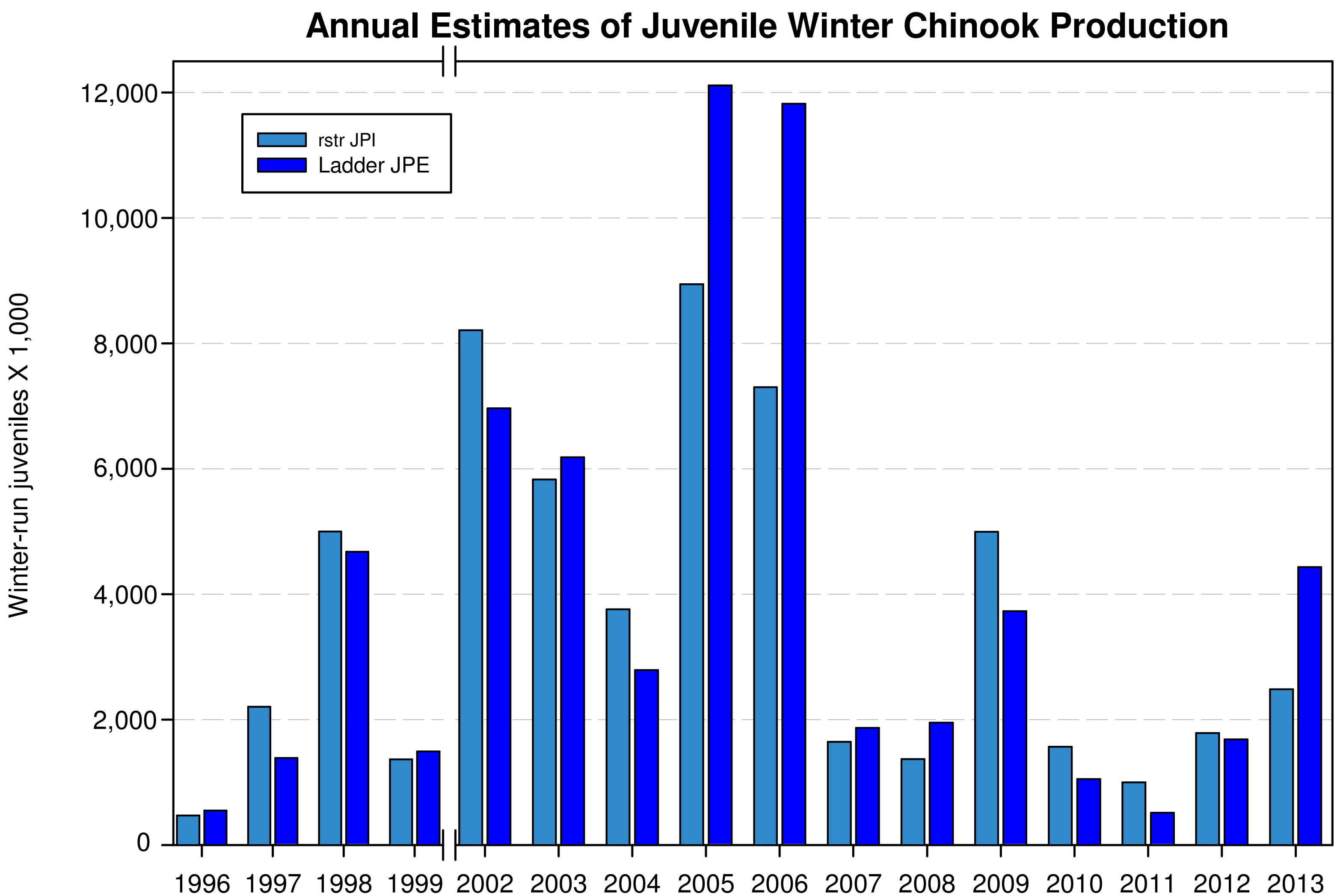

Figure 9. Time series comparison of annual estimates of juvenile winter-run production using rotary-screw trap fry-equivalent JPI's (light blue) and carcass survey JPE's (dark blue).

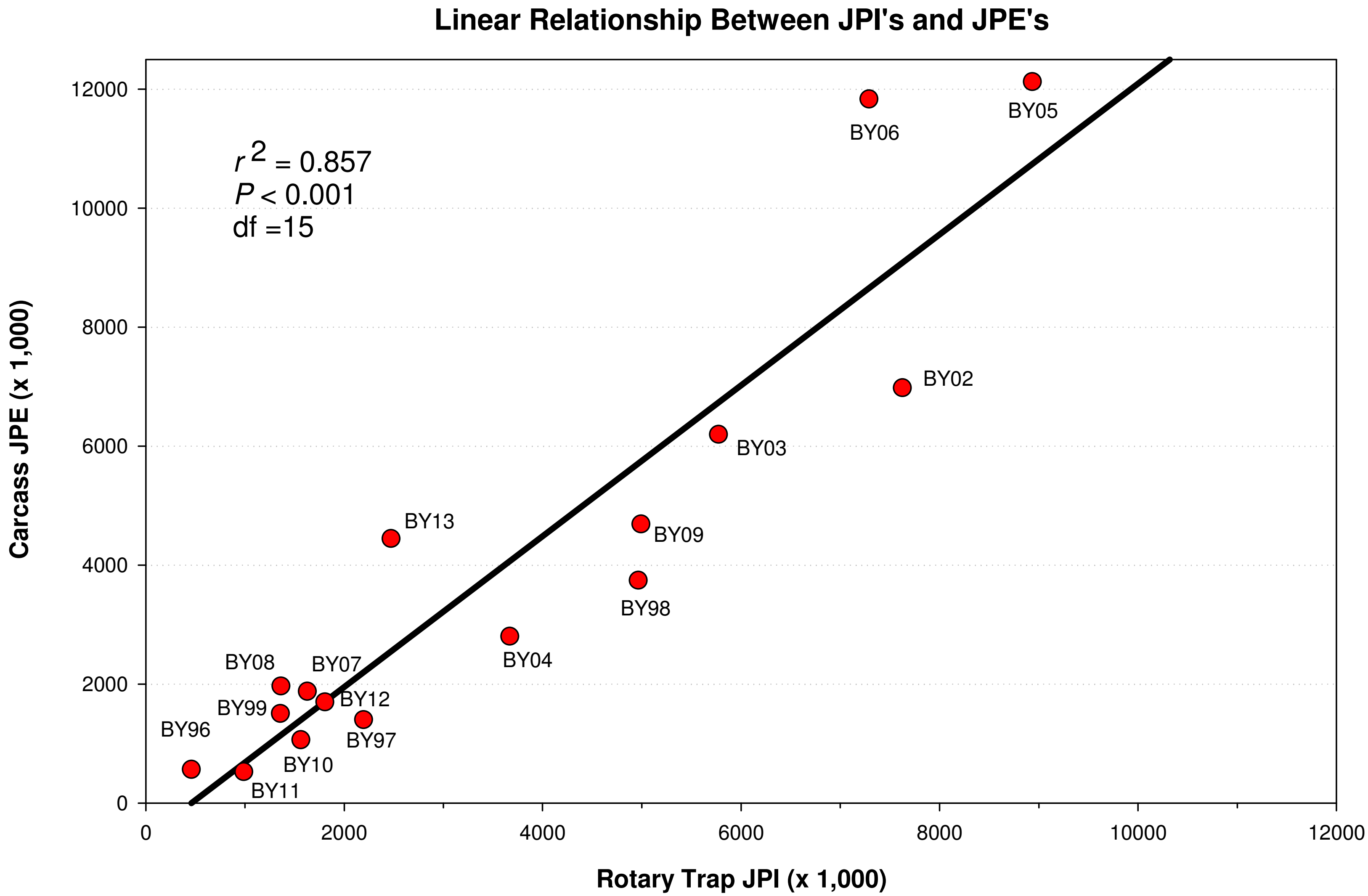

Figure 10. Linear relationship between rotary-screw trap fry-equivalent juvenile production indices (Rotary Trap JPI) and carcass survey derived juvenile production estimates (Carcass JPE).

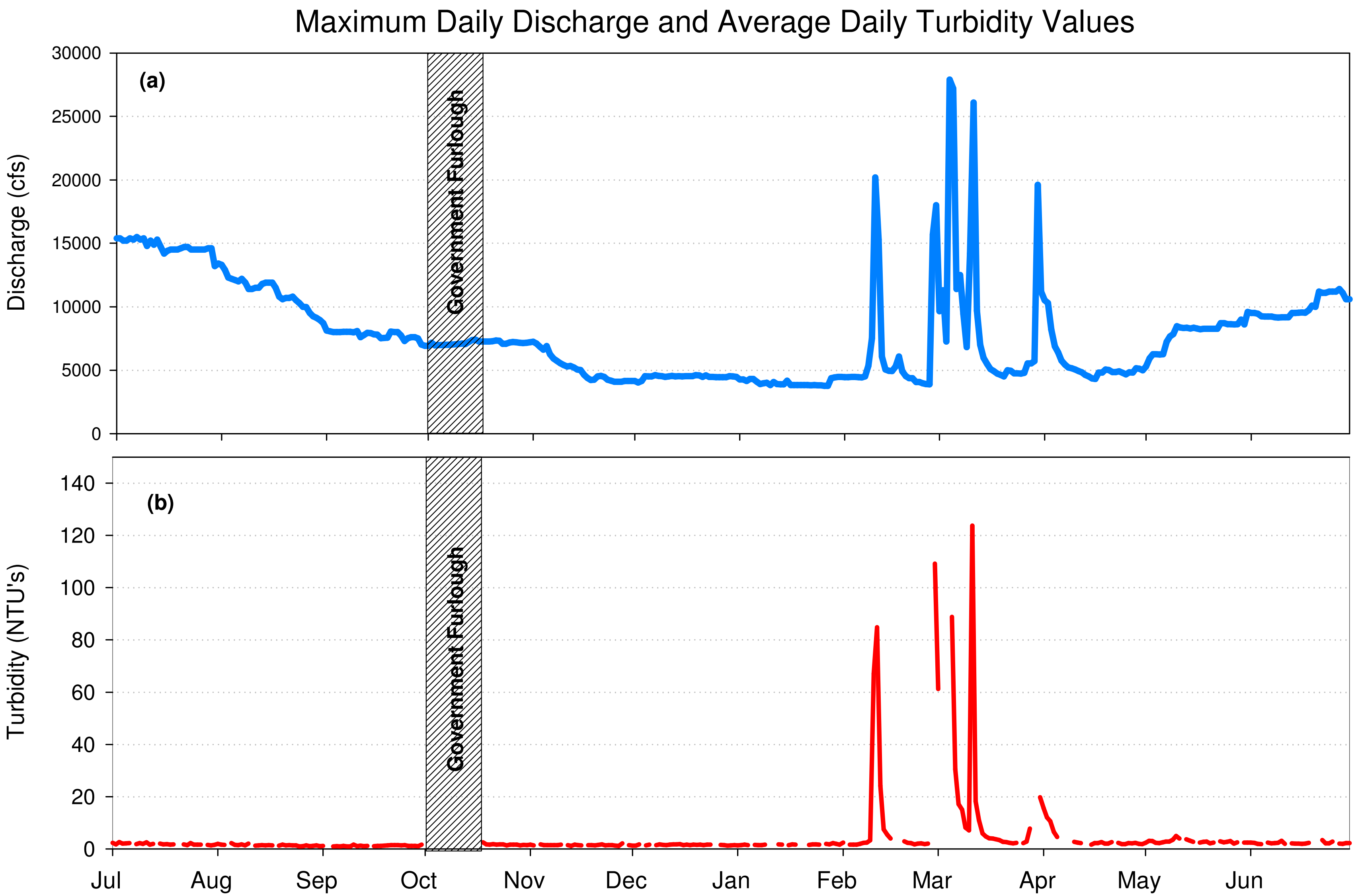

Figure 11. Maximum daily discharge (a) calculated from the California Data Exchange Center's Bend Bridge gauging station and average daily turbidity values (b) from rotary-screw traps at RBDD for the period July 1, 2013 through June 30, 2014.

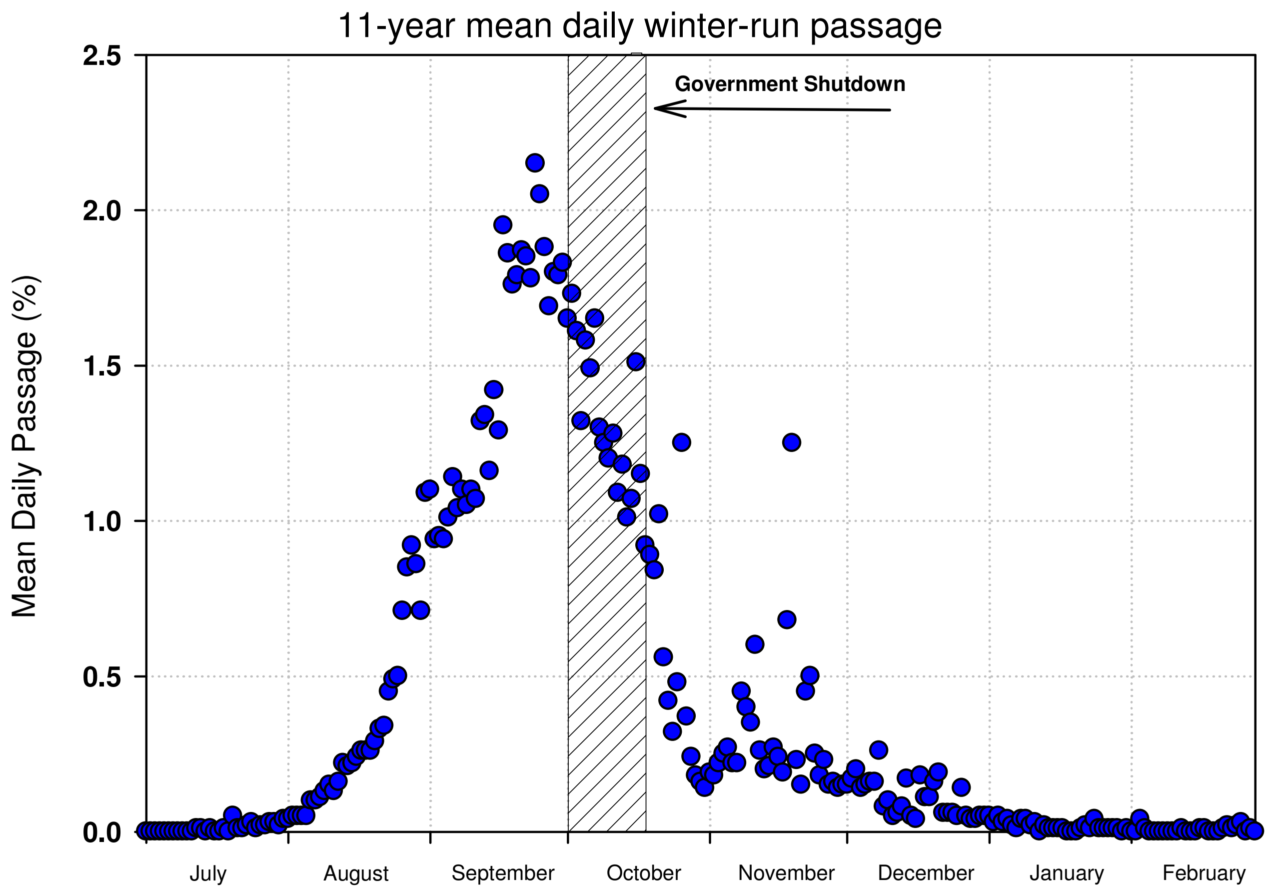

Figure 12. Mean daily percent passage of juvenile winter Chinook at RBDD between 2002 and 2012. The shaded box is representative of the unsampled period (October 1 to October 17, 2013) due to a Federal Government shutdown in 2013.

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, 2013 through November 30, 2014 (Brood-year 2013). Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry- equivalents. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry-to-pre-smolt/smolt survival rate (59% or approximately 1.7:1, Hallock undated).

Fall run Chinook Brood-year 2013							
	Fry		Pre-smolt/smolts		Total		Fry-equivalent
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
48 (Dec)	4,675	33	0	0	4,675	33	4,675
49	24,872	34	0	0	24,872	34	24,872
50	61,241	35	0	0	61,241	35	61,241
51	163,953	36	0	0	163,953	36	163,953
52	629,403	36	0	0	629,403	36	629,403
1 (Jan)	548,831	37	0	0	548,831	37	548,831
2	370,418	37	0	0	370,418	37	370,418
3	545,389	37	1,061	46	546,450	37	547,193
4	696,064	36	1,414	47	697,478	36	698,467
5 (Feb)	686,017	37	2,708	47.5	688,726	37	690,622
6	10,623,026	37	219,939	49	10,842,965	37	10,996,923
7	575,307	37	52,287	49	627,594	37	664,194
8	107,953	37	11,358	52	119,311	37	127,262
9 (Mar)	11,976,948	36	115,951	51	12,092,900	37	12,174,065
10	1,243,019	37	302,028	52	1,545,047	38	1,756,466
11	93,403	36	73,605	57	167,008	47	218,532
12	11,367	36	37,264	62	48,631	60	74,716
13 (Apr)	90,818	36	98,024	65	188,841	55	257,458
14	61,227	37	299,128	67	360,355	62	569,744
15	7,873	37	235,106	75	242,978	75	407,552
16	553	41	163,337	76	163,890	76	278,225
17	259	42	167,453	77	167,712	77	284,929
18 (May)	653	44	185,353	76	186,007	76	315,754
19	453	45	191,403	76	191,857	76	325,839
20	0	0	211,681	76	211,681	76	359,858

Table A1.— (continued)

Week	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
21	0	0	185,351	74	185,351	74	315,097
22 (Jun)	0	0	142,640	73	142,640	73	242,488
23	0	0	103,655	74	103,655	74	176,213
24	0	0	160,918	77	160,918	77	273,561
25	0	0	134,269	74	134,269	74	228,257
26	0	0	56,320	77	56,320	77	95,745
27 (Jul)	0	0	46,393	82	46,393	82	78,868
28	0	0	68,479	85	68,479	85	116,415
29	0	0	18,919	86	18,919	86	32,162
30	0	0	9,877	87	9,877	87	16,790
31 (Aug)	0	0	5,683	89	5,683	89	9,662
32	0	0	7,460	97	7,460	97	12,683
33	0	0	2,786	99	2,786	99	4,736
34	0	0	496	103	496	103	843
35 (Sep)	0	0	897	109	897	109	1,526
36	0	0	584	114	584	114	992
37	0	0	473	116	473	116	803
38	0	0	324	124	324	124	552
39	0	0	276	121	276	121	468
*40 (Oct)**	*0*	*0*	*138*	*119*	*138*	*119*	*234*
*41**	*0*	*0*	*155*	*124*	*155*	*124*	*263*
42	0	0	41	146	41	146	69
43	0	0	1,000	142	1,000	142	1,700
44 (Nov)	0	0	681	138	681	138	1,157
45	0	0	628	149.5	628	149.5	1,068
46	0	0	129	159	129	159	219
47	0	0	105	164	105	164	179
BY total	28,523,723		3,317,776		31,841,500		34,163,943

* Traps were removed from the river during Government shutdown between October 1 and October 17, 2013 and passage was interpolated for weeks 40 and 41.

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, 2013 through March 31, 2014 (Brood-year 2013). Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry- equivalents. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry-to-pre-smolt/smolt survival rate (59% or approximately 1.7:1, Hallock undated).

Late-fall run Chinook Brood-year 2013

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
13 (Apr)	0	0	0	-	0	-	0
14	6,955	34	0	-	6,955	34	6,955
15	228	34	0	-	228	34	228
16	655	35	0	-	655	35	655
17	264	35	0	-	264	35	264
18 (May)	2,258	34	0	-	2,258	34	2,258
19	946	34	0	-	946	34	946
20	1,051	36	0	-	1,051	36	1,051
21	480	37	64	46	544	38	588
22 (Jun)	55	35	239	49	294	47.5	461
23	477	41.5	650	49	1,128	47	1,583
24	216	36	679	52	895	51	1,370
25	0	-	406	53	406	53	689
26	0	-	896	57	896	57	1,523
27 (Jul)	0	-	1,270	59	1,270	59	2,159
28	0	-	1,099	62.5	1,099	62.5	1,869
29	0	-	2,203	66	2,203	66	3,746
30	0	-	1,897	69	1,897	69	3,225
31 (Aug)	0	-	2,201	69	2,201	69	3,742
32	0	-	2,848	73	2,848	73	4,842
33	52	45	1,720	75	1,771	75	2,975
34	0	-	1,231	79	1,231	79	2,092
35 (Sep)	0	-	1,315	81	1,315	81	2,235
36	0	-	845	87	845	87	1,437
37	0	-	748	86	748	86	1,272

Table A2.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
38	0	-	2,803	93	2,803	93	4,765
39	0	-	2,668	87	2,668	87	4,536
*40 (Oct)**	*0*	-	*6,829*	-	*6,829*	-	*11,609*
*41**	*0*	-	*6,829*	-	*6,829*	-	*11,609*
42	0	-	5,258	95	5,258	95	8,939
43	0	-	8,229	91.5	8,229	91.5	13,989
44 (Nov)	0	-	6,117	111	6,117	111	10,400
45	0	-	7,734	112	7,734	112	13,148
46	0	-	5,393	110	5,393	110	9,168
47	0	-	11,654	111	11,654	111	19,812
48 (Dec)	0	-	6,654	111	6,654	111	11,312
49	0	-	14,961	112	14,961	112	25,434
50	0	-	19,434	110	19,434	110	33,038
51	0	-	4,872	111	4,872	111	8,283
52	0	-	1,899	112	1,899	112	3,228
1 (Jan)	0	-	744	121	744	121	1,265
2	0	-	209	126	209	126	356
3	0	-	0	-	0	0	0
4	0	-	0	-	0	0	0
5 (Feb)	0	-	312	188	312	188	531
6	0	-	2,370	149	2,370	149	4,030
7	0	-	0	-	0	-	0
8	0	-	0	-	0	-	0
9 (Mar)	0	-	10,414	237	10,414	237	17,703
10	0	-	0	-	0	-	0
11	0	-	0	-	0	-	0
12	0	-	0	-	0	-	0
BY total	13,638		145,696		159,334		261,321

* Traps were removed from the river during Government shutdown between October 1 and October 17, 2013 and passage was interpolated for weeks 40 and 41.

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 15, 2013 through October 14, 2014 (Brood-year 2013). Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry- equivalents. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry-to-pre-smolt/smolt survival rate (59% or approximately 1.7:1, Hallock undated).

Spring run Chinook Brood-year 2013							
	Fry		Pre-smolt/smolts		Total		Fry-equivalent
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
42	9,740	34	0	-	9,740	34	9,740
43	22,533	35	0	-	22,533	35	22,533
44 (Nov)	13,375	35	0	-	13,375	35	13,375
45	9,317	36	0	-	9,317	36	9,317
46	1,186	36	0	-	1,186	36	1,186
47	4,451	34.5	0	-	4,451	34.5	4,451
48 (Dec)	13,854	35	0	-	13,854	35	13,854
49	19,812	36	583	47	20,395	36	20,803
50	19,301	37	850	48	20,151	37	20,745
51	15,757	39	1,035	50	16,792	39	17,516
52	4,827	41	706	47	5,532	41	6,027
1 (Jan)	944	45	1,238	47	2,182	47	3,049
2	992	45	1,029	49	2,021	45.5	2,741
3	0	-	3,132	50	3,132	50	5,324
4	0	-	2,576	58	2,576	58	4,379
5 (Feb)	0	-	4,512	57	4,512	57	7,670
6	0	-	79,760	58	79,760	58	135,592
7	0	-	22,719	58	22,719	58	38,623
8	0	-	12,638	62	12,638	62	21,485
9 (Mar)	0	-	25,597	66	25,597	66	43,514
10	0	-	29,382	67	29,382	67	49,949
11	0	-	16,267	72	16,267	72	27,654
12	0	-	22,886	74	22,886	74	38,905
13 (Apr)	0	-	38,475	77	38,475	77	65,408
14	0	-	318,995	80	318,995	80	542,292

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	-	202,186	82	202,186	82	343,717
16	0	-	53,905	86	53,905	86	91,639
17	0	-	22,094	91	22,094	91	37,559
18 (May)	0	-	9,533	96	9,533	96	16,205
19	0	-	7,978	101	7,978	101	13,563
20	0	-	4,295	105	4,295	105	7,301
21	0	-	1,758	110	1,758	110	2,988
22 (Jun)	0	-	943	112	943	112	1,603
23	0	-	104	119	104	119	176
24	0	-	332	123.5	332	123.5	565
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	136,087		885,507		1,021,594		1,641,449

* Traps were removed from the river during Government shutdown between October 1 and October 17, 2013 and passage was interpolated for weeks 40 and 41.