BROOD-YEAR 2007 WINTER CHINOOK JUVENILE PRODUCTION INDICES WITH COMPARISONS TO JUVENILE PRODUCTION ESTIMATES DERIVED FROM ADULT ESCAPEMENT

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Brood-year 2007 winter Chinook juvenile production indices with comparisons to juvenile production estimates derived from adult escapement

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Abstract.— Brood-year 2007 juvenile winter-run Chinook salmon passage at Red Bluff Diversion Dam (RBDD) was 1,444,786 fry and pre-smolt/smolts combined, representing a 56% decrease in that observed during the passage of this cohort in brood-year 2004. Fry-equivalent production was 1,642,575. 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 as the primary variate. Two separate JPE's were calculated, the first using adult escapement estimates from the winter-run Chinook salmon carcass survey and the second using adult escapement estimates from the RBDD fish ladders. Rotary-screw trap JPI's continued to be correlated strongly in trend when compared to carcass survey JPE's ($r^2 = 0.85$, $P < 0.001$, df = 9). Comparisons between rotary trap JPI's to fish ladder JPE's continued to be moderately strong ($r^2 = 0.60$, $P = 0.005$, df = 10), yet the fish ladder JPE overestimated the number of juveniles produced for the first time in eleven years of comparisons. Paired comparisons revealed a significant difference in production estimates between JPI's and fish ladder JPE's ($t = -2.35$, $P = 0.029$, df = 10). The 2007 fish ladder JPE slightly exceeded the 90% C.I. around the rotary trap JPI by 0.21%. Conversely, no significant difference was detected between rotary trap JPI's and carcass survey JPE's ($t = -0.31$, $P = 0.761$, df = 9). Overall, the relationship between the direct measure of juvenile abundance (JPI) and the indirect or modeled approach using carcass survey data remains strong. The addition of the 2007 data continues to support this relationship.

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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 been implemented to protect and conserve the endangered winter-run Chinook salmon. One protective measure is to manage water exports adaptively 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). The NOAA Fisheries uses a juvenile production model to estimate abundance of the juvenile winter Chinook population entering the Delta. Historically, the model has used adult escapement estimates derived from Red Bluff Diversion Dam (RBDD) fish ladder counts (Diaz-Soltero 1995, 1997; Lecky 1998, 1999, 2000), and more recently, escapement estimates derived from the winter Chinook carcass survey (McInnis 2002, NMFS 2004).

The NOAA Fisheries juvenile production model uses estimated adult escapement as the primary variate. The two survey methods (carcass surveys and RBDD ladder counts) typically have produced greatly dissimilar adult escapement estimates. Consequently, winter Chinook juvenile production estimates (JPE's) differ greatly as well.

One factor contributing to the incongruence in JPE's, with respect to the annual RBDD adult ladder count estimate, is the annual variability in migration timing. The gates at RBDD are currently only closed during a portion of the winter Chinook spawning migration, and the fish ladders are operational only when the gates are closed. Therefore, the majority of winter Chinook adults pass above RBDD without using the fish ladders. Estimates of annual escapement are derived by assuming the proportion of adults using the fish ladders is 15% on average, and expanding accordingly. However, the proportion of adults passing during the gates closed period has ranged from 3% to 48%, based on data from 1969-1985 when gates at RBDD were closed year-round (Snider et al. 2001).

Another factor associated with the incongruence between the JPE's is the estimate of female spawners, the second variate of the model. The female escapement estimates derived from the two survey techniques differ, at times, greatly. This may be due to the dissimilar methodologies the two surveys use to produce each estimate. For the carcass

[1] The Sacramento River winter-run Chinook salmon was listed as endangered May of 1989 under the California Endangered Species Act (California Code of Regulations, Title XIV, section 670.5, filed September 1989), and listed as endangered under the Federal Endangered Species Act (1973, as amended) by the National Marine Fisheries Service in February 1994 (59 FR 440). Their federal endangered status was reaffirmed in June 2005 (70 FR 37160).

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). 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). For the RBDD ladder counts the sex ratio is determined by an assumed 1:1 sex ratio as gender differentiation is questionable. These disparities in sex ratios between survey techniques can have large net effects on the estimated number of spawning females, which in turn, can have remarkable effects on the JPE.

In light of the technical difficulties in estimating adult escapement described above, the use of the JPE model with either survey technique 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). The overall result being the production of fewer juveniles than the JPE model would predict.

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.

The objectives of this study were to (1) estimate the abundance of brood year (BY) 2007 juvenile winter Chinook passing RBDD, (2) define temporal patterns of abundance, and (3) determine if JPI's from rotary trapping support JPE's generated from the carcass survey and the RBDD ladder counts.

This annual report addresses, in detail, our juvenile winter Chinook monitoring activities at RBDD for the period July 1, 2007 through June 30, 2008. This report includes JPI's for the complete 2007 brood-year emigration period and will be submitted to the California Department of Fish and Game and GCAP Services Inc. to comply with contractual reporting requirements for Ecosystem Restoration Program Grant Agreement Number P0685507.

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 remains mostly unrestricted below Keswick Dam and supports areas of intact riparian vegetation. In contrast, urban and agricultural development has impacted much of the river between Red Bluff, California and San Francisco Bay. Impacts include, but are not limited to, channelization, water diversion, agricultural and municipal run-off, and loss of associated riparian vegetation.

Red Bluff Diversion Dam is located at river-kilometer 391 (RK391) 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. Between gates are concrete piers 2.4 m in width. The USBR's dam operators are able to raise the RBDD gates allowing for run-of-the-river conditions or lower them to impound and divert river flows into the Tehama-Colusa Canal. USBR operators generally raise the RBDD gates from September 16 through May 14 and lower them May 15 through September 15 of each year (NOAA 2004).

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 random periods to reduce incidental mortality. When abundance of winter Chinook was very high, 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 and associated elevated river discharge levels, the 24 hour sampling period was divided into four or six non-overlapping strata and one stratum was randomly selected for sampling (Martin et al 2001). Estimates were extrapolated to un-sampled strata by dividing catch by the strata-selection probability (i.e., $P = 0.25$ or 0.17). If further reductions in impact were needed or river conditions were intolerable sampling was not conducted.

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 were collected at each trap servicing and 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 (http://cdec2.water.ca.gov/cgi-progs/queryFx?bnd).

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, seven days weekly. 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 seven 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 6-24 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) was modeled with $\%Q$ to develop a simple least-squares regression equation. The equation was then used to calculate daily trap efficiencies based on daily river volume sampled. To model trap efficiency with $\%Q$, we conducted mark-recapture trials and estimated trap efficiency during trials as noted above.

Passage estimates.—Winter Chinook passage was estimated by employing the model developed to predict daily trap efficiency ($\hat{T}_d$). The trap efficiency model was developed by conducting 123 mark/recapture trials at RBDD and used $\%Q$ as the primary variate (Martin et al. 2001, Poytress and Carrillo 2008). Trap efficiency estimates from trials were plotted against $\%Q$ to develop a least squares regression equation (eq. 5), whereby daily trap efficiencies could be predicted.

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] 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.

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. $$\hat{T}_d = (0.00645)(\%\hat{Q}_d) + 0.00303$$

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

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 was variable among years, therefore, we standardized juvenile production by estimating a fry-equivalent JPI for among-year comparisons. Fry-equivalent JPI's were estimated by the summation of fry JPI'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.

Hypotheses testing.— The JPI is a direct measure of juvenile production and has been used to track the JPE, an indirect measure of juvenile production (Martin et al., 2001). Juvenile production estimates derived from effective spawner populations based on the RBDD adult ladder counts (RBDD JPE) and carcass survey (Carcass JPE) were used for comparisons with the fry-equivalent JPI. The hypotheses we tested were:

H_{o1} : RBDD JPE does not differ from in-river estimates of juvenile abundance (JPI)
H_{a1} : RBDD JPE differs from in-river estimates of juvenile abundance (JPI)

H_{o2} : Carcass JPE does not differ from in-river estimates of juvenile abundance (JPI)
H_{a2} : Carcass JPE differs from in-river estimates of juvenile abundance (JPI)

We used a paired *t*-test for testing significant differences using years as replicates. We currently have nine data points to compare with the RBDD JPE and eight with the Carcass JPE. BY 2007 data was added to the prior years' data and compared. Within-year evaluations were made by comparing carcass and ladder JPE's with the JPI and determining whether the JPE's fall within the confidence intervals about the JPI.

Results

Sampling effort.—Weekly sampling effort throughout the 2007 brood-year emigration period was highly variable and ranged from 0.20 to 1.00 ($\bar{x}$ = 0.78, *N* = 52 weeks; Table 1). Weekly sampling effort ranged from 0.32 to 1.00 ($\bar{x}$ = 0.91, *N* = 26 weeks) between July and December, the period of greatest juvenile winter Chinook emigration, and 0.20 to 1.00 ($\bar{x}$ = 0.66, *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) RBDD gate operations, (2) intentional reductions in effort resulting from cone modification(s), sampling < 4 traps, or unsampled days, and (3) unintentional reductions in effort resulting from high flows, elevated debris loads, or inoperable equipment (Figure 3). Seven of 52 weeks sampled had 2 or more different reasons why sampling effort was reduced from the maximum value of 1.00 or 28 possible samples (i.e., 4 traps sampling unmodified for 7 days).

Trap efficiency trials.—Five mark-recapture trials were conducted using naturally produced fall run fry sized Chinook during the winter of 2008 to estimate rotary-screw trap efficiency (Table 2). Sacramento River discharge sampled during the trials ranged from 5,762 to 8,122 cfs. Estimated *%Q* during trap efficiency trials ranged from 2.19% to 5.28% ($\bar{x}$ = 3.66 %; Table 2).

Trials were conducted with RBDD gates raised (*N* = 5), rotary traps modified to sample with half cones (*N* = 1), unmodified (standard cone; *N* = 3), modified and unmodified cones (mixed cones; *N* = 1), and while sampling with 4 traps (*N* = 4) or 3 traps (*N* = 1). All trials were conducted using Chinook sampled from rotary traps, and trap efficiencies ranged from 2.24 to 4.16% ($\bar{x}$ = 2.96%). The number of marked fish released per trial ranged from 1,703 to 2,324 ($\bar{x}$ = 2,066) and the number of marked fish recaptured after release ranged from 48 to 83 ($\bar{x}$ = 61). All fish were released after sunset and 95% of recaptures occurred within the first 24 hours, and 100% within 48 hrs.

Fork lengths of fish marked and released ranged from 34 to 46 mm ($\bar{x}$ = 37.9 mm). Fork lengths of recaptured marked fish ranged from 34 to 44 mm ($\bar{x}$ = 38.1 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.

Trap efficiency modeling.—Trap efficiency was positively correlated to *%Q*, with higher efficiencies occurring as river discharge volumes decreased and the proportion of discharge volume sampled by rotary-screw traps increased (Figure 4). Regression analysis revealed a significant relationship between trap efficiency and *%Q* ($P < 0.001$). The strength of the relationship was relatively unchanged from that in 2006 (Poytress and Carrillo 2008) with the addition of 5 trials conducted during brood-year 2007 ($r^2 = 0.41$; Figure 4).

Fork length evaluations.—Weekly median fork length of brood-year 2007 winter Chinook increased slowly from 36.0 mm in week 29 to 38.0 mm in week 42 (Table 3). Median fork lengths increased rapidly from 48.0 mm in week 43 to 100.0 mm in week 3 followed by unexpected variability and an overall sharp decrease in week 4 through week 7. Median fork lengths steadily increased thereafter to 151.0 mm in week 16 (Figure 5a).

Brood-year 2007 winter Chinook fry median fork lengths ranged from 36.0 mm in week 29 to 45.0 mm in week 48, increasing 0.47 mm per week on average (Figure 6a). Brood-year 2007 pre-smolt/smolt median fork length ranged from 47.0 to 56.0 mm from week 34 to 45, increasing by 0.82 mm per week on average (Figure 7a). From week 46 to 3, however, average weekly median fork length increase was 5.0 mm per week from 55.0 to 100.0 mm.

The length frequency distribution of brood-year 2007 juveniles captured at RBDD ranged from 30.0 mm to 166.0 mm (Figure 8). Fry sized individuals ranged from 30.0 to 45.0 mm and comprised 77.5% of all samples collected. Pre-smolt/smolt sized individuals ≥46.0 mm represented the remaining 22.5% of brood-year 2007 winter Chinook samples.

Patterns of abundance.—Brood-year 2007 winter Chinook juvenile passage at RBDD was 1,444,786 fry and pre-smolt/smolts combined (Table 3). Peak passage of winter Chinook juveniles occurred predominantly during weeks 36 through 42, the first week of September and first half of October (Figure 5b). Winter Chinook juvenile passage increased from 4,166 (week 30; July) to 207,536 (week 40; first half of October). Juvenile passage generally declined through week 43 (latter half of October) to 44,275. Total passage between weeks 29 through 52 was 1,421,395 and accounted for 98.4% of total annual passage.

Brood-year 2007 fry sized juveniles (≤45 mm FL) comprised 80% of total winter Chinook passage (Table 3). Fry began to pass RBDD during week 29 (mid-July). Weekly fry passage increased sporadically and was variable through week 38. The estimated peak passage of 201,620 fry sized juveniles was observed during the first week in October in week 40 (Figure 6b). Fry passage decreased steadily from week 41 through week 48 (Figure 5b). Weekly fry passage began with 10,775 in Mid-July (week 29) and declined to 4,166 the following week (week 30), ranged from 4,957 to 34,851 in August, and 32,932 to 153,780 in September. Fry passage steeply declined from 201,620 to 17,235 in October, 3,402 to 316 in November, and 37 to 0 in December (Table 3).

Brood-year 2007 pre-smolt/smolt sized juveniles (≥46 mm FL) comprised 20% of total passage and the first observed emigration past RBDD occurred in week 34 (late August; Table 3). Weekly passage increased from 100 with minor fluctuations through week 41 to 10,726. Peak passage was observed in week 42 (October) at 40,277 (Table 3; Figure 7b). Weekly passage declined after week 51 with sharp sporadic increases in passage through week 5 (January) eventually subsiding in week 16 (April) of 2008 (Figure 7b).

Comparisons of JPI and JPE. —The fry-equivalent rotary trap JPI for brood-year 2007 was 1,642,575 (Table 3). The NOAA Fisheries brood-year 2007 fry-equivalent carcass survey and fish ladder JPE's were 1,864,521 and 2,231,474, respectively (Table 4; Figure 9). The carcass survey JPE fell within the 90% C.I. about the rotary trap JPI, whereas the fish ladder JPE did not (Table 4). By direct comparison, the carcass survey JPE was a modest 13.5% greater than the rotary trap JPI. Alternately, the fish ladder JPE was 36.0% more than the JPI and exceeded the 90% C.I. by 0.21%. The difference in numerical values equated to 221,946 and 1,411,101 for the carcass JPE and ladder JPE, respectively (Table 4).

We combined data from 1995 to 2006 with brood-year 2007 JPI's and JPE's to evaluate the linear relationship between the estimates. Ten 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. Eleven observations were available to evaluate using RBDD ladder data (1995-1999, 2002-2007). Rotary trap JPI's were significantly correlated in trend to carcass survey JPE's ($r^2 = 0.85$, $P < 0.001$, df = 9; Figure 10a) and to a lesser extent fish ladder JPE's ($r^2 = 0.60$, $P = 0.005$, df = 10; Figure 10b).

In terms of the magnitude of the two estimates, a paired t-test detected no significant difference among rotary trap JPI's and carcass survey JPE's ($t = -0.31$, $P = 0.761$, df = 9). For the combined ten years of data, carcass survey JPE's averaged 6% greater than rotary trap JPI's (range = -37 to +62%).

In contrast, paired comparisons revealed a significant difference in fry-equivalent production estimates between rotary trap JPI's and fish ladder JPE's ($t = -2.35$, $P = 0.029$, df = 10). Moreover, the 2007 fish ladder JPE exceeded the 90% C.I. about the rotary trap JPI, minutely, for the first time in 11 years of comparisons (Table 4). On average, fish ladder JPE's were 63% less than rotary trap JPI's (range = -30 to -90%).

Discussion

*Sampling effort***.—**During BY 2007, sampling effort was very high. In comparison to recent years (2002-2006), effort was not reduced intentionally to decrease capture of winter Chinook juveniles during the typical peak emigration period (September – October). Fewer fish sampled and less production in 2007 was attributed to the low abundance of female spawners as noted in the winter Chinook carcass survey (USFWS 2008; Table 4).

Most reductions in effort during the July through December period were attributed to the project's inability to sample a fourth trap during the late summer period (week 33 – 38) when Sacramento River flows were below 11,000 cfs and RBDD diversions were occurring. New RBDD operating criteria put in place in June of 2007 to reduce the potential to impact downstream migrating green sturgeon adults resulted in a reduced number of RBDD gates being open as flows decreased in the fall. The result was less area behind the RBDD to sample traps and sampling of the fourth trap was discontinued. Moreover, sampling was not possible during the majority of week 37 and first day of week 38 due to RBDD operations associated with the annual drawdown of Lake Red Bluff.

During the secondary migration period, effort was reduced to minimize catch of fall run production fish released from Coleman National Fish Hatchery (April – May) by modifying traps or sampling less than 4 traps (Figure 3). Inadequate staffing levels were not a factor in effort reductions during the 2007-2008 emigration period.

Eight days were not sampled due to high discharge and debris conditions associated with winter storm events. Unintended sampling effort reduction occurred during three storm events that resulted in discharges over 20,000 cfs (Figure 11).

Trap efficiency modeling.—On 5 occasions in 2008, we measured the efficiency of our rotary-screw traps by conducting mark-recapture trials using naturally produced fish collected during trap sampling activities. Data from the 5 trials were combined with data from 118 previously conducted trials to model the relationship between trap efficiency and %*Q* at RBDD (Figure 4). Trap efficiency was moderately correlated with %*Q* (r^2 = 0.41), yet regression Analysis of Variance continues to indicate a highly significant relationship exists between model variables ($P < 0.001$, df = 122). Overall, the relationship was minutely changed from that reported in Poytress and Carrillo 2008 and Poytress 2007 indicating consistent conditions for modeling trap efficiency.

Patterns of abundance.—Brood-year 2007 winter Chinook juvenile passage at RBDD, from July 1, 2007 through June 30, 2008, was 1,444,786 fry and pre-smolt/smolts combined, representing the lowest value of juvenile passage for this cohort since monitoring began in 1995 (Martin et al. 2001, Poytress et al. 2006). In comparison to brood-year 2004, estimated juvenile passage was 56% less in 2007 representing a juvenile cohort replacement rate of 0.44. The reduction in juvenile production is directly related to the low number of adult winter Chinook spawners estimated in the Upper Sacramento River in 2007 (USFWS 2008). The winter Chinook adult return of this year was the first indicator of a what was an unexpected significant systemwide decline for multiple runs of adult Chinook returning to the Central Valley as a whole during 2007 (See Lindley et al. 2009).

Causative factors analyzed for the fall Chinook decline are applicable to winter Chinook as both runs enter the ocean in the spring time (USFWS 2007). Lindley et al. 2009 suggest a combination of factors influenced the survival of outmigrating juvenile Chinook in the spring of 2005 and to a lesser extent in 2006. Winter Chinook adults returning to produce the BY 2007 progeny were entering the ocean in the spring of 2005. Juvenile Chinook entering the ocean during the spring of 2005 encountered “anomalous conditions in the coastal ocean” which is estimated to have resulted in poor physical fitness of juveniles during an important phase in their life history and period of significant growth typically (Lindley et al. 2009).

Peak passage, representing 74% of the annual total estimate, occurred within a six week period in September through mid-October (Figure 5b). Between October and the end of December (week 42 – week 52), the first storm events of the fall season produced minor rises in discharge volume and increased turbidity (Figure 12) resulting in a moderate increase of fry and pre-smolt/smolt winter Chinook passage (Table 3). The first storm related flow increase occurred during week 42 (mid-October) which coincided with the largest weekly passage estimate of pre-smolt/smolts, accounting for 14% of passage. Poytress (2007) stated initial storm events may be an important cue for pre-smolt/smolt winter Chinook migration out of the upper Sacramento River and the 2007 data moderately support this.

Comparisons of JPI's and JPE's.—Among-year comparison of passage estimates from RBDD may be misleading with reference to juvenile year class strength if abundance is the foremost consideration. Each brood-year the population of juvenile winter Chinook passing RBDD is composed of both fry and pre-smolt/smolts, and the ratio of fry to pre-smolt/smolts is variable among years (Martin et al. 2001). It is possible that differential survival exists between these subpopulations (USFWS 2001) and, therefore, we would expect juvenile year class strength to vary, perhaps even greatly, given equal passage estimates among years. Therefore, we converted passage estimates to fry-equivalent juvenile production indices (JPI's) for among-year comparisons (Table 4). For brood-year 2007, fry size class individuals composed 80% of passage and therefore the calculation of 1.7 fry:1 pre-smolt/smolt (based on estimated 59% fry to smolt survival; Hallock undated) had a moderate effect (20%) on the overall estimate. The NOAA Fisheries JPE model generates a fry-equivalent production value as an intermediate step in the computation, so comparisons among JPI's and JPE's are straightforward.

Fish ladder JPE's were not supportive of JPI's with respect to the magnitude of fry-equivalent JPI values (t = -2.35, P = 0.029, df = 10). We therefore reject the null hypothesis that Fish Ladder JPE's do not differ from in-river estimates of juvenile abundance (JPI's). Furthermore, the 2007 fish ladder JPE *overestimated* juvenile production relative to JPI's and carcass survey JPE's for the first time in eleven years of comparisons (Table 4; Figure 9). In contrast, rotary-screw trap JPI's and carcass survey JPE's have historically and continue to be strongly correlated. The 2007 JPE estimate was 13.5% greater than the rotary trap JPI, yet the numerical value was a modest 221,946 juveniles (Table 4). Significant differences in the magnitude of JPI's and carcass survey JPE's were not detected with the addition of 2007 data (t = -0.31, P = 0.761, df = 9). We therefore accept the hypothesis that Carcass Survey JPE's do not differ from in-river estimates of juvenile abundance (JPI's).

Overall, the relationship between the direct measure of juvenile abundance (JPI) and the indirect or modeled approach using carcass survey data remains strong. The addition of the 2007 data continues to support this relationship.

Acknowledgments

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Table 1.—Annual summary of weekly rotary trapping 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, seven days a week. A winter Chinook brood-year (BY) is identified as beginning on July 1 and ending on June 30.

Sampling effort			
Week	BY 2007	Week	BY 2007
27 (Jul)	0.89	1 (Jan)	0.60
28	1.00	2	0.36
29	1.00	3	0.86
30	1.00	4	0.71
31 (Aug)	1.00	5 (Feb)	0.27
32	1.00	6	0.41
33	0.89	7	0.61
34	0.54	8	0.70
35 (Sep)	0.75	9 (Mar)	0.55
36	0.75	10	1.00
37	0.32	11	1.00
38	0.68	12	1.00
39	1.00	13 (Apr)	1.00
40 (Oct)	0.96	14	1.00
41	0.86	15	0.96
42	1.00	16	1.00
43	1.00	17	0.57
44 (Nov)	1.00	18 (May)	0.20
45	1.00	19	0.71
46	1.00	20	0.52
47	0.96	21	0.00
48 (Dec)	1.00	22 (Jun)	0.32
49	1.00	23	0.64
50	1.00	24	0.75
51	0.96	25	0.75
52	1.00	26	0.75

Table 2.— Summary of results from mark-recapture trials conducted in 2008 (*N* = 5) 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 4 trap efficiency (TE %), percent river volume sampled by rotary-screw traps (%Q), number of traps sampling during trials, modification status as to whether or not traps were structurally modified to reduce volume sampled by 50% (Traps modified), and RBDD gate configuration at the time of the trial.

Trial#	Year	Number released	Release FL (mm)	Number recaptured	Recapture FL (mm)	TE (%)	%Q	Number of traps sampling	Traps modified	RBDD Gate Configuration
1	2008	2,234	38.41	50	38	2.24	3.99	4	No	Raised
2	2008	2,324	38.14	60	38	2.58	2.19	4	Yes	Raised
3	2008	1,993	38.41	83	39	4.16	3.39	4	Mixed	Raised
4	2008	1,703	37.19	48	37	2.82	5.28	4	No	Raised
5	2008	2,080	37.65	63	38	3.03	3.45	3	No	Raised

Table 3.— Weekly passage estimates, median fork length and juvenile production indices (JPI's) for winter Chinook salmon passing Red Bluff Diversion Dam (RK391) for the period July 1, 2007 through June 30, 2008 (Brood-year 2007). 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).

Brood-year 2007

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
27 (Jul)	0	-	0	-	0	-	0
28	0	-	0	-	0	-	0
29	10,775	36	0	-	10,775	36	10,775
30	4,166	37	0	-	4,166	37	4,166
31 (Aug)	4,957	37	0	-	4,957	37	4,957
32	16,221	36	0	-	16,221	36	16,221
33	29,402	37	0	-	29,402	37	29,402
34	34,851	37	100	47	34,951	37	35,021
35 (Sep)	32,932	36	255	47.5	33,187	36	33,366
36	145,103	36	942	49.5	146,045	36	146,705
37	105,011	36	0	-	105,011	36	105,011
38	182,715	36	2,582	49	185,297	36	187,104
39	153,780	36	5,902	51	159,682	36	163,814
40 (Oct)	201,620	36	5,915	50	207,536	36	211,676
41	129,969	36	10,726	51	140,696	36	148,204
42	87,998	37	40,277	52	128,274	38	156,468
43	17,235	40	27,040	53	44,275	48	63,203
44 (Nov)	3,402	43	23,677	55	27,079	54	43,653
45	1,343	43	17,586	56	18,929	55	31,239
46	397	44.5	10,041	59	10,438	58	17,466
47	316	45	29,667	62	29,983	62	50,751

Table 3.— (continued)

Week	Fry		Pre-smolt/smolts		Total		Fry-equivalents
	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
48 (Dec)	37	45	18,359	65	18,396	65	31,248
49	0	-	25,847	67	25,847	67	43,940
50	0	-	4,573	69	4,573	69	7,774
51	0	-	31,996	72	31,996	72	54,394
52	0	-	3,679	75	3,679	75	6,254
1 (Jan)	0	-	1,044	82	1,044	82	1,774
2	0	-	9,636	89	9,636	89	16,381
3	0	-	1,524	100	1,524	100	2,590
4	0	-	829	70	829	70	1,409
5 (Feb)	0	-	7,010	92	7,010	92	11,917
6	0	-	233	112	233	112	396
7	0	-	433	94.5	433	94.5	736
8	0	-	0	-	0	-	0
9 (Mar)	0	-	1,103	111.5	1,103	111.5	1,875
10	0	-	257	109.5	257	109.5	437
11	0	-	128	115	128	115	217
12	0	-	67	112	67	112	114
13 (Apr)	0	-	69	123	69	123	117
14	0	-	534	112.5	534	112.5	907
15	0	-	429	120.5	429	120.5	729
16	0	-	98	151	98	151	166
17	0	-	0	-	0	-	0
18 (May)	0	-	0	-	0	-	0
19	0	-	0	-	0	-	0
20	0	-	0	-	0	-	0
21	0	-	0	-	0	-	0
22 (Jun)	0	-	0	-	0	-	0
23	0	-	0	-	0	-	0

Table 3.— (continued)

Week	Fry		Pre-smolt/smolts		Total		Fry-equivalents
	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
24	0	-	0	-	0	-	0
25	0	-	0	-	0	-	0
26	0	-	0	-	0	-	0
BY total	1,162,230		282,556		1,444,786		1,642,575

Table 4.—Comparisons between juvenile production estimates (JPE) and rotary trapping juvenile production indices (JPI). Fish ladder JPE's and carcass survey JPE's were derived from the estimated adult female escapement from fish ladder counts at Red Bluff Diversion Dam and the upper Sacramento River winter Chinook carcass survey. From BY95 through BY99, assumptions used in the carcass survey 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 BY07, assumptions 1-3 were estimated using carcass survey data gathered on the spawning grounds, from Livingston Stone National Fish Hatchery, and aerial redd surveys, respectively. The upper Sacramento River carcass survey did not begin until the 1996 brood-year. Rotary trapping was not conducted in 2000 or 2001.

	Rotary-trapping [a]			Carcass survey [b]		Fish ladder [c]	
		90% C.I.					
Brood-year	Fry-equivalent JPI	Lower	Upper	Fry-equivalent JPE	# female spawners	Fry-equivalent JPE	# female spawners
1995	1,816,984	1,658,967	2,465,169	-	-	573,062	594
1996	469,183	384,124	818,096	550,872	571	279,778	290
1997	2,205,163	1,876,018	3,555,314	1,386,346	1,437	219,963	228
1998	5,000,416	4,617,475	6,571,241	4,676,143	4,847	770,835	799
1999	1,366,161	1,052,620	2,652,305	1,490,249	1,626	491,058	509
2000	-	-	-	4,946,418	5,397	651,635	563
2001	-	-	-	5,643,635	4,827	1,469,637	1,257
2002	8,205,609	4,287,999	12,162,377	6,964,626	5,670	5,766,419	4,685
2003	5,826,672	4,091,200	7,563,240	6,181,925	5,179	3,801,578	3,133
2004	3,758,790	2,673,168	4,846,169	[d]2,786,832	3,185	1,105,900	1,264
2005	8,941,241	6,024,027	12,034,853	12,109,474	8,807	2,766,151	2,012
2006	7,301,362	4,891,041	9,706,610	11,818,006	8,626	3,123,320	2,278
2007	1,642,575	1,058,274	2,226,877	1,864,521	1,517	2,231,474	1,746

[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 (2000-2007), NOAA Fisheries pers comm.

[c] Fish ladder JPE obtained from Diaz-Soltero 1995-1996, Lecky 1997-1999, and Bruce Oppenheim (2000-2004), NOAA Fisheries, pers comm. RBDD fish ladder fry-equivalent JPE estimated for 2002-2007; calculated from estimates of winter-run escapement based on counts at RBDD by USFWS as NOAA Fisheries no longer estimates fish ladder JPE's (Bruce Oppenheim 2005, NOAA Fisheries, pers comm.).

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

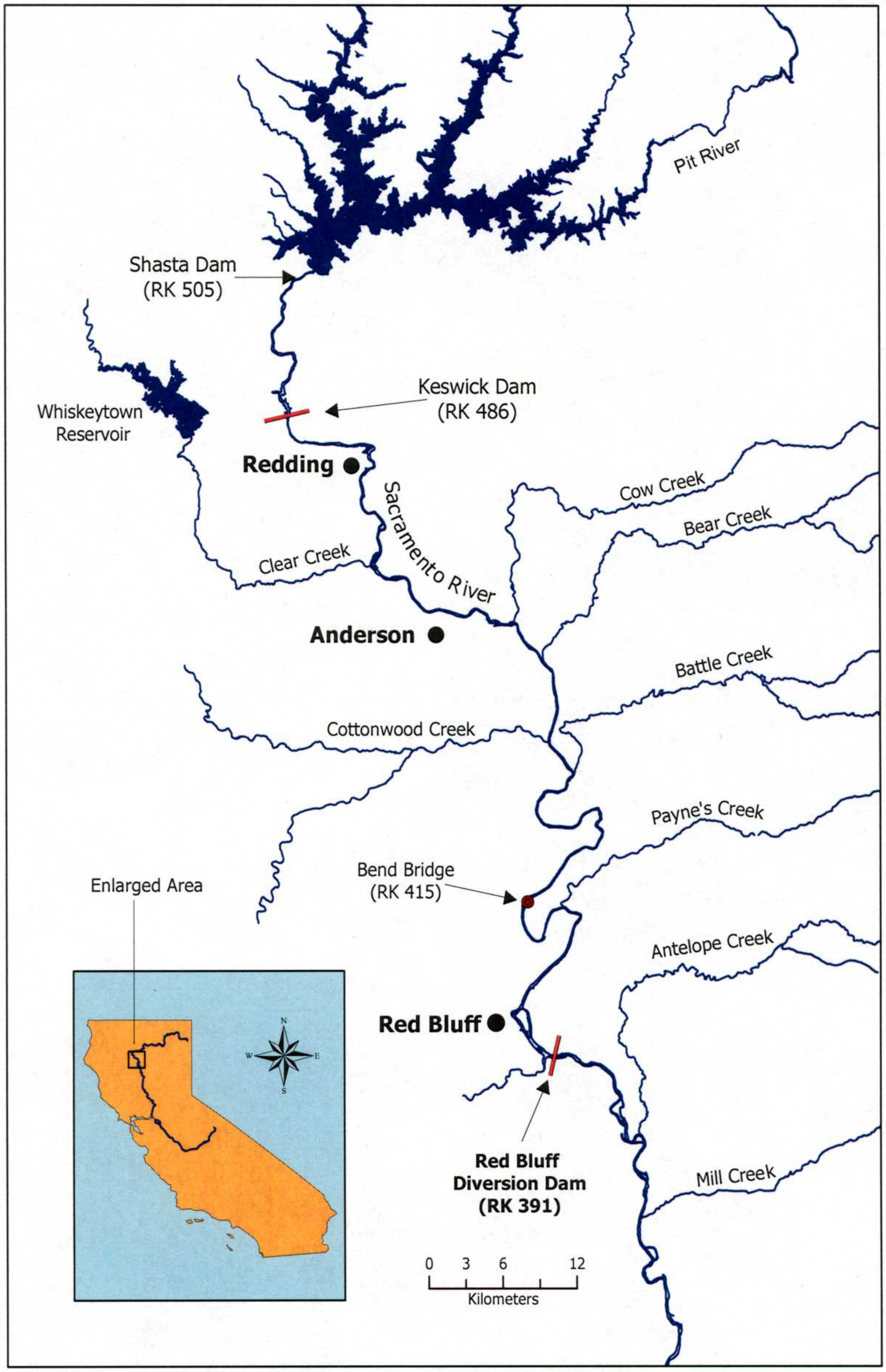

Figure 1. Location of Red Bluff Diversion Dam on the Sacramento River, California at river kilometer 391 (RK 391).

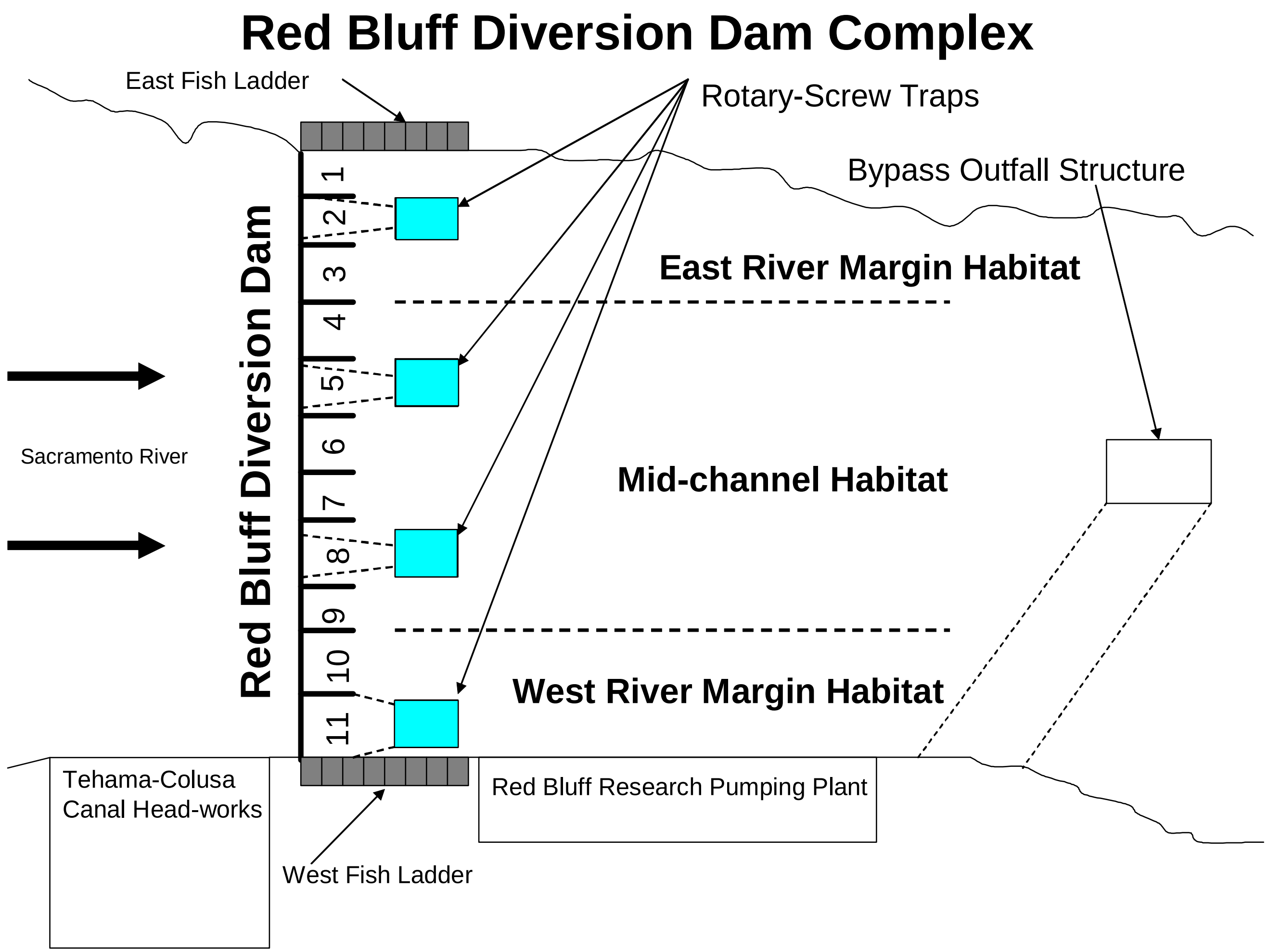

Figure 2. Rotary-screw trap sampling transect at Red Bluff Diversion Dam Complex (RK391) on the Sacramento River, California.

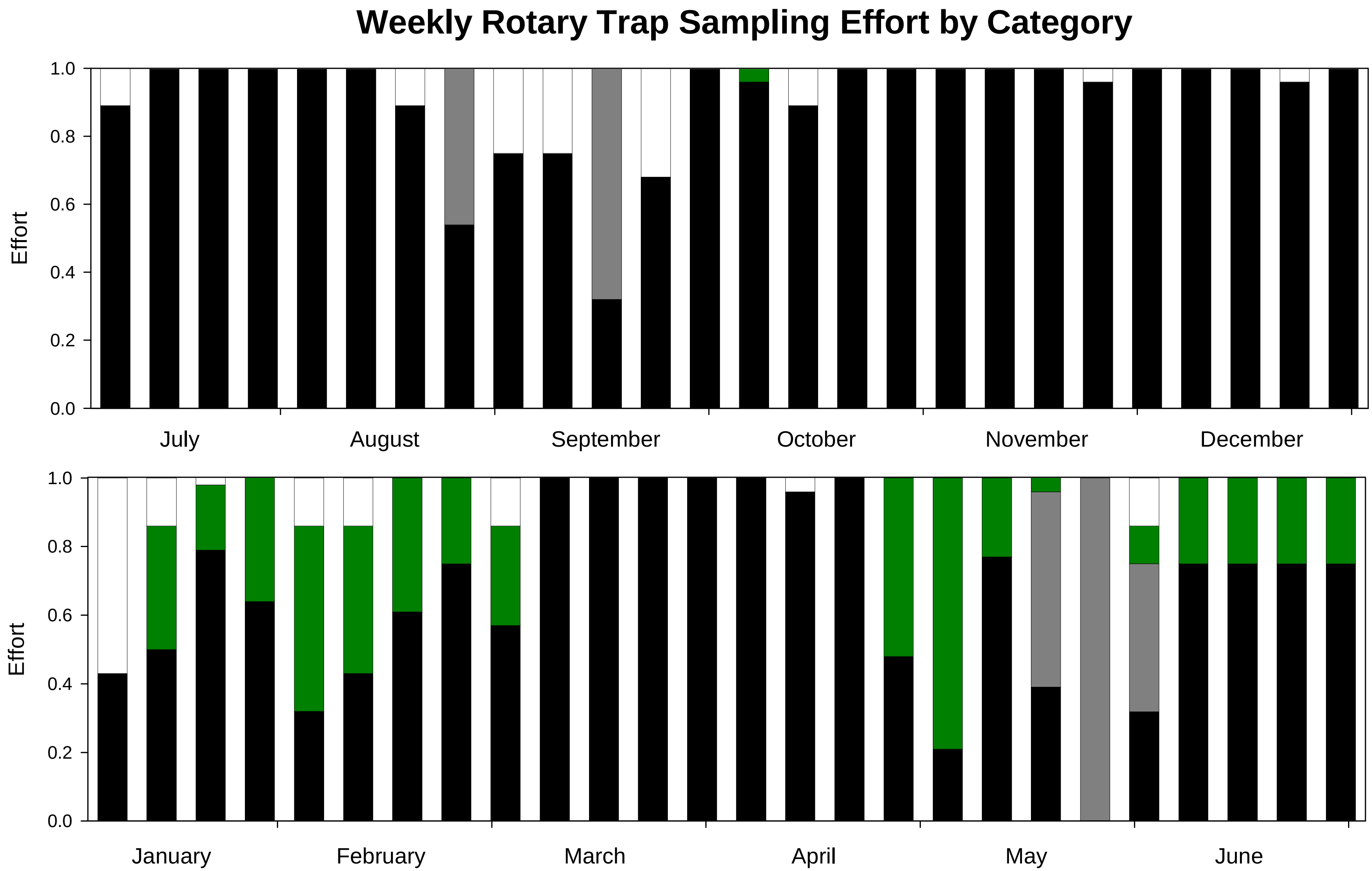

Figure 3. Weekly (bars) and monthly rotary trap sampling effort shown by category. Sampled portions represented by black bars; unsampled portions designated in descending order of frequency: intentional reductions in effort (dark green), RBDD operations (dark grey) and unintentional reductions (white).

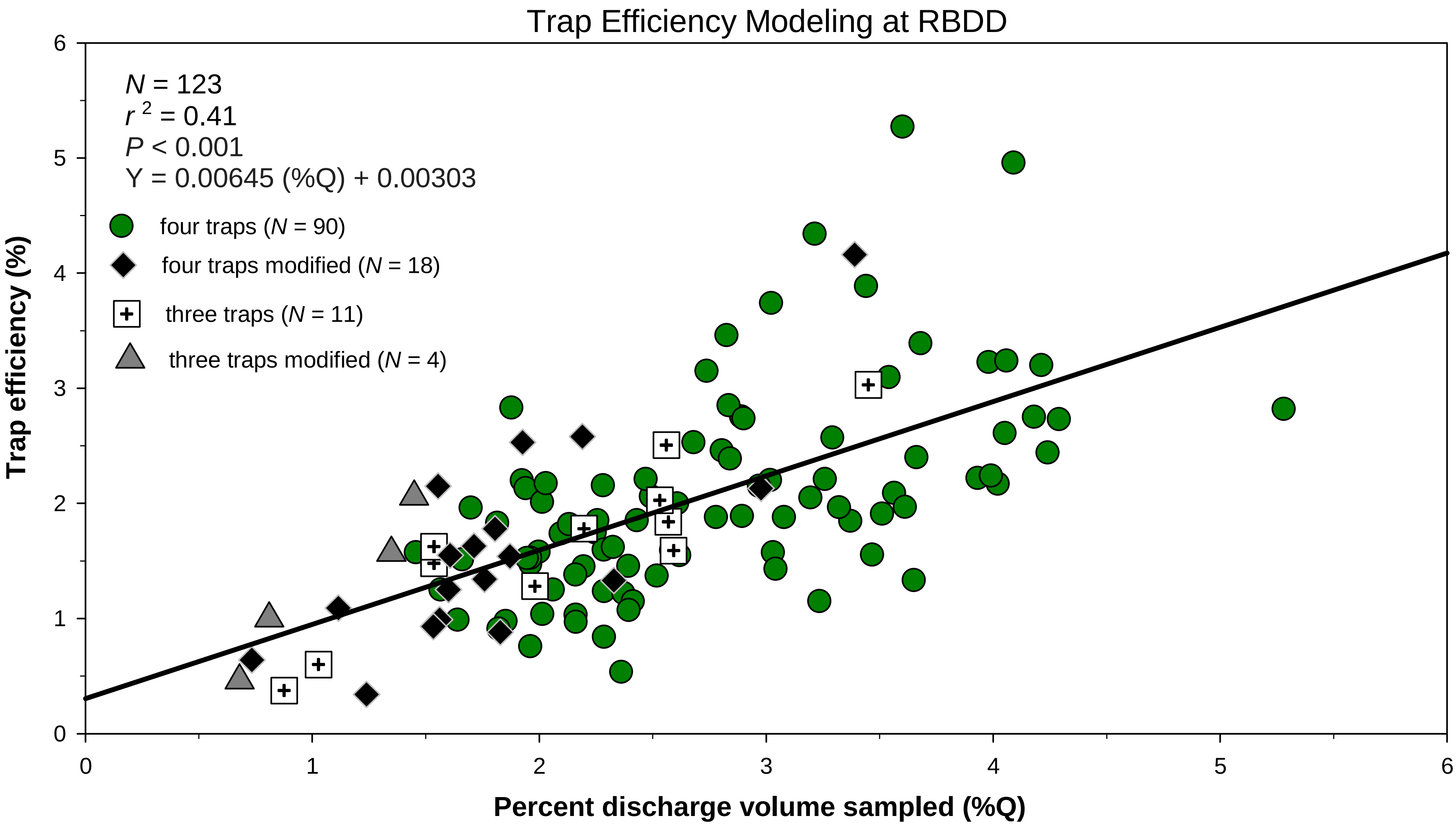

Figure 4. Trap efficiency model for combined 2.4 m diameter rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four traps (*N* = 90), three traps (*N* = 11), or with traps modified to sample one-half the normal volume of water (*N* = 22).

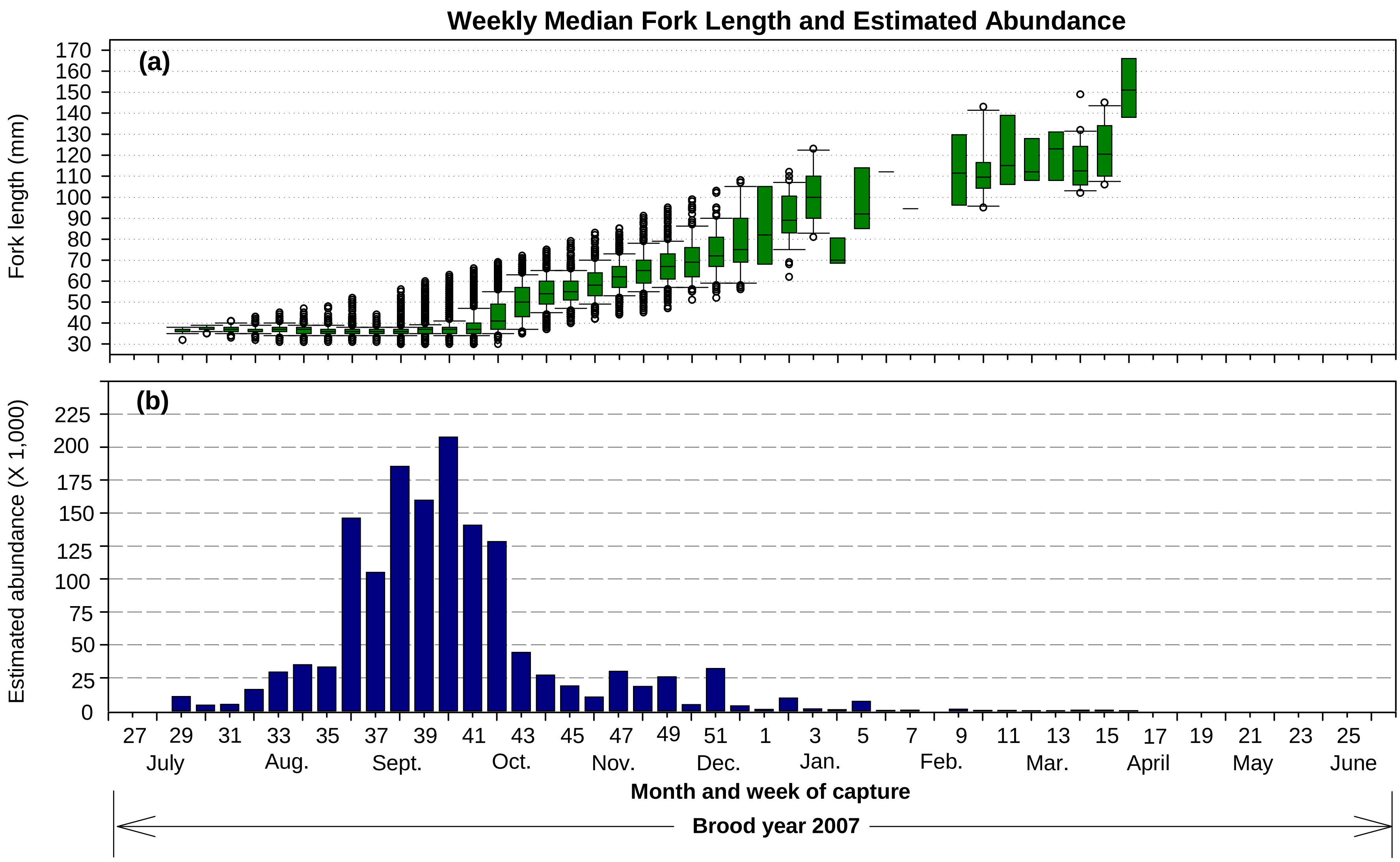

Figure 5. Weekly median fork length (a) and estimated abundance (b) of juvenile winter Chinook salmon passing Red Bluff Diversion Dam (RK391), Sacramento River, California. Winter Chinook salmon were sampled by rotary-screw traps for the period July 1, 2007 through June 30, 2008. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

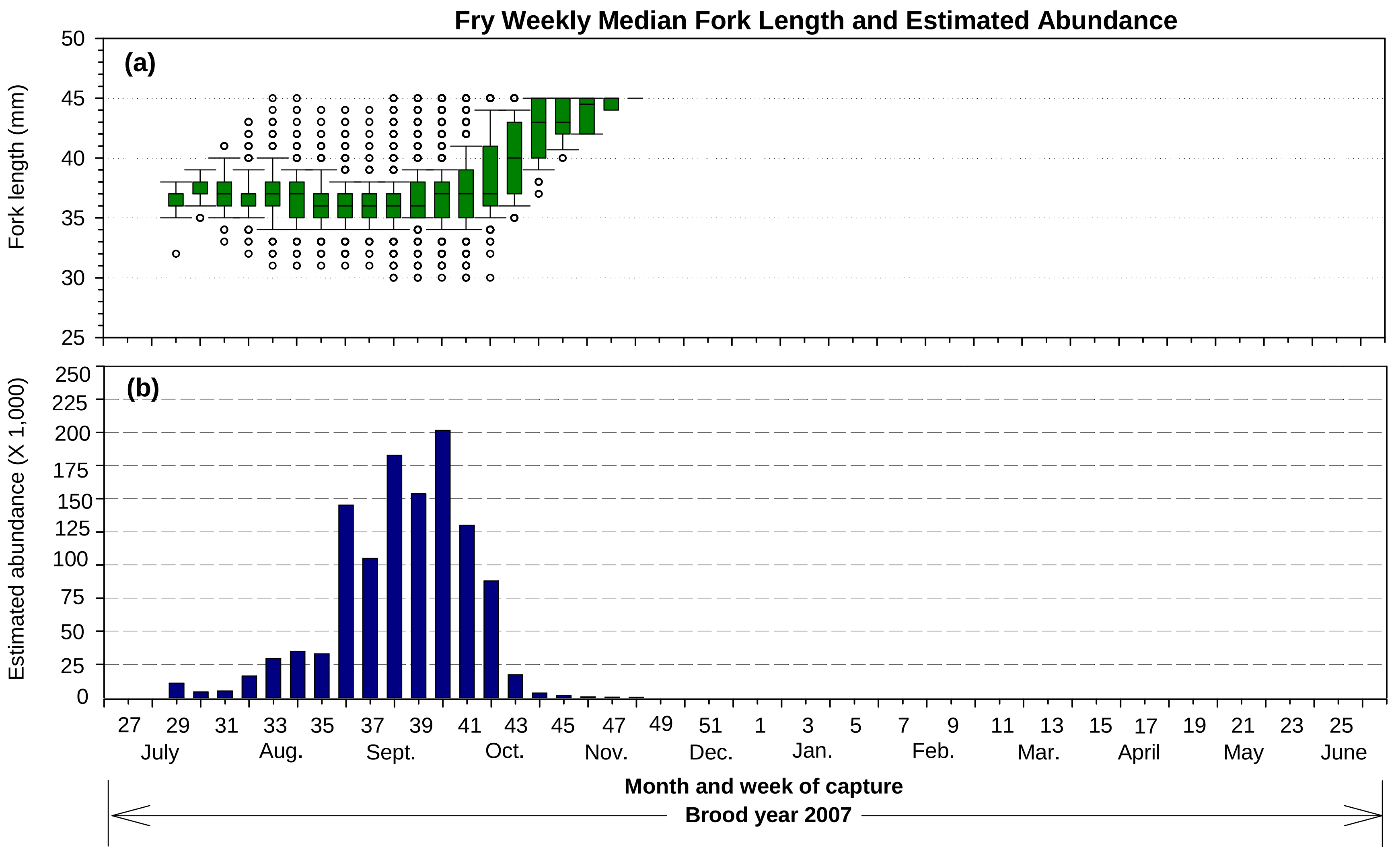

Figure 6. Weekly median fork length (a) and estimated abundance (b) of winter Chinook salmon fry passing Red Bluff Diversion Dam (RK391), Sacramento River, California. Winter Chinook juveniles were sampled by rotary-screw traps for the period July 1, 2007 through June 30, 2008. Box plots display weekly median fork length, 10th, 25th, 75th,and 90th percentiles and outliers.

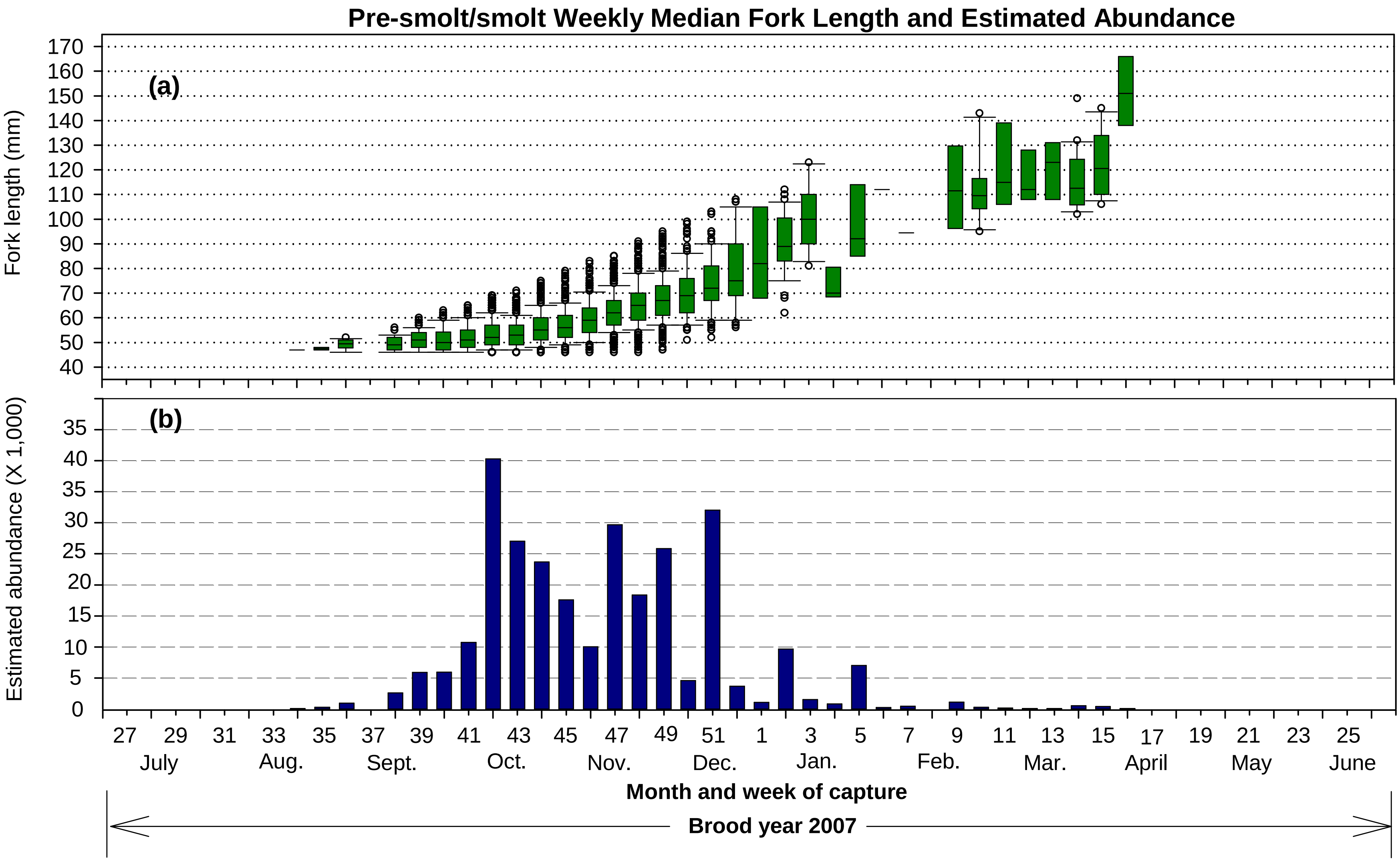

Figure 7. Weekly median fork length (a) and estimated abundance (b) of winter Chinook pre-smolt/smolts passing Red Bluff Diversion Dam (RK391), Sacramento River, California. Winter Chinook juveniles were sampled by rotary-screw traps for the period July 1, 2007 through June 30, 2008. Box plots display weekly median fork length, 10^{th}, 25^{th}, 75^{th},and 90^{th} percentiles and outliers.

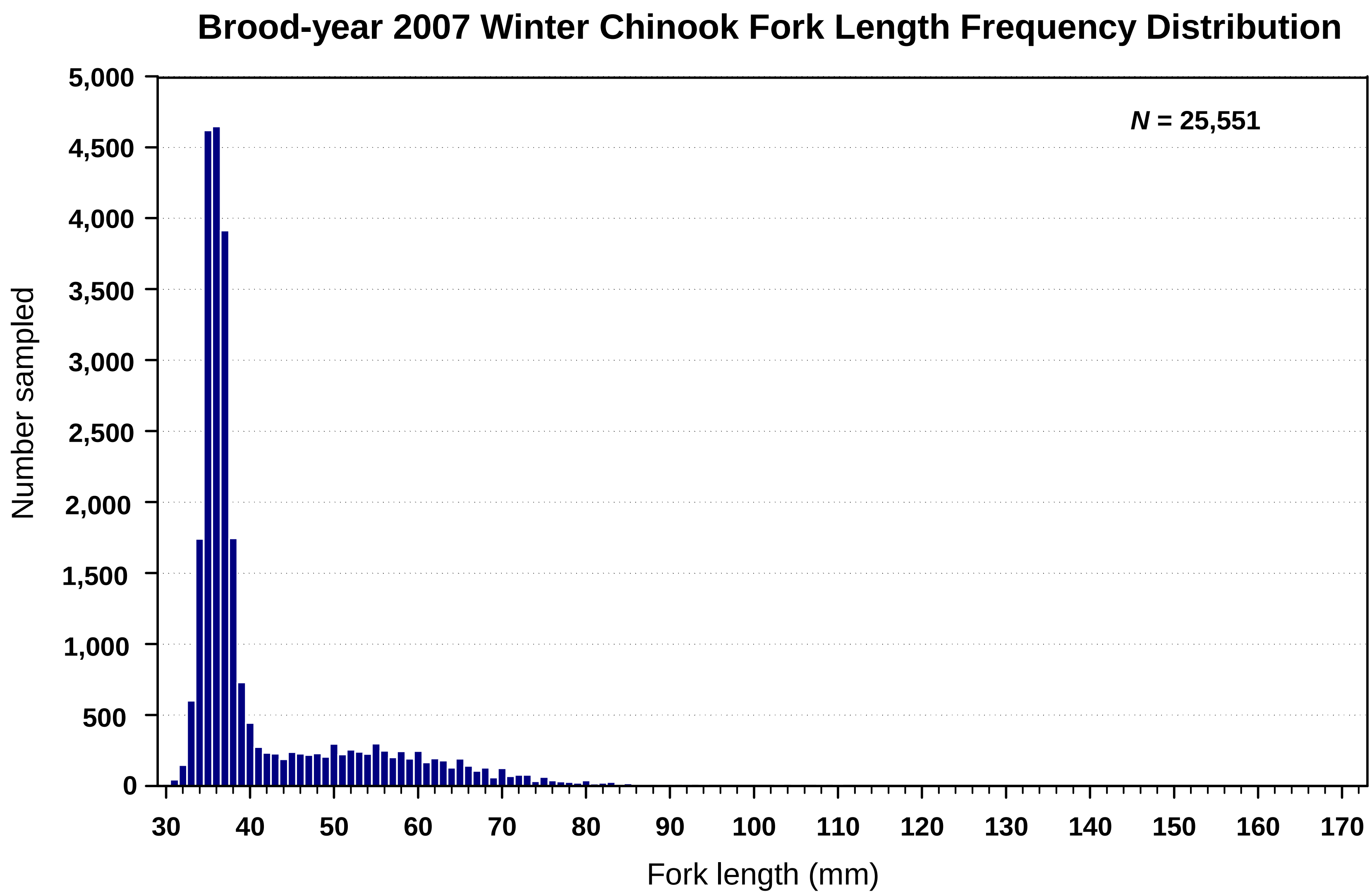

Figure 8. Fork length frequency distribution of brood-year 2007 juvenile winter Chinook salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fork length data was expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from July 1, 2007 through June 30, 2008.

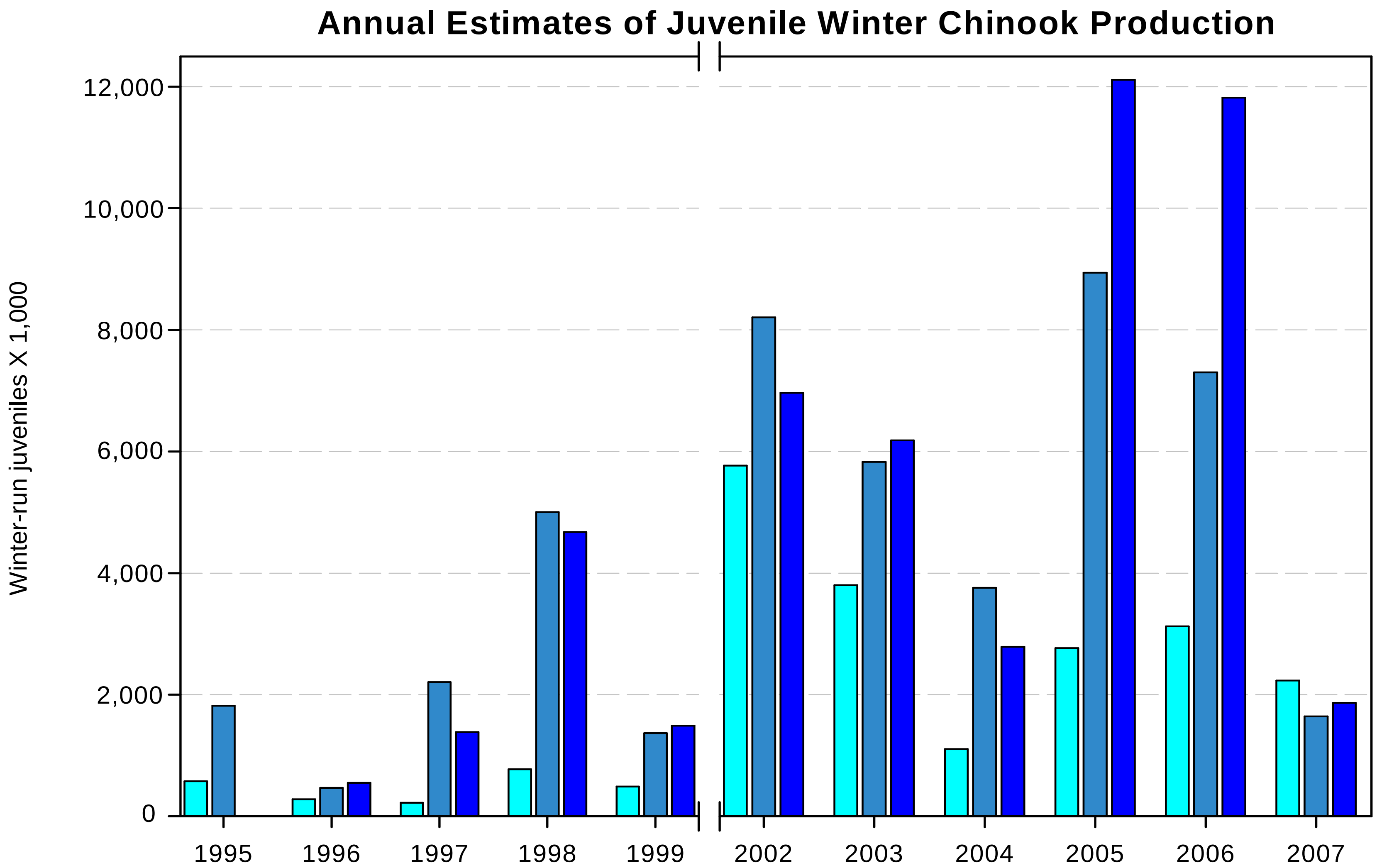

Figure 9. Time series comparison of annual estimates of juvenile winter-run production using RBDD ladder data JPE's (light blue), rotary-screw trap fry-equivalent JPI's (medium blue), and carcass survey JPE's (dark blue).

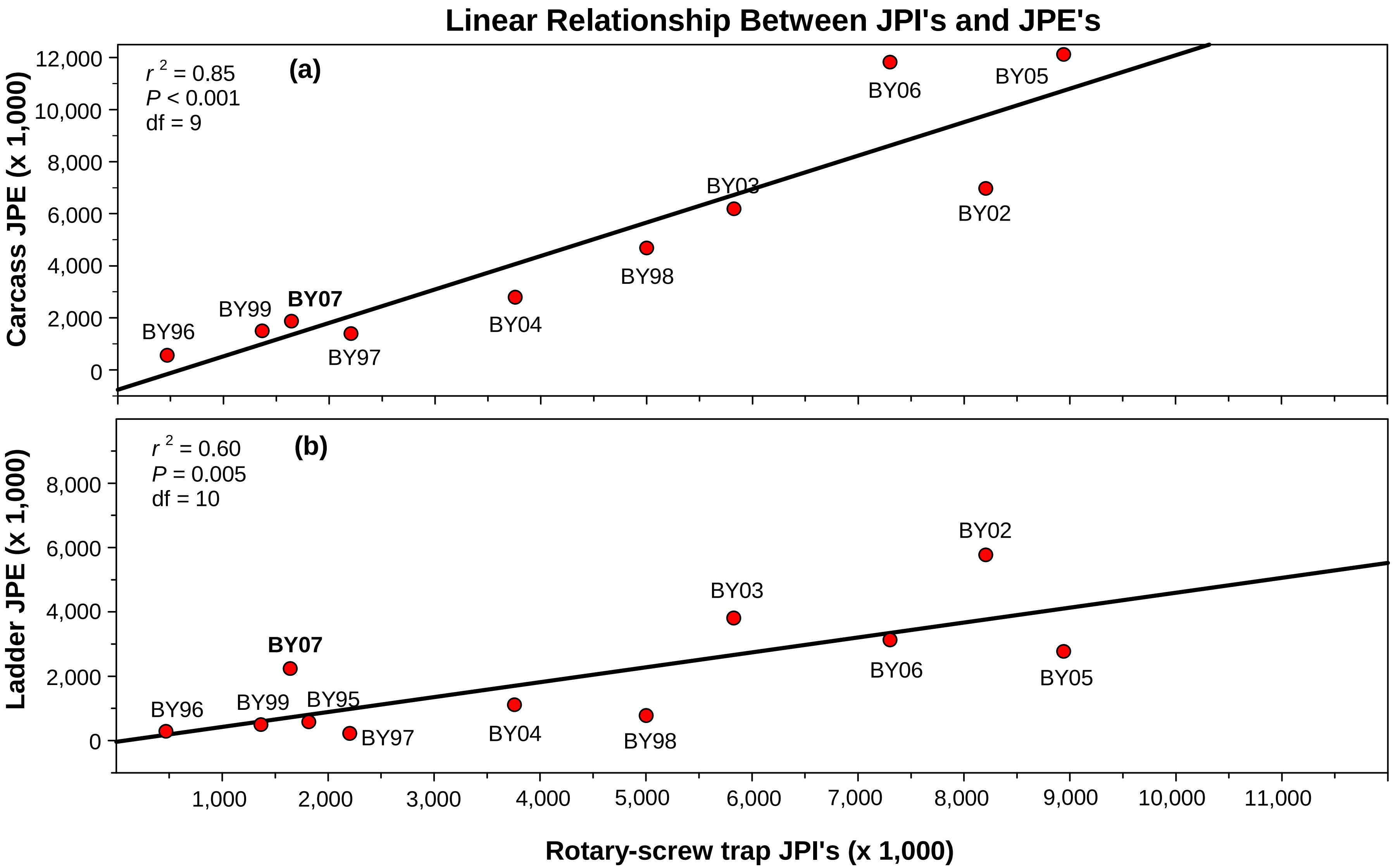

Figure 10. Linear relationship between rotary-screw trap fry-equivalent juvenile production indices (JPI) and (a) carcass survey derived juvenile production estimates (JPE) and (b) RBDD ladder count derived JPE's (2007 data point highlighted in bold).

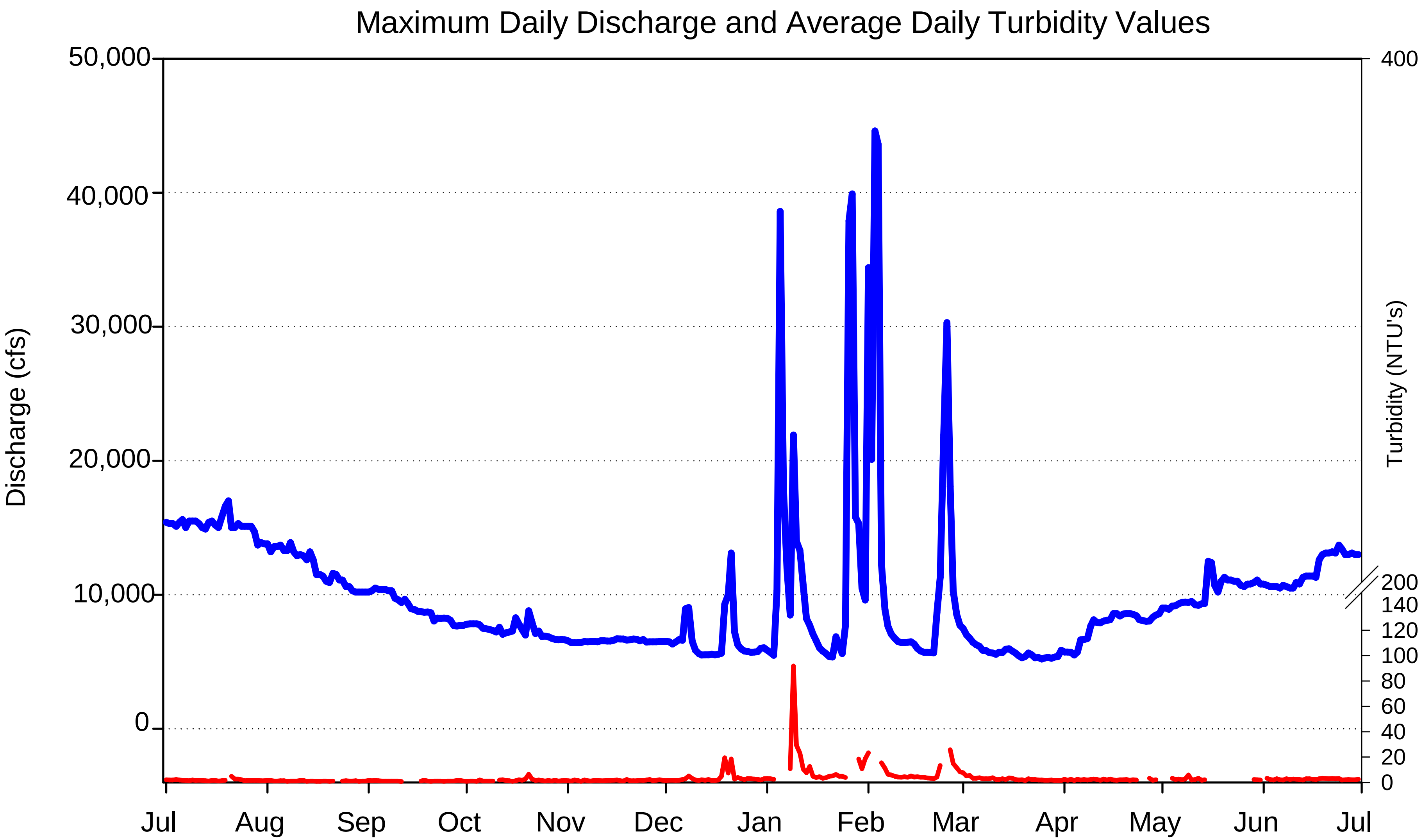

Figure 11. Maximum daily discharge (thick/blue line) calculated from the California Data Exchange Center's Bend Bridge gauging station and average daily turbidity values (thin/red line) from rotary-screw traps at RBDD for the period July 1, 2007 through June 30, 2008.