BROOD-YEAR 2006 WINTER CHINOOK JUVENILE PRODUCTION INDICES WITH COMPARISONS TO JUVENILE PRODUCTION ESTIMATES DERIVED FROM ADULT ESCAPEMENT

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Brood-year 2006 winter Chinook juvenile production indices with comparisons to juvenile production estimates derived from adult escapement

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Abstract.— Brood-year 2006 juvenile winter-run Chinook salmon passage at Red Bluff Diversion Dam (RBDD) was 6,686,780 fry and pre-smolt/smolts combined, representing a 12% increase in that observed during the passage of this cohort in brood-year 2003. Fry-equivalent production was 7,301,362. 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 = 0.84, P < 0.001, df = 8), yet the relationship diminished for the third consecutive year. Comparison between rotary trap JPI's to fish ladder JPE's continued to be moderately strong (r^2 = 0.68, P = 0.003, df = 9). Paired comparisons revealed a significant difference in production estimates between JPI's and fish ladder JPE's (t = 4.48, P = 0.002, df = 9) with fish ladder JPE's falling below the lower 90% confidence interval (C.I.) about the rotary trap JPI in 2006. Conversely, no significant difference was detected between rotary trap JPI's and carcass survey JPE's (t = -0.83, P = 0.433, df = 8), yet the 2006 carcass survey JPE *exceeded* the upper 90% C.I. about the rotary trap JPI by 22%. In comparison, the 2006 NOAA Fisheries JPE model overestimated juvenile winter-run Chinook salmon production by 62% using carcass survey data while underestimating juvenile production by 57% using RBDD fish ladder escapement estimates.

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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) 2006 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, 2006 through June 30, 2007. This report includes JPI's for the complete 2006 brood-year emigration period and will be submitted to the California Department of Fish and Game and the California Bay-Delta Authority 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 118 mark/recapture trials at RBDD and used *%Q* as the primary variate (Martin et al. 2001, Poytress 2007). 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. $$\hat{T}_d = (0.00665)(\%\hat{Q}_d) + 0.00240$$

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

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. $$Var(\hat{T}_d) = \text{ error variance of the trap efficiency model}$$

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 2006 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 2006 brood-year emigration period was highly variable and ranged from 0.21 to 1.00 ($\bar{x}$ = 0.74, N = 52 weeks; Table 1). Weekly sampling effort ranged from 0.21 to 1.00 ($\bar{x}$ = 0.73, N = 26 weeks) between July and December, the period of greatest juvenile winter Chinook emigration, and 0.21 to 1.00 ($\bar{x}$ = 0.75, 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) suboptimal staff levels, (2) RBDD gate operations, (3) intentional reductions in effort resulting from cone modification(s), sampling < 4 traps, or unsampled days, and (4) unintentional reductions in effort resulting from high flows, elevated debris loads, or inoperable equipment (Figure A1). A quarter of the 52 weeks sampled had 3 or more different reasons why sampling effort was reduced from the maximum of 28 possible samples (i.e., 4 traps sampling unmodified for 7 days).

Trap efficiency trials.—Eight mark-recapture trials were conducted using naturally produced fall run fry sized Chinook during the winter and spring of 2007 to estimate rotary-screw trap efficiency (Table 2). Sacramento River discharge sampled during the trials ranged from 6,023 to 8,687 cfs. Estimated *%Q* during trap efficiency trials ranged from 0.81% to 4.28% ($\bar{x}$ = 3.32 %; Table 2).

Trials were conducted with RBDD gates raised (N = 8), rotary traps modified to sample with half cones (N = 2), unmodified (standard cone; N = 6), and while sampling with 4 traps (N = 7) or 3 traps (N = 1). All trials were conducted using Chinook sampled from rotary traps, and trap efficiencies ranged from 0.91 to 3.39% ($\bar{x}$ = 2.16%). The number of marked fish released per trial ranged from 835 to 2,909 ($\bar{x}$ = 1,565) and the number of marked fish recaptured after release ranged from 18 to 54 ($\bar{x}$ = 30). All fish were released after sunset and 94% of recaptures occurred within the first 24 hours, 99% within 48 hours, and 100% within 72 hours.

Fork lengths of fish marked and released ranged from 32 to 56 mm ($\bar{x}$ = 37.8 mm). Fork lengths of recaptured marked fish ranged from 34 to 56 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, as indicated by the results of a Kolmogorov-Smirnov two sample test (P = 0.307).

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 3). 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 2005 (Poytress 2007) with the addition of 8 trials conducted during brood-year 2006 (r^2 = 0.42; Figure 3).

Patterns of abundance.—Brood-year 2006 winter Chinook juvenile passage at RBDD was 6,686,780 fry and pre-smolt/smolts combined (Table 3). Peak passage of winter Chinook juveniles occurred predominantly during weeks 35 through 42, the latter half of August and first half of October (Figure 4b). Winter Chinook juvenile passage increased from 665 (week 27; July) to 981,827 (week 38; mid-September). Juvenile passage generally declined through week 45 (November) to 48,696. A second smaller mode occurred between week 46 and 50 (mid-November to mid-December; Figure 4b). Total passage between weeks 27 through 50 was 6,662,501 and accounted for 99.6% of total annual passage.

Brood-year 2006 fry sized juveniles (≤45 mm FL) comprised 87% of total winter Chinook passage (Table 3). Fry began to pass RBDD during week 27 (early July). Weekly fry passage increased progressively through week 34, with a minor peak occurring during week 35 followed by a brief decline in week 36. Weekly passage then resumed a steady increase to week 38 whereby the estimated peak passage of 979,475 fry sized juveniles was observed (Figure 5b). Fry passage generally decreased from week 38 through week 48 (Figure 5b). Weekly fry passage increased from 665 to 28,464 in July, 41,049 to 358,541 in August, and 747,839 to 979,475 in September. Fry passage declined from 429,016 to 125,005 in October, 28,047 to 2,273 in November, and 1,065 to 0 in December (Table 3).

Brood-year 2006 pre-smolt/smolt sized juveniles (≥46 mm FL) comprised 13% of total passage and the first observed emigration past RBDD occurred in week 34 (late August; Table 3). Weekly passage increased from 1,134 with minor fluctuations through week 48 to 148,404. Peak passage was observed in week 50 (December) at 148,573 (Table 3; Figure 6b). Weekly passage declined sharply after week 50 and tapered off through week 23 (June) of 2007 with minor sporadic increases in passage through week 16 (April) of 2007 (Figure 6b).

Fork length evaluations.—Weekly median fork length of brood-year 2006 winter Chinook increased slowly from 34.0 mm in week 27 to 37.0 mm in week 42 (Table 3). Median fork lengths increased rapidly from 40.0 mm in week 43 to 66.5 mm in week 52 and steadily increased, thereafter, to 121.5 mm in week 16 (Figure 4a). One winter run sized individual was captured in week 23 (June) resulting in a weekly median fork length of 161.0 mm.

Brood-year 2006 winter Chinook fry median fork lengths ranged from 34.0 mm in week 27 to 45.0 mm in week 48, increasing 0.55 mm per week on average (Figure 5a). Brood-year 2006 pre-smolt/smolt median fork length ranged from 46.5 to 54.0 mm from week 34 to 45, increasing by 0.68 mm per week on average (Figure 6a). From week 46 to 51, however, average weekly median fork length increase was 2.4 mm per week from 55.0 to 67.0 mm.

The length frequency distribution of brood-year 2006 juveniles captured at RBDD ranged from 29.0 mm to 172.0 mm (Figure 7). Fry sized individuals ranged from 29.0 to 45.0 mm and comprised 82% of all samples collected. Pre-smolt/smolt sized individuals ≥46.0 mm represented the remaining 18% of brood-year 2006 winter Chinook samples.

Temporal distribution patterns.—The temporal distribution pattern exhibited by BY 2006 juvenile winter Chinook fry (Figure 8a), pre-smolt/smolts (Figure 8b) and combined or total passage (Figure 8c) was nearly identical to the patterns exhibited in the previous 4 years of sampling. The presmolt/smolt distribution pattern was later, occurring

predominantly in the latter half of November, compared to previous years, albeit slightly. Overall, the temporal distribution pattern was not significantly different than prior years (Kruskal-Wallis test, $P = 0.61$, df = 4).

Comparisons of JPI and JPE. —The fry-equivalent rotary trap JPI for brood-year 2006 was 7,301,362 (Table 3). The NOAA Fisheries brood-year 2006 fry-equivalent carcass survey and fish ladder JPE's were 11,818,006 and 3,123,320, respectively (Table 4; Figure 9). Neither the carcass survey JPE nor the fish ladder JPE fell within the 90% C.I. about the rotary trap JPI (Table 4). By direct comparison, the carcass survey JPE was 62% greater than the JPI and exceeded the 90% C.I. by 22%. Alternately, the fish ladder JPE was 57% less than the JPI and fell short of the 90% C.I. by 36%. The difference in numerical values equated to 4,516,644 and 4,178,042 for the carcass JPE and ladder JPE, respectively (Figure 10).

We combined data from 1995 to 2005 with brood-year 2006 JPI's and JPE's to evaluate the linear relationship between the estimates. Nine 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. Ten observations were available to evaluate using RBDD ladder data (1995-1999, 2002-2006). Rotary trap JPI's were significantly correlated in trend to carcass survey JPE's ($r^2 = 0.84$, $P < 0.001$, df = 8; Figure 11a) and to a lesser extent fish ladder JPE's ($r^2 = 0.68$, $P = 0.003$, df = 9; Figure 11b).

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 ($t = -0.83$, $P = 0.433$, df = 8). For the combined nine years of data, carcass survey JPE's averaged 5% 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 ($t = 4.48$, $P = 0.002$, df = 9). Moreover, the 2006 fish ladder JPE fell below the lower 90% C.I. about the rotary trap JPI, similarly to the previous eight out of nine years (Table 4). On average, fish ladder JPE's were 61% less than rotary trap JPI's (range = -30 to -90%; Figure 10).

Discussion

Sampling effort.—During BY 2006, effort was primarily reduced *intentionally* to reduce capture of winter-run juveniles (September – October) or fall run production fish released from Coleman National Fish Hatchery (April – May) by modifying traps or sampling less than 4 traps (Figure A1). Intentional reduction in effort accounted for 10% of annual sample effort reduction. During weeks 38 through 43, the peak period of winter Chinook capture, traps were modified primarily in the mid-channel habitat by reducing the amount of water volume sampled by the rotary trap cones. Modification of rotary trap cones was performed to reduce capture of endangered winter-run Chinook salmon while maintaining the accuracy of passages estimates (Gaines and Poytress 2004).

The second greatest reduction in effort resulted from suboptimal staff levels and accounted for a 7% loss in annual effort. This occurred primarily during weeks 27 through 37 whereby sampling was not conducted on weekends while the project pursued full field staffing levels to cover 7 day per week sampling.

Varied manipulations of RBDD gates and dam operations resulted in the third greatest loss of effort, nearly 6%. For example, sampling was not possible during the latter half of week 37 and first half of week 38 due to USBR RBDD operations associated with the annual drawdown of Lake Red Bluff. Additionally, an "emergency closure" of the RBDD gates occurred for a six day period spanning weeks 18 and 19 (May) resulting in a lack of ability to sample immediately prior to and following the event.

Interestingly, only three days were not sampled due to high discharge and debris conditions typically associated with storm events. Sampling effort reduction occurred during three events that resulted in discharges over 20,000 cfs (Figure 12). Overall, sampling effort was reduced a mere 3% due to hydrologic conditions or trap maintenance. Weekly sampling effort between January and June of 2007 was nearly twice as great as the previous years' sampling due to lack of high flow events (Poytress 2007). The result was less estimation of winter Chinook passage during unsampled periods; however, for ten years of sampling this period represents a modest 3.8% of the annual estimate, on average.

Trap efficiency modeling.—On 8 occasions in 2007, 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 8 trials were combined with data from 110 previously conducted trials to model the relationship between trap efficiency and %Q at RBDD (Figure 3). Trap efficiency was moderately correlated with %Q (r^2 = 0.42), yet regression Analysis of Variance continues to indicate a highly significant relationship exists between model variables (P< 0.001, df = 117). Overall, the relationship was minutely changed from that reported in Poytress 2007 and Poytress et al 2006 indicating consistent conditions for modeling trap efficiency.

Patterns of abundance.—Brood-year 2006 winter Chinook juvenile passage at RBDD, from July 1, 2006 through June 30, 2007, was 6,686,780 fry and pre-smolt/smolts combined, representing the highest value of juvenile passage for this cohort since monitoring began in 1995 (Martin et al 2001, Gaines and Poytress 2004). In comparison to brood-year 2003, estimated juvenile passage was 26.9% greater in 2006 representing a juvenile cohort replacement rate of 1.27. Peak passage, representing 86% of the annual total estimate, occurred within an eleven-week period in the last half of August through late October (Figure 8c). The substantial pulse of fry in late August (Figure 5b) was likely due to natural variability in outmigration as the temporal distribution pattern of returning adults did not appear earlier than previous years (USFWS 2007).

Between November and December (week 46 – week 50), the first storm events of the fall season produced minor rises in discharge volume and increased turbidity (Figure 12) resulting in a considerable increase of pre-smolt/smolt winter Chinook passage (Table 3; Figure 6b). The largest of 4 flow increases occurred during week 50 which coincided with the largest single daily passage event of pre-smolt/smolts, accounting for 12% of passage. Passage occurring during the initial storm events equated to 67% of the total estimated pre-smolt/smolt passage for the year (Table 3). 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 2006 data gives further credence to this concept. Further analysis of initial flow and turbidity data associated with pre-smolt/smolt mass outmigration events in the fall may further explain this perceived phenomenon.

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 2006, fry size class individuals composed 87% 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 nominal effect (9%) 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 ($t = 4.48$, $P = 0.002$, df = 9). We therefore reject the null hypothesis that Fish Ladder JPE's do not differ from in-river estimates of juvenile abundance (JPI's). Furthermore, it appears that fish ladder JPE's consistently underestimate juvenile production, relative to JPI's and carcass survey JPE's (Table 4, Figure 10). In contrast, rotary-screw trap JPI's and carcass survey JPE's have historically been strongly correlated. Significant differences in the magnitude of JPI's and carcass survey JPE's were not detected with the addition of 2006 data ($t = -0.83$, $P = 0.433$, df = 8). We therefore accept the hypothesis that Carcass Survey JPE's do not differ from in-river estimates of juvenile abundance (JPI's).

Poytress (2007) indicated that the rotary-screw trap JPI was strongly correlated in trend to carcass survey JPE's ($r^2 = 0.89$), and to a lesser extent, fish ladder JPE's ($r^2 = 0.67$). For the third consecutive year the addition of new data resulted in a weakening of the relationship between the JPI and the carcass survey ($r^2 = 0.84$, df = 8; Figure 9a) as well as the fish ladder JPE's ($r^2 = 0.68$, df = 9; Figure 9b). Moreover, the 2006 JPE *exceeded* the 90% C.I. about the JPI by an estimated 22%, a difference equating to more than 2 million juveniles.

With the addition of the 2006 data, the linear relationship exhibited by the two variables appears to have peaked three years prior with a mere 5 data points (Gaines and Poytress 2003). As noted by Brown and Austen (1996) when more datapoints are added the *reliability* of a relationship will improve. We believe with the current 9 data points and related flux over the past 5 years we may be observing a more reliable value of correlation. Overall, the relationship between the direct measure of juvenile abundance (JPI) and the indirect or modeled approach using carcass survey data remains strong. We therefore believe that JPI's support JPE's using carcass survey data, but do not support fish ladder JPE's.

In the last two years (2006 and 2005) adult returns of winter Chinook have been nearly twice that of their previous generation, 2003 and 2002 respectively (USFWS 2007). It is interesting to note that as adult returns have reached their highest values since 1981 (Killam 2006), the range of values used to make juvenile production comparisons has increased and included the highest levels of juvenile abundance ever

recorded since monitoring began (Martin et al. 2001, Poytress 2007). The linear approach of the JPE model using carcass survey data mechanically dictates that the presence of ever-increasing female winter Chinook spawners will produce ever-increasing numbers of juveniles, barring increased pre-spawn mortality or unsuitable water temperatures (or other density independent factors). The 2006 data and to a lesser extent the 2005 data do not appear to overwhelmingly support this linear function at the recent high levels of winter Chinook spawner abundance. The relationship may more closely resemble a non-linear relationship between adults and recruits similar to a Beverton-Holt Recruit Spawner Curve or a Ricker Recruit-Spawner Curve (Maceina and Pereira 2007). With the limited data available, we cannot fully determine whether a linear or non-linear relationship is more likely.

We compared female escapement and the rotary-trap JPI as a non-linear function (Figure A2). We found a highly significant relationship existed ($r^2 = 0.92$, $P < 0.001$, df = 8). We caution the reader of these results as this comparison is based on limited data and more data is needed before this should be considered reliable. Overall, it is probable that the difference observed between the 2006 JPI and JPE is due simply to natural variability, but reduced juvenile abundance in light of post Endangered Species Act listing record adult returns may imply some form of density dependence. One source of data that may support this concept is the spatial distribution pattern of fresh female winter Chinook carcasses as depicted in USFWS (2007). Spatial distribution data indicates that spawning in the last 5 years is occurring predominantly (>70%) in the upper 6 miles of the Sacramento River below Keswick Dam. It appears that although suitable conditions exist in the upper 20 miles of the Sacramento River, winter Chinook exhibit a predisposition to use certain habitat. It is only at higher levels of abundance, as seen in 2006, that this may result in reduced recruitment or density dependent effects. Overall, we recommend redd superimposition studies be considered, especially during years of substantial winter Chinook escapement (e.g., >12,000 adults), to reduce uncertainty associated with the concept of density dependent factors possibly restraining recovery of the species by limiting juvenile production in the Sacramento River.

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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 2006	Week	BY 2006
27 (Jul)	0.46	1 (Jan)	0.25
28	0.57	2	0.98
29	0.54	3	1.00
30	0.71	4	0.93
31 (Aug)	0.71	5 (Feb)	0.71
32	0.71	6	0.50
33	0.82	7	0.57
34	0.71	8	1.00
35 (Sep)	0.57	9 (Mar)	0.91
36	0.54	10	1.00
37	0.21	11	1.00
38	0.36	12	1.00
39	0.57	13 (Apr)	1.00
40 (Oct)	0.79	14	1.00
41	0.79	15	0.71
42	0.82	16	0.61
43	0.88	17	0.21
44 (Nov)	0.88	18 (May)	0.43
45	1.00	19	0.57
46	0.86	20	0.21
47	0.86	21	0.75
48 (Dec)	1.00	22 (Jun)	0.77
49	1.00	23	1.00
50	1.00	24	0.79
51	1.00	25	0.82
52	0.63	26	0.86

Table 2.— Summary of results from mark-recapture trials conducted in 2007 ($N = 8$) 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	2007	1,520	-	33	37.79	2.17	4.02	4	No	Raised
2	2007	1,987	37.64	18	37.80	0.91	1.82	4	Yes	Raised
3	2007	2,909	37.49	29	37.33	1.00	0.81	3	Yes	Raised
4	2007	1,782	37.89	34	38.53	1.91	3.51	4	No	Raised
5	2007	1,591	38.52	54	38.59	3.39	3.68	4	No	Raised
6	2007	953	37.63	26	37.63	2.73	4.29	4	No	Raised
7	2007	835	37.58	23	38.75	2.75	4.18	4	No	Raised
8	2007	944	37.71	23	38.00	2.44	4.24	4	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, 2006 through June 30, 2007 (Brood-year 2006). 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).

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
			Brood-year 2006				
27 (Jul)	665	34	0	-	665	34	665
28	2,232	35	0	-	2,232	35	2,232
29	9,241	35	0	-	9,241	35	9,241
30	28,464	35	0	-	28,464	35	28,464
31 (Aug)	41,049	35	0	-	41,049	35	41,049
32	82,216	35	0	-	82,216	35	82,216
33	230,411	35	0	-	230,411	35	230,411
34	358,541	35	1,134	46.5	359,675	35	360,467
35 (Sep)	747,839	35	4,992	48	752,831	35	756,324
36	459,682	36	2,148	47.5	461,827	36	463,331
37	609,567	36	6,328	50.5	615,895	36	620,332
38	979,475	36	2,351	50	981,827	36	983,472
39	837,189	36	5,490	49	842,678	36	846,522
40 (Oct)	429,016	36	16,971	50	445,987	36	457,866
41	523,436	36	34,716	50	558,152	36	582,452
42	304,785	36	27,247	51	332,032	37	351,103
43	125,005	38	49,321	51	174,326	40	208,853
44 (Nov)	28,047	42	52,554	51	80,601	48	117,390
45	5,141	43	43,558	54	48,696	53	79,187
46	7,503	44	98,352	55	105,853	55	174,699
47	2,273	45	109,404	57	111,677	57	188,259

Table 3.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
48 (Dec)	1,065	45	148,404	59	149,469	59	253,350
49	0	-	78,081	62	78,081	62	132,741
50	0	-	148,573	64	148,573	64	252,576
51	0	-	2,158	67	2,158	67	3,671
52	0	-	17,587	66.5	17,587	66.5	32,704
1 (Jan)	0	-	3,819	92	3,819	92	6,493
2	0	-	2,655	81.5	2,655	81.5	4,513
3	0	-	1,112	105	1,112	105	1,889
4	0	-	567	87.5	567	87.5	963
5 (Feb)	0	-	2,595	90	2,595	90	4,413
6	0	-	1,840	88	1,840	88	3,128
7	0	-	6,336	86	6,336	86	10,769
8	0	-	294	84.5	294	84.5	503
9 (Mar)	0	-	1,758	97	1,758	97	2,989
10	0	-	291	102	291	102	494
11	0	-	203	105	203	105	346
12	0	-	450	113	450	113	767
13 (Apr)	0	-	1,098	111	1,098	111	1,867
14	0	-	788	118	788	118	1,339
15	0	-	74	145	74	145	124
16	0	-	532	121.5	532	121.5	903
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	-	167	161	167	161	285

Table 3.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	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	5,813,842		873,947		6,686,780		7,301,362

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 BY06, 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

[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 (2000-2006), 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 2002-2005; 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..).

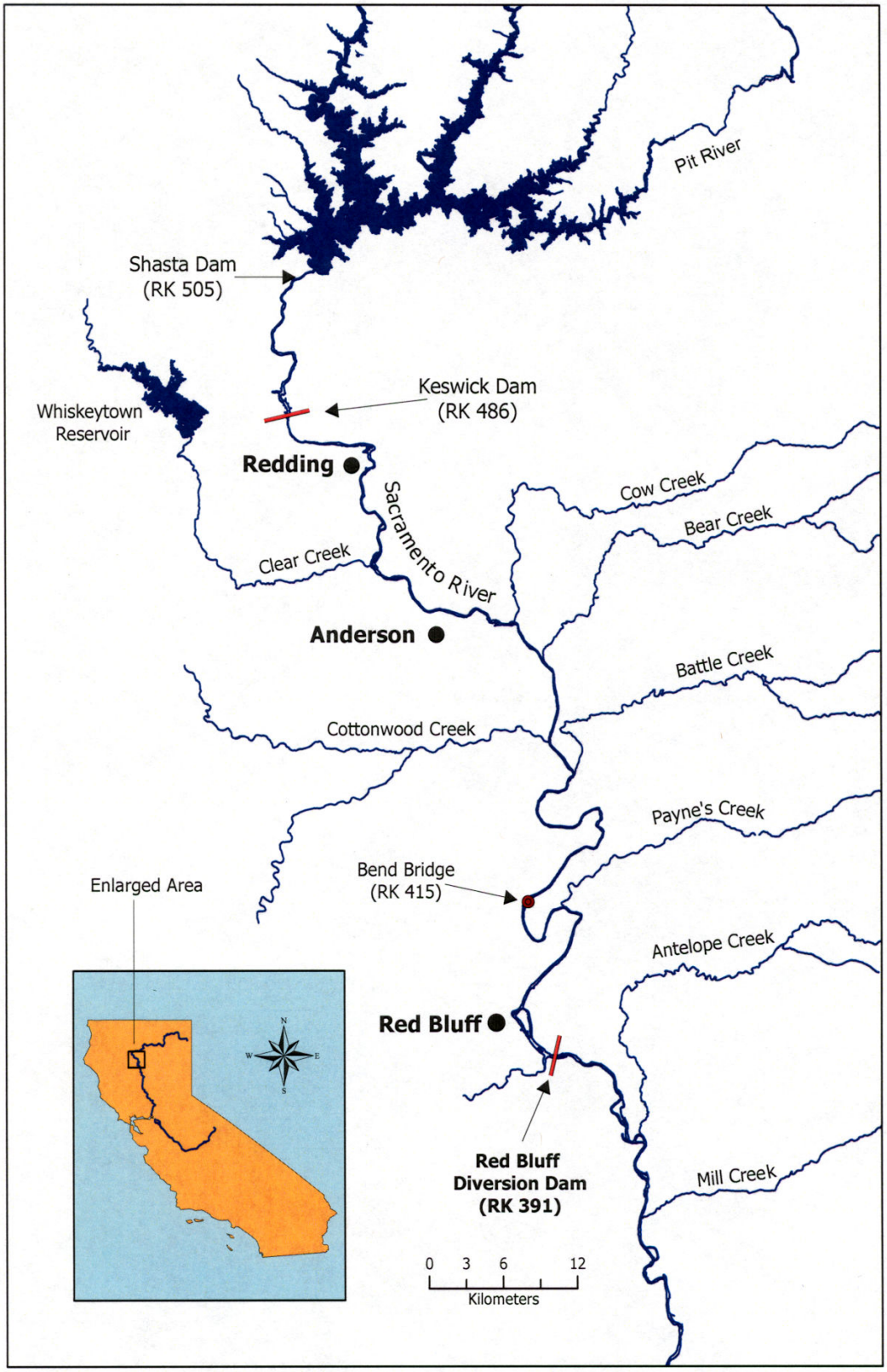

Figure 1. Location of Red Bluff Diversion Dam on the Sacramento River, California at river kilometer 391 (RK 391).

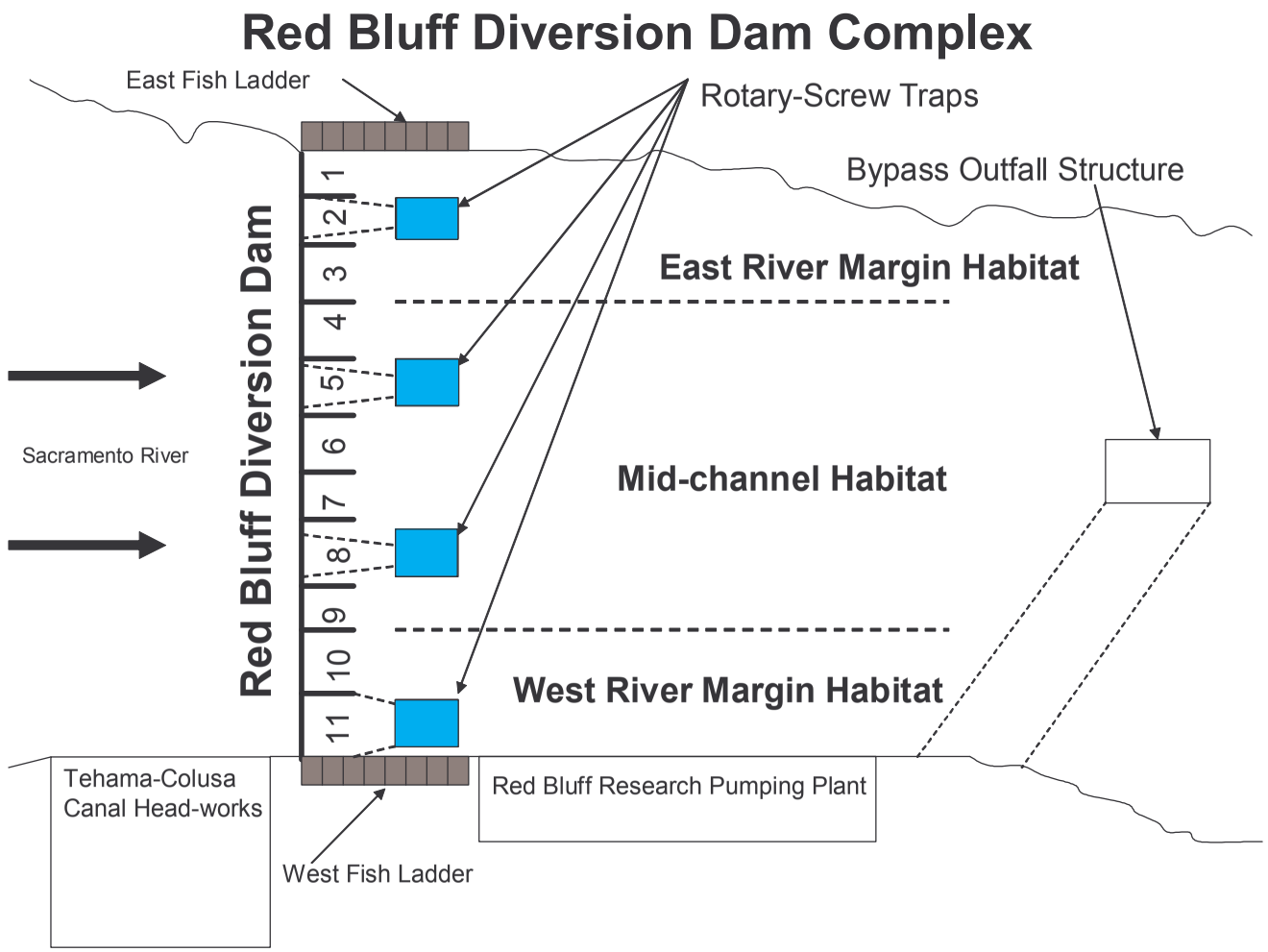

Figure 2. Rotary-screw trap sampling transect at Red Bluff Diversion Dam Complex (RK391) on the Sacramento River, California.

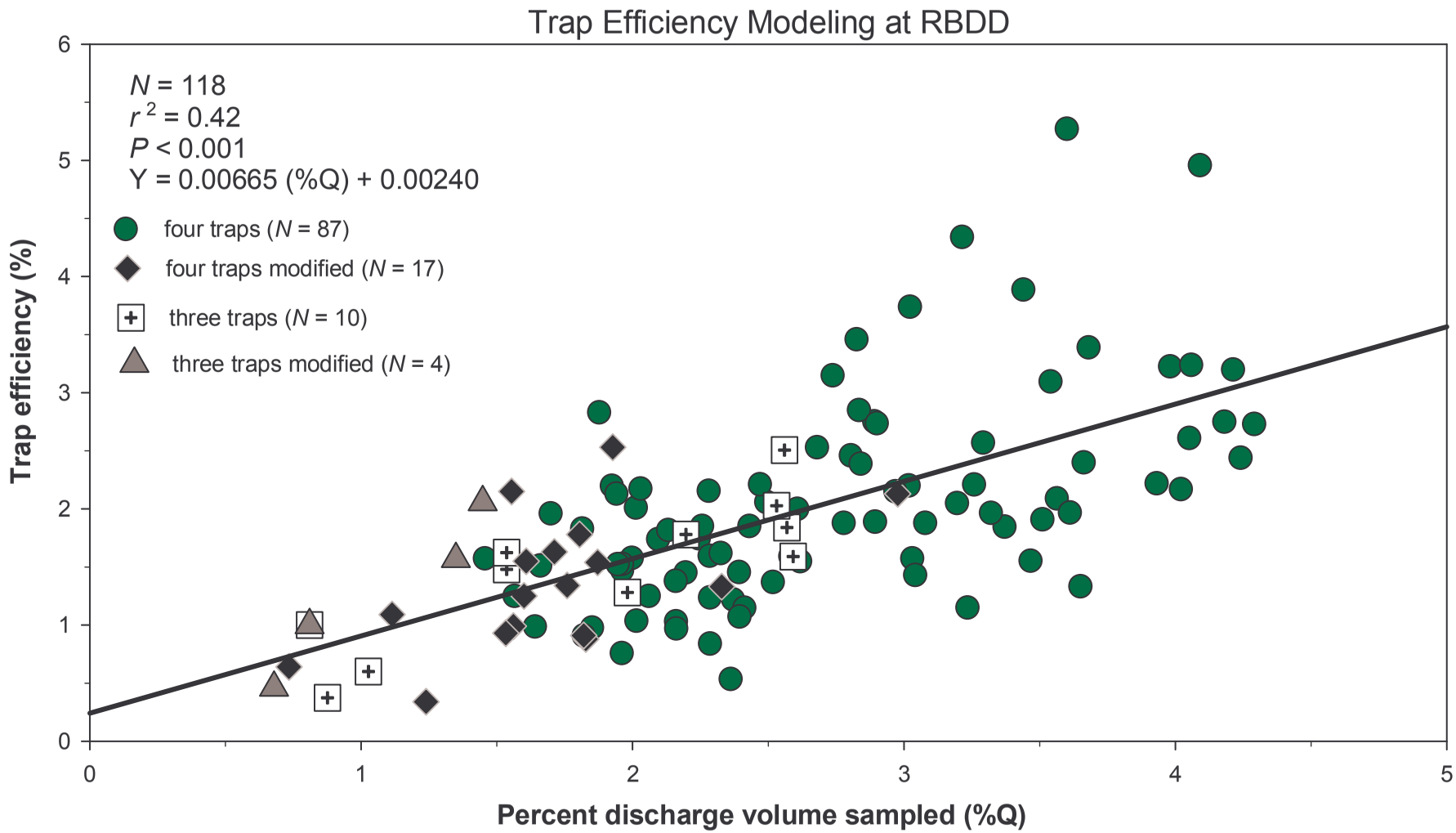

Figure 3. Trap efficiency model for combined 2.4 m diameter rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four traps (N = 86), three traps (N = 11), or with traps modified to sample one-half the normal volume of water (N = 21).

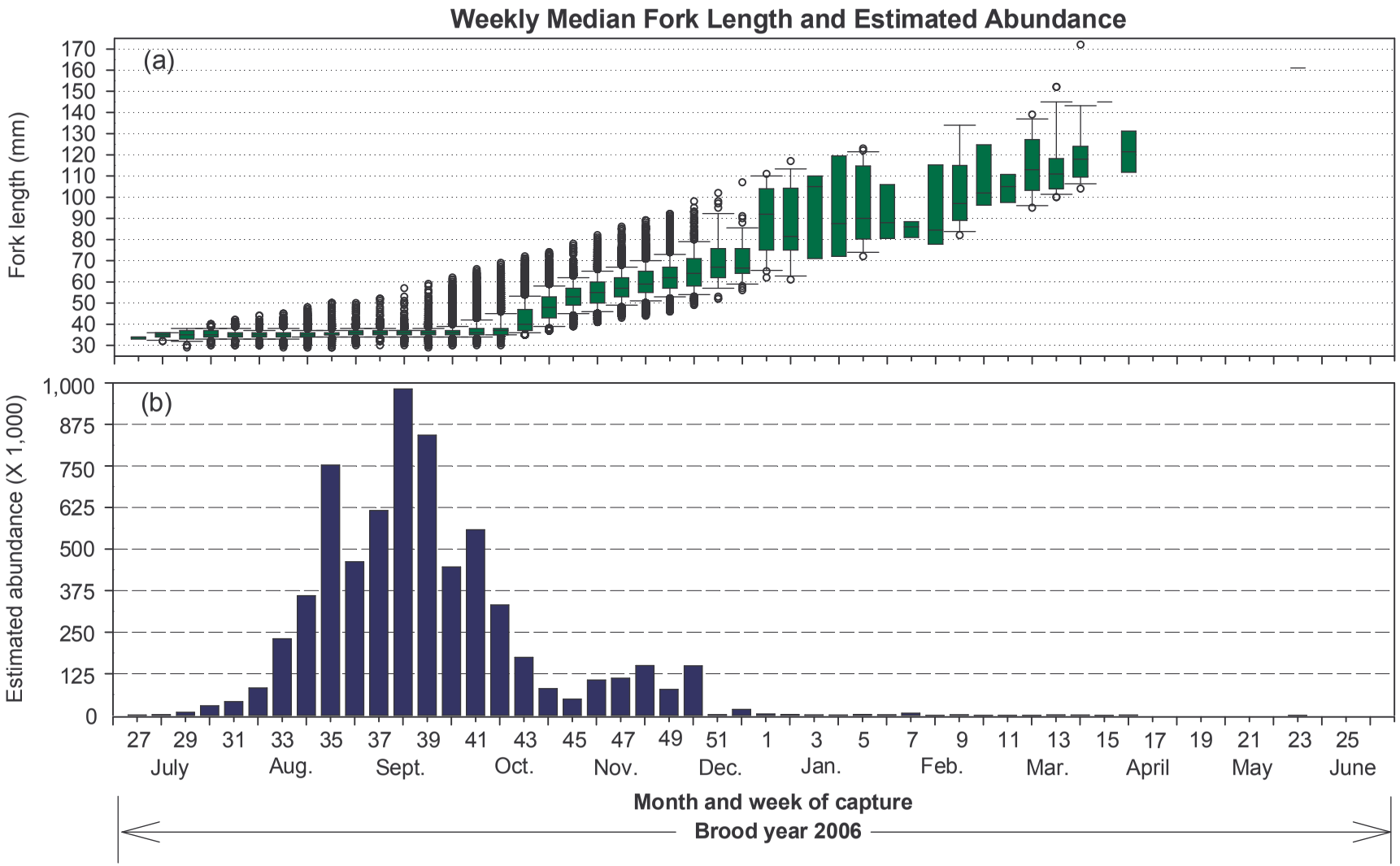

Figure 4. Weekly median fork length (a) and estimated abundance (b) of juvenile winter Chinook salmon passing Red Bluff Diversion Dam (RK391), Sacramento River, California. Winter Chinook salmon were sampled by rotary-screw traps for the period July 1, 2006 through June 30, 2007. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

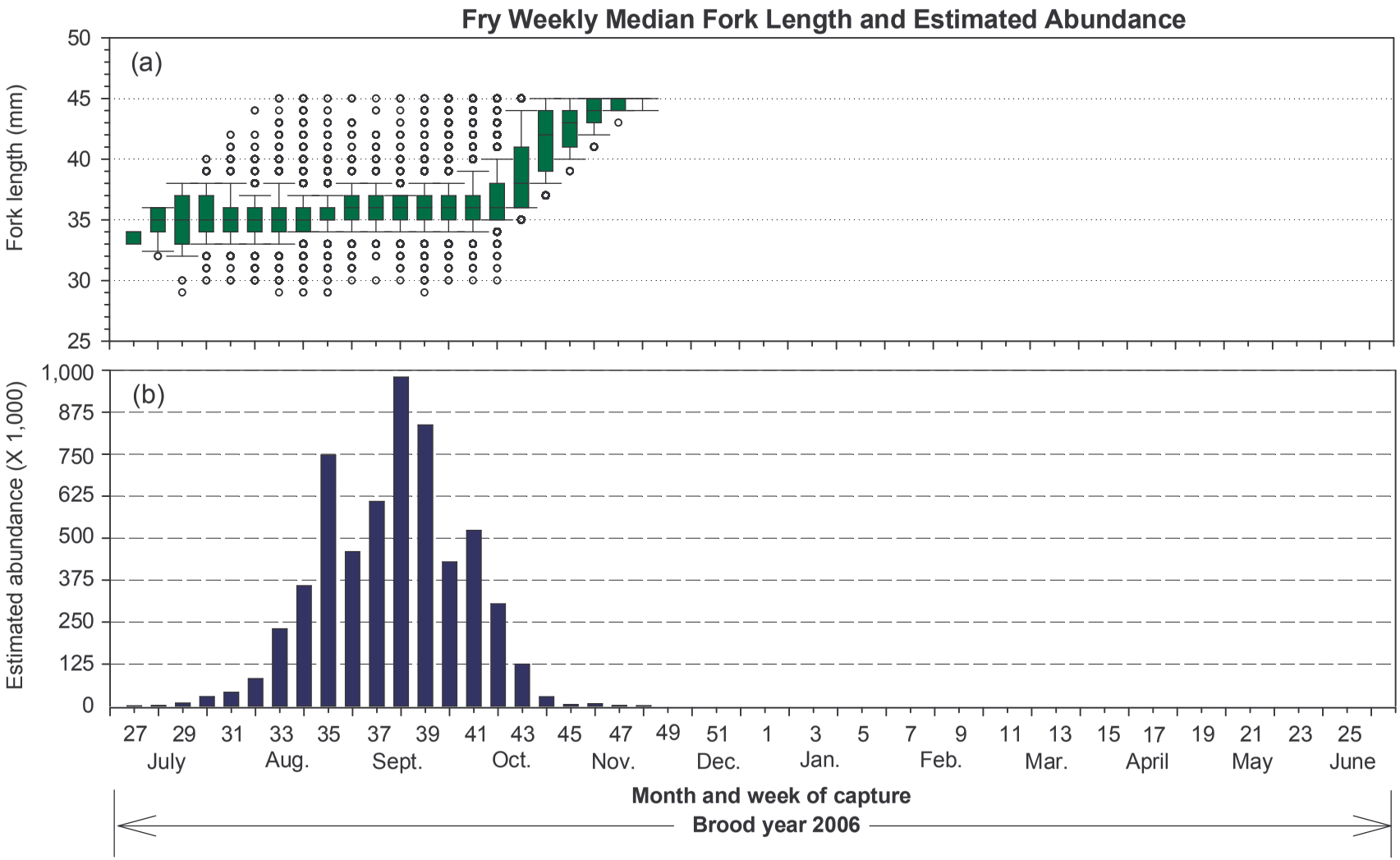

Figure 5. Weekly median fork length (a) and estimated abundance (b) of winter Chinook salmon fry passing Red Bluff Diversion Dam (RK391), Sacramento River, California. Winter Chinook juveniles were sampled by rotary-screw traps for the period July 1, 2006 through June 30, 2007. Box plots display weekly median fork length, 10th, 25th, 75th,and 90th percentiles and outliers.

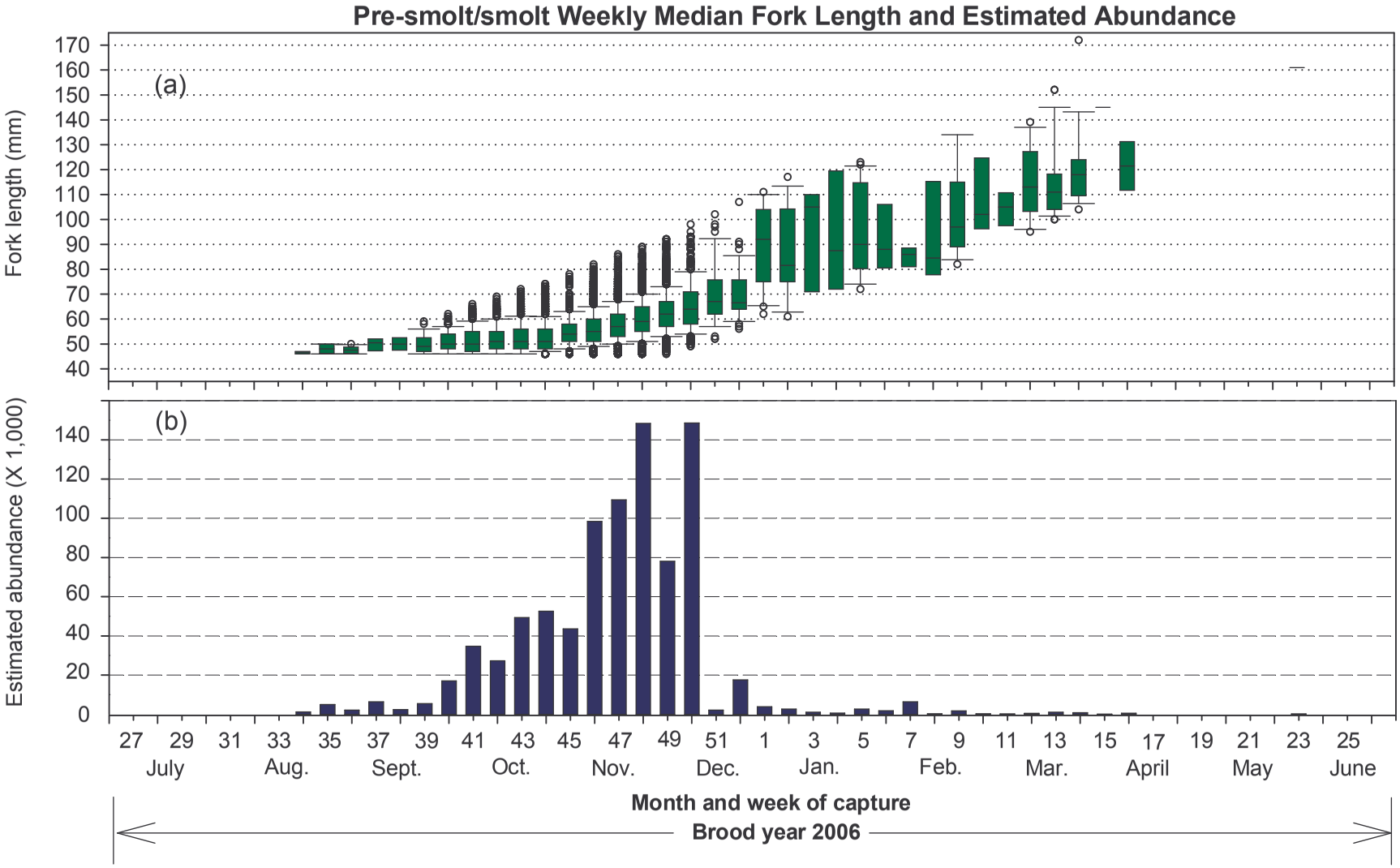

Figure 6. Weekly median fork length (a) and estimated abundance (b) of winter Chinook pre-smolt/smolts passing Red Bluff Diversion Dam (RK391), Sacramento River, California. Winter Chinook juveniles were sampled by rotary-screw traps for the period July 1, 2006 through June 30, 2007. Box plots display weekly median fork length, 10th, 25th, 75th,and 90th percentiles and outliers.

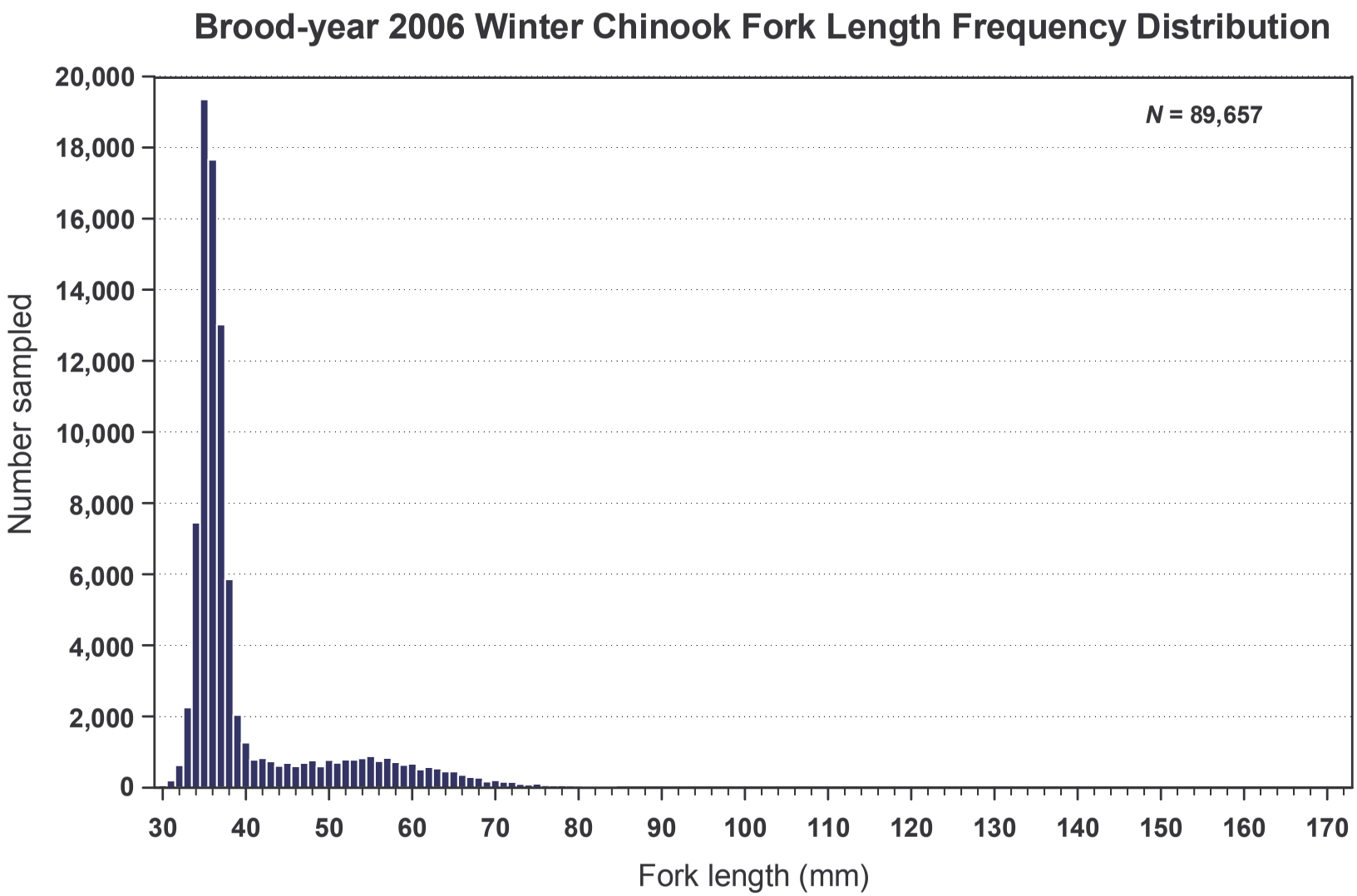

Figure 7. Fork length frequency distribution of brood-year 2006 juvenile winter Chinook salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fork length data was expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from July 1, 2006 through June 30, 2007.

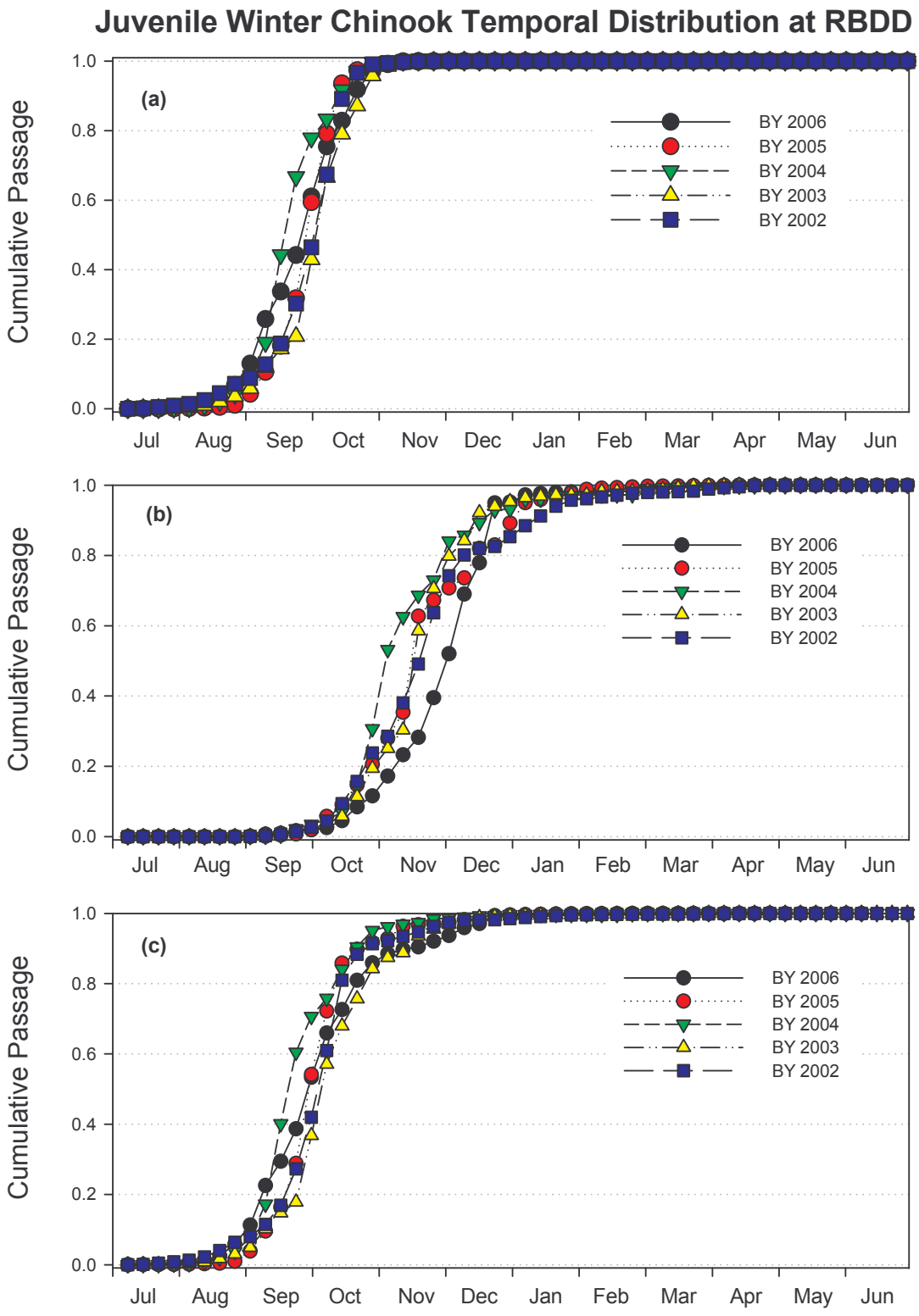

Figure 8. Temporal distribution of (a) Fry, (b) Pre-smolt/smolt, and (c) combined size classes of juvenile winter-run Chinook salmon passing Red Bluff Diversion Dam, Sacramento River, California for brood years 2002 - 2006.

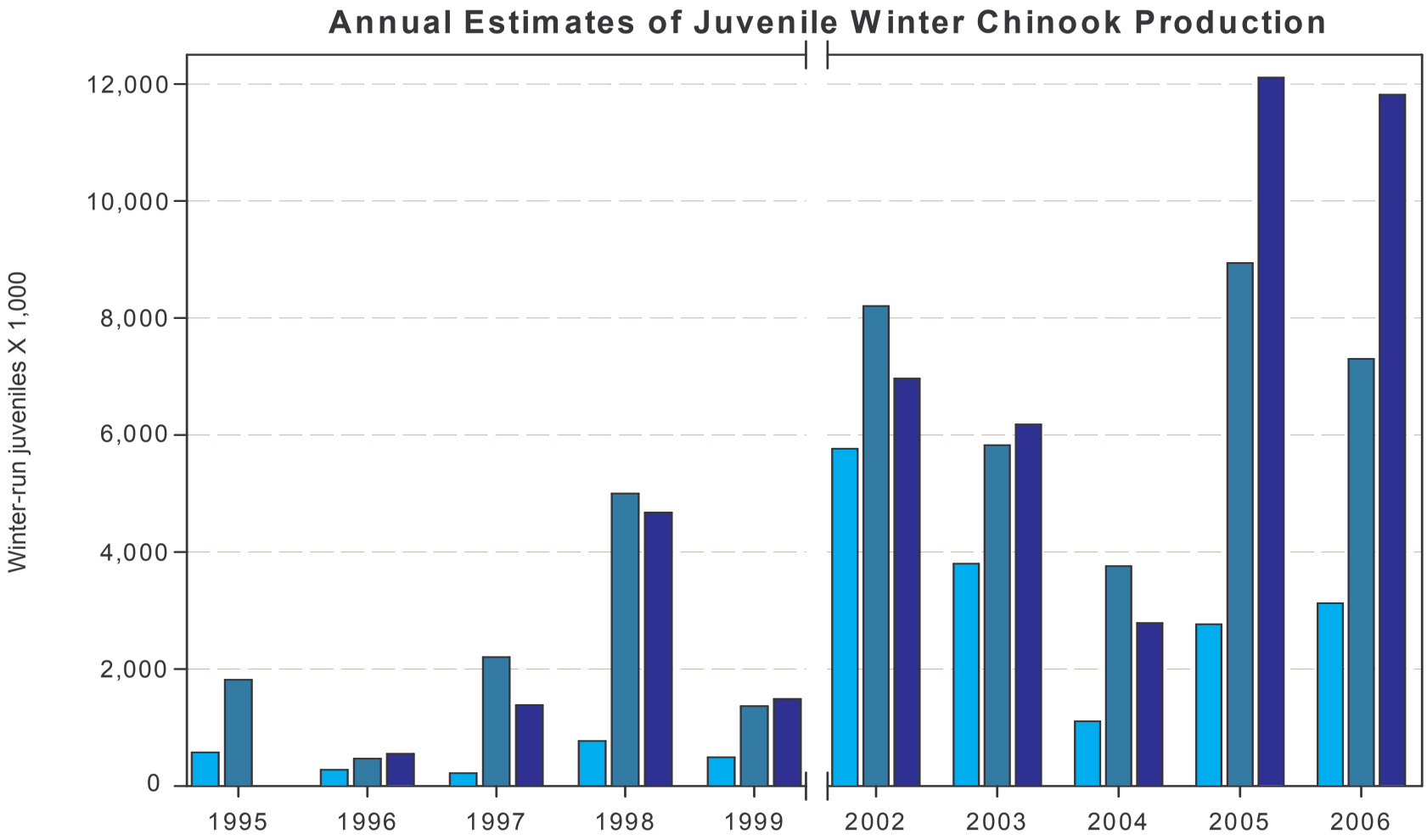

Figure 9. Time series comparison of annual estimates of juvenile winter-run production using RBDD ladder data JPE's (light blue) , rotary-screw trap fry-equivalent JPI's (medium blue), and carcass survey JPE's (dark blue).

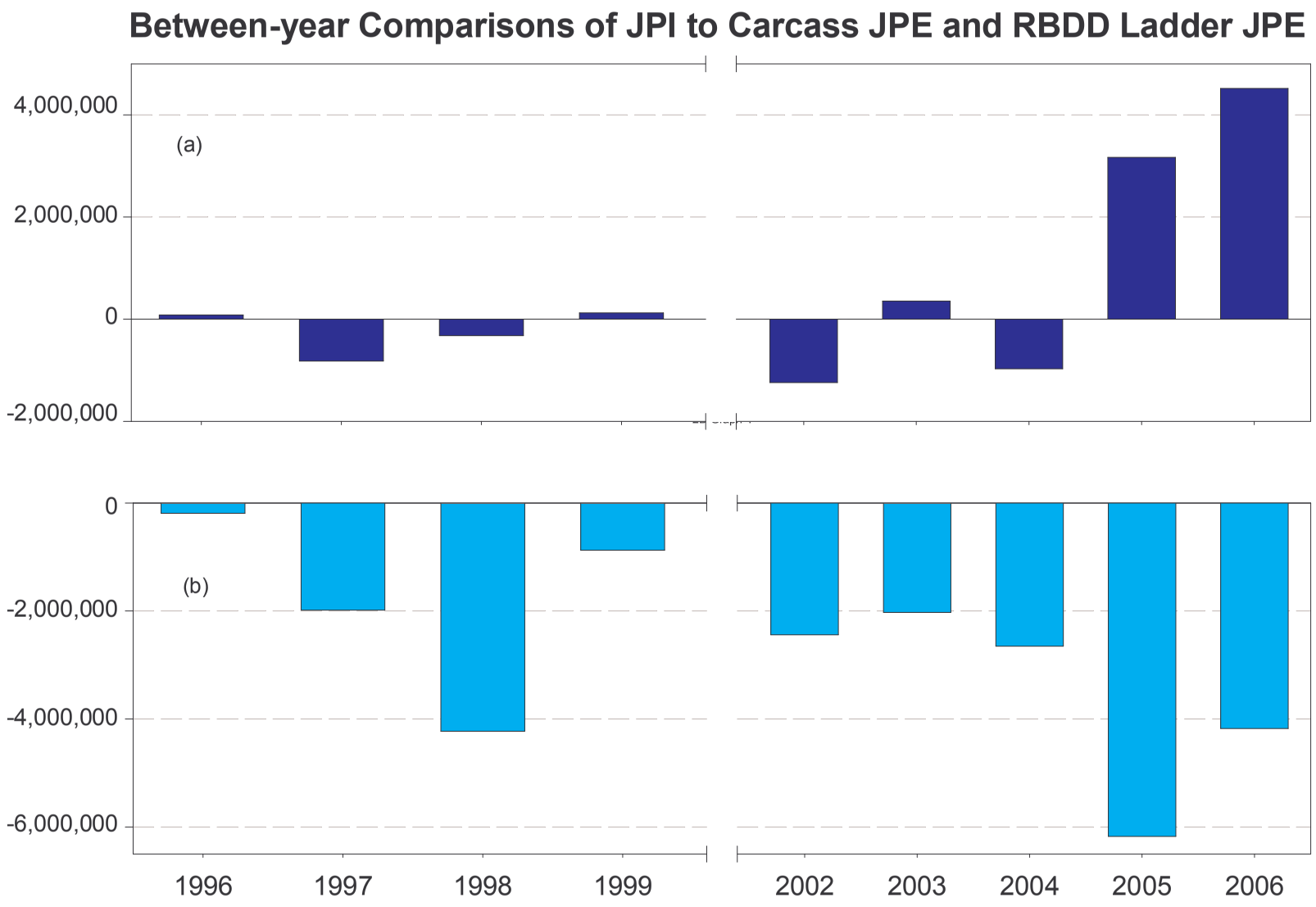

Figure 10. Between-year comparisons of differences between annual estimates from rotary trap fry equivalent JPI estimate (value of zero) and (a) carcass survey JPE's; and (b) RBDD ladder count JPE's; for brood-years 1996 - 1999 and 2002 - 2006.

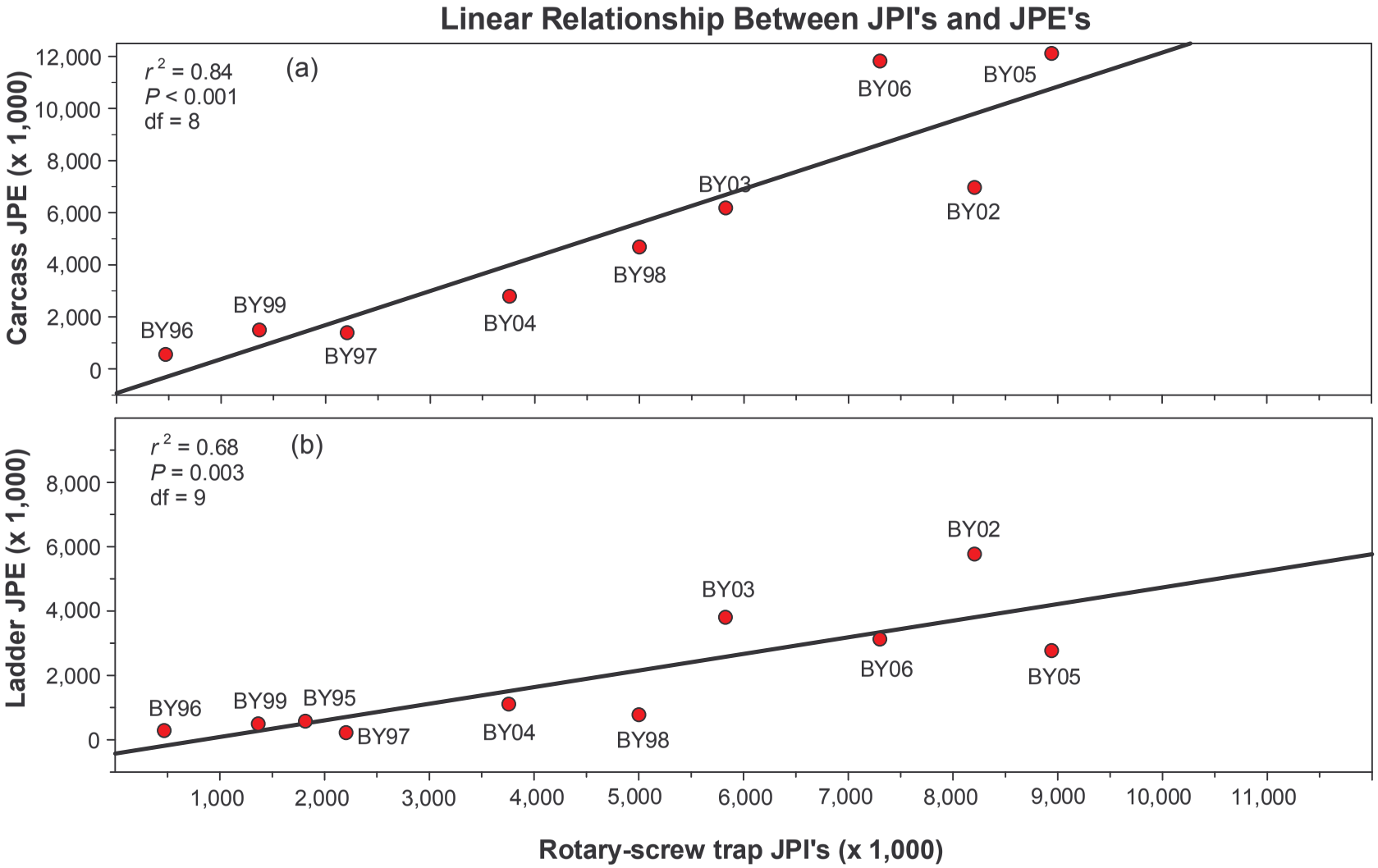

Figure 11. Linear relationship between rotary-screw trap fry-equivalent juvenile production indices (JPI) and (a) carcass survey derived juvenile production estimates (JPE) and (b) RBDD ladder count derived JPE's.

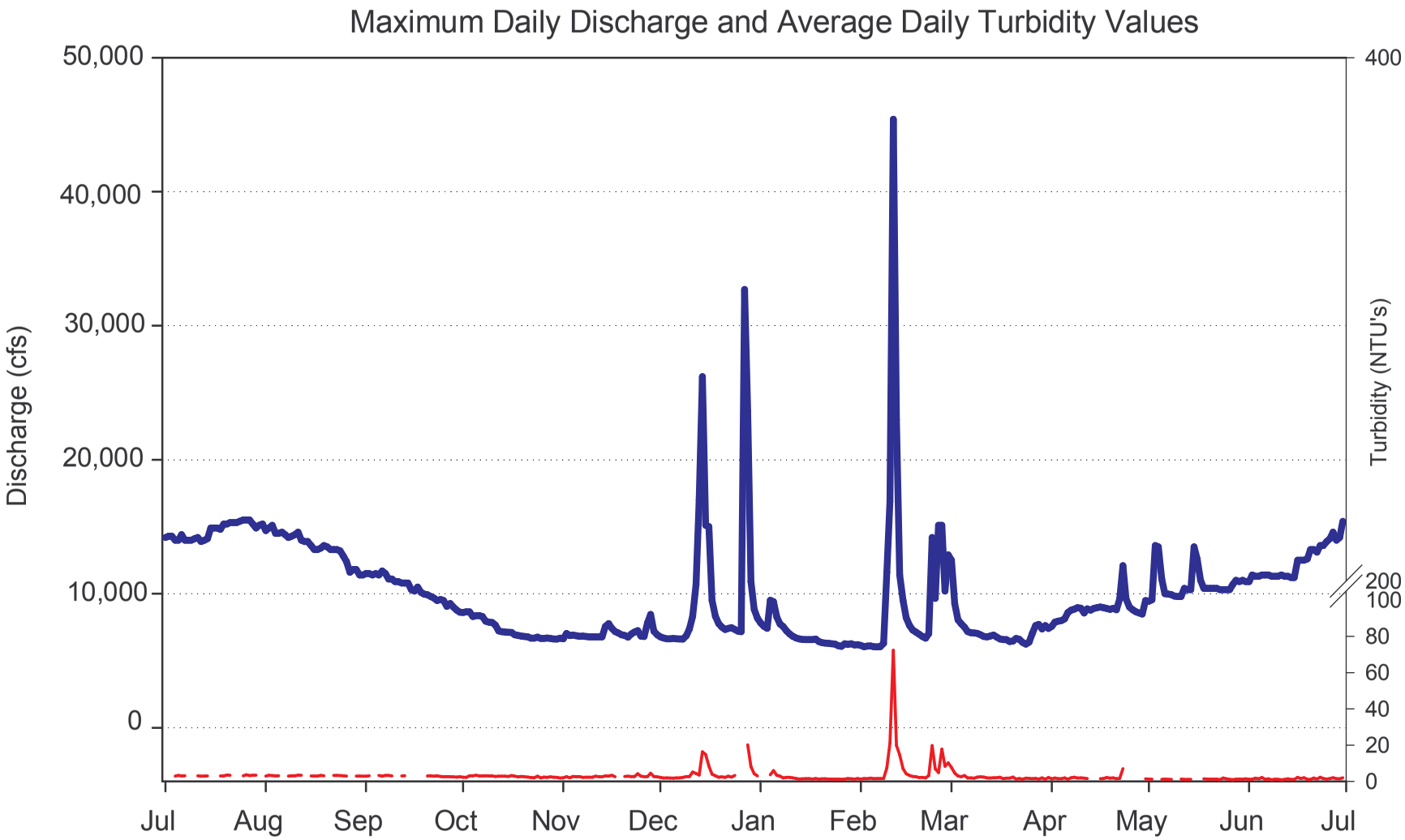

Figure 12. Maximum daily discharge (thick line) calculated from the California Data Exchange Center's Bend Bridge gauging station and average daily turbidity values (thin line) from rotary-screw traps at RBDD for the period July 1, 2006 through June 30, 2007.

APPENDIX I

APPENDIX 1 (List of Figures)

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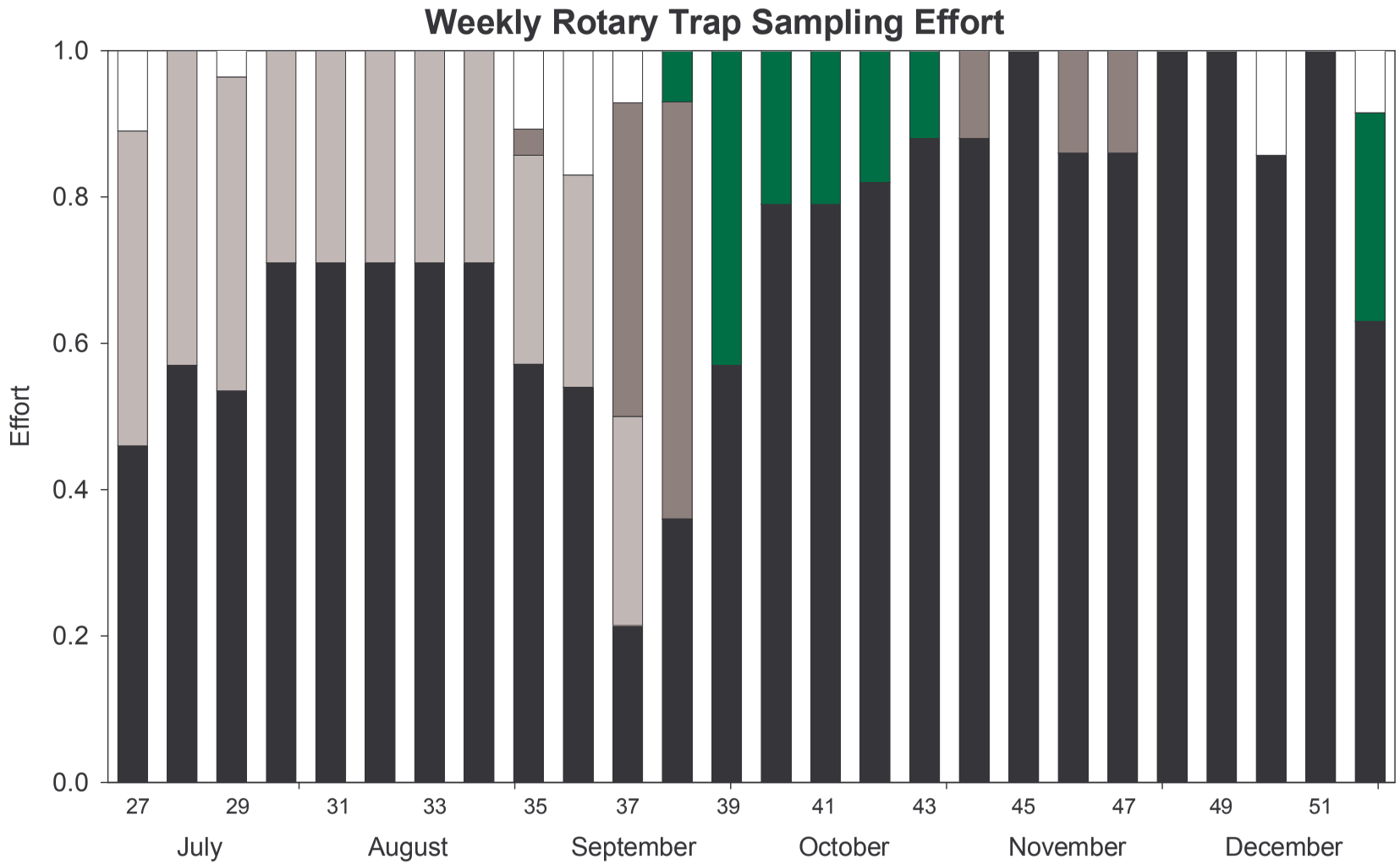
A2. Alternate comparison: non-linear relationship of winter-run Chinook salmon females (estimated females) and juvenile production (recruits). Data includes carcass survey female escapement estimates and rotary trapping fry equivalent juvenile production indices for brood-years (BY) 1996-1999 and 2002-2006.....39



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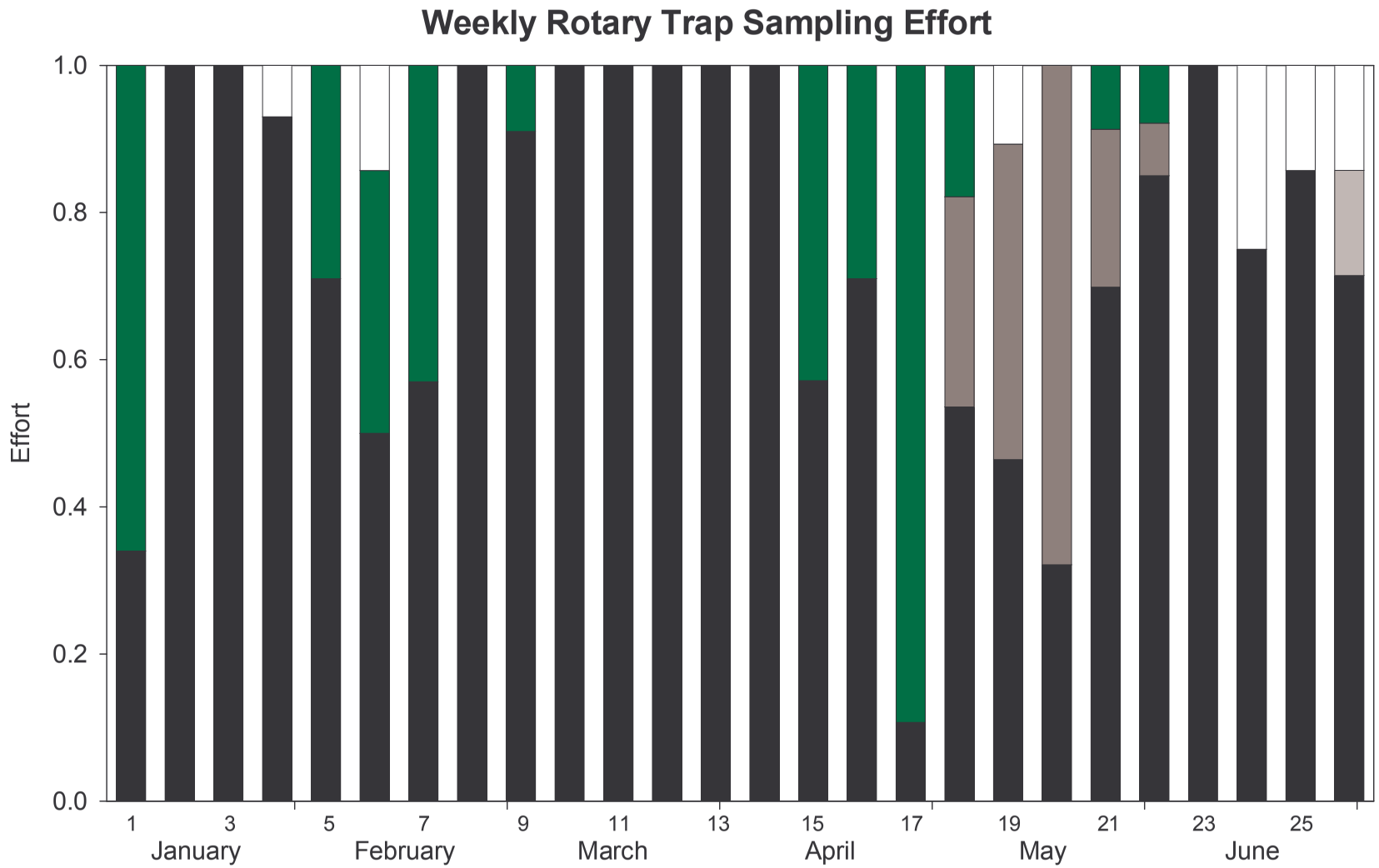

Figure A1 continued. Weekly rotary trap sampling effort shown by category. Sampled portions represented by black bars; unsampled portions designated in descending order of frequency: intentional reductions in effort (dark green), limited field staff (grey), RBDD operations (dark grey) and unintentional reductions (white).

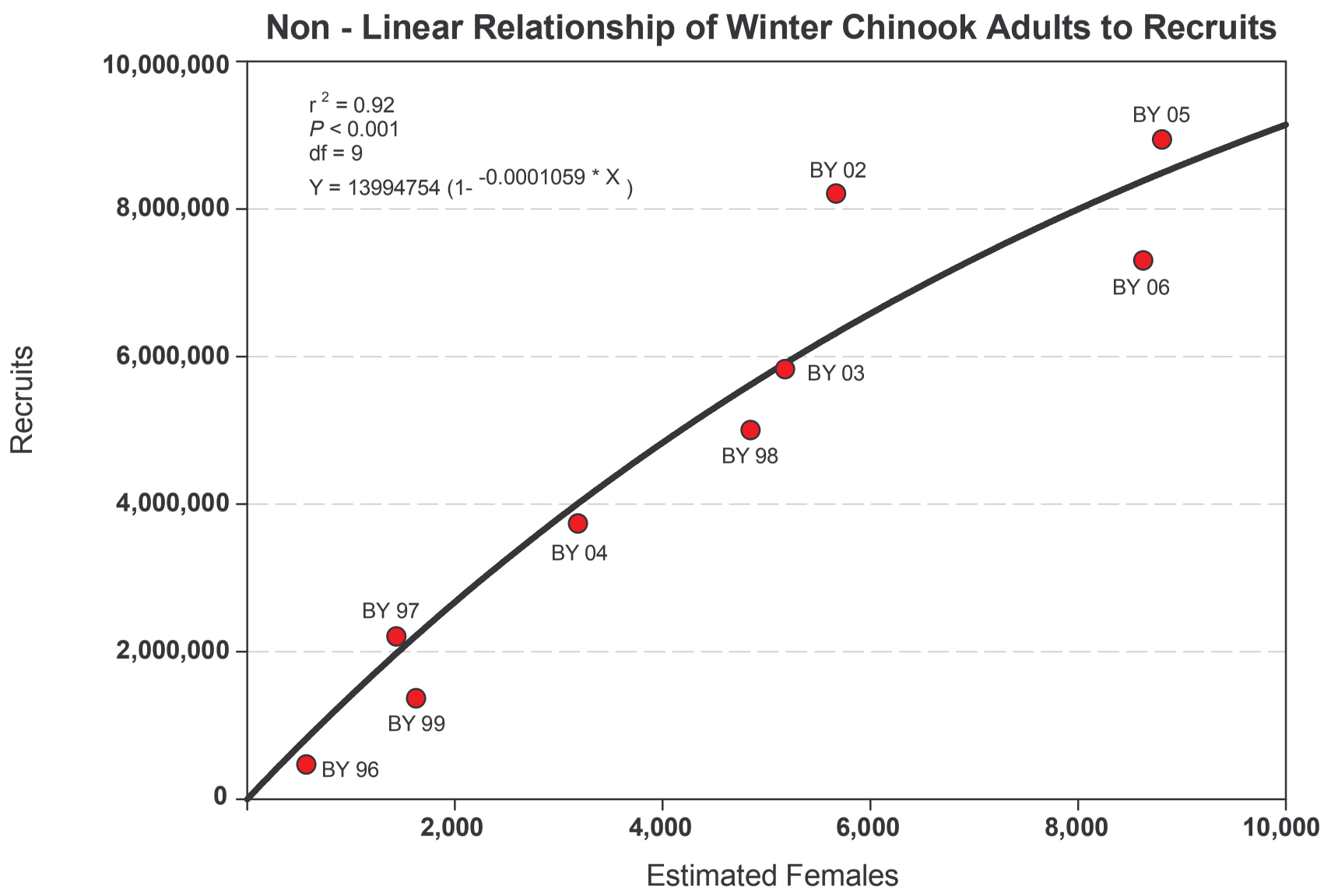

Figure A2. Alternate comparison: non-linear relationship of winter-run Chinook salmon females (Estimated Females) and juvenile production (recruits). Data includes carcass survey female escapement estimates and rotary trapping fry equivalent juvenile production indices for brood-years (BY) 1996 -1999 and 2002 - 2006.