BROOD-YEAR 2004 WINTER CHINOOK JUVENILE PRODUCTION INDICES WITH COMPARISONS TO JUVENILE PRODUCTION ESTIMATES DERIVED FROM ADULT ESCAPEMENT

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Brood-year 2004 winter Chinook juvenile production indices with comparisons to juvenile production estimates derived from adult escapement

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Abstract.— Brood-year 2004 juvenile winter-run Chinook salmon passage at Red Bluff Diversion Dam (RBDD) was 3,515,486 fry and pre-smolt/smolts combined, representing a 33% and 54% reduction in that observed for brood-years' 2003 and 2002, respectively. Fry-equivalent passage was 3,758,790. 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 (NOAA Fisheries) 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 were strongly correlated in trend to carcass survey JPE's (r^2 = 0.95, P < 0.001, df = 6) and, to a lesser extent, fish ladder JPE's (r^2 = 0.78, P = 0.035, df = 7). However, paired comparisons revealed a significant difference in production estimates between JPI's and fish ladder JPE's (t = 4.36, P = 0.003, df = 7). Moreover, fish ladder JPE's fell below the lower 90% confidence interval (C.I.) about the rotary trap JPI in seven of eight years evaluated, providing further evidence that fish ladder JPE's consistently underestimate juvenile winter-run Chinook salmon production, relative to JPI's. Conversely, no significant difference was detected between rotary trap JPI's and carcass survey JPE's (t = 1.71, P = 0.138, df = 6), and carcass survey JPE's fell within the 90% C.I. for rotary trap JPI's in six of seven years evaluated. We concluded that the 2004 NOAA Fisheries JPE model, using carcass survey and RBDD fish ladder escapement estimates, underestimated juvenile winter-run Chinook salmon production by 26% and 71%, respectively.

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Introduction

Winter Chinook 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 federally endangered winter-run Chinook salmon. One measure is to adaptively manage water exports from the Central Valley Project's Tracy Pumping Plant and the State Water Project's Harvey Banks Delta Pumping Plant in the Sacramento-San Joaquin Delta (Delta). Exports are managed to limit entrainment of juvenile winter-run Chinook salmon (hereafter referred to as winter Chinook) annually migrating through the Delta seaward. The United States Bureau of Reclamation 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 at these facilities (CDFG 1996). The NOAA Fisheries uses a juvenile production model to estimate abundance of the juvenile 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).

The NOAA Fisheries juvenile production model uses estimated adult escapement as the primary variate. The two survey methods (carcass surveys and RBDD ladder counts) have typically 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 spawning migration, and the fish ladders are operational only when the gates are closed. Therefore, the majority of winter-run 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. 2000).

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 survey the size composition of fish sampled often leads to skewed sex-ratios (Snider et al. 2000). Adult females are generally larger and may be more easily recognized and

[1] The Sacramento River winter-run Chinook salmon was state 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 an endangered species 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 June, 2005 (70 FR 37160).

recovered, than their male counterparts. For example, in 1999 the carcass survey male to female ratio was 1:8.4. 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 if conditions are not conducive for successful reproduction, fewer juveniles would be produced than the model would predict.

Direct monitoring of juvenile winter Chinook passage at RBDD has been conducted by the United States Fish and Wildlife Service since 1994. Martin et al. (2001) developed quantitative methodologies for indexing juvenile passage using rotary-screw traps. These rotary trap juvenile production indices (JPI's) have been used in support of estimates of production 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) 2004 juvenile winter Chinook passing RBDD, (2) define seasonal and 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 January 1, 2004 through June 30, 2005. The report includes JPI's from the latter half of the 2003 winter Chinook brood year (January 1 – June 30, 2004) and the entire 2004 brood year emigration period (July 1, 2004 – June 30, 2005). The report also includes juvenile monitoring data gathered during BY 2002 and BY 2003, for comparison. This report will be submitted to the California Bay-Delta Authority to comply with contractual reporting requirements for project ERP-01-N44.

Study Area

The Sacramento River is the largest river system in California, flowing south through 600 km (400 miles) 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 have impacted much of the river between Red Bluff, CA. 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, CA, approximately 3 km southeast of the city of Red Bluff. The dam is 226 m wide and has eleven fixed-wheel gates 18 m wide. Between gates are concrete piers 2.4 m in width. Gates can be raised allowing for run-of-the-river conditions, or lowered to impound and divert river flows into the Tehama-Colusa Canal. The RBDD gates are normally raised from September 16 through May 14 and lowered May 15 through September 15 of each year.

Methods

Sampling gear.— Sampling was conducted along a transect using four 2.4-m diameter rotary-screw traps (E.G. Solutions® Corvallis, Oregon) attached 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 checked/serviced once daily, except during periods of high winter Chinook abundance, elevated river flows, or heavy debris loads. During these occasions, traps were checked/serviced multiple times per day or continuously to prevent incidental mortality. 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. 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 limits. The specific sub-sampling protocol implemented was contingent upon the number of winter Chinook captured. 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 to reduce impact, we decreased the number of traps sampling from four to three.

Data collection.— All fish captured were anesthetized, identified to species, and enumerated, and fork lengths measured (nearest mm). Chinook salmon race was assigned using length-at-date criteria developed by Greene[2] (1992).

Other data were collected at each trap check/servicing and included: (1) length of time trap sampled, (2) velocity of water immediately in front of the cone at a depth of 0.6 m, and (3) depth of cone "opening" submerged. Water velocity was measured using an Oceanic® Model 2030 flow torpedo. These data were used to calculate the volume of

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[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 are placed with the latter spawning run

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 (DWR Station ID: *BND*).

Trap efficiency trials.— Fish were marked with bismark brown stain (Mundie and Traber 1983). Fish were stained in bismark brown staining solution prepared at a concentration of 21.0 mg/L of water. Fish were stained in solution for 45-50 minutes and removed. Marked fish were held for 6-24 h before being released, generally 4 km upstream from RBDD.

Trap efficiency modeling.— We modeled trap efficiency (i.e., the proportion of the juvenile population passing RBDD captured by traps) 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.

Passage estimates.— Winter Chinook passage was estimated by using a model developed to predict daily trap efficiency ($\hat{T}_d$). The trap efficiency model was developed by conducting 105 mark/recapture trials at RBDD and used $\%Q$ as the primary variate (Martin et al. 2001, Gaines and Poytress 2004). 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. $$X_d = \sum_{i=1}^{t} X_{di}$$

The $\%Q$ was estimated from the ratio of water volume sampled (X_d) to river discharge (Q_d) on day d.

3. $$\%Q_d = \frac{X_d}{Q_d}$$

Total salmonid passage was estimated on day d (d=1,…,n) by

4. $$\hat{P}_d = \frac{C_d}{\hat{T}_d}$$

where,

5. $$\hat{T}_d = (0.007099)(\%Q) + 0.001688$$

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

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

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

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

Annual JPI's were estimated by summing $\hat{P}$ across weeks.

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

Winter Chinook fry (≤ 45 mm FL) and pre-smolt/smolt (> 45 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 pre-smolt/smolt JPI (59% fry-to-presmolt/smolt survival; Hallock undated). Rotary trap JPI's could then be directly compared to JPE's.

Results

Sampling effort.— Weekly sampling effort was greater overall (+11%) in BY 04 than in BY 03 (Table 1). Weekly sampling effort ranged from 0.18 to 1.00 ($\bar{x}$ = 0.91, *N* = 26 weeks) during the first half of BY 04, the period of greatest juvenile winter Chinook emigration (Table 1). Weekly sampling effort during the same period of BY 03 ranged from 0.00 to 1.00 ($\bar{x}$ = 0.86, *N* = 26 weeks; Table 1).

Trap efficiency trials.— Twenty-one mark-recapture trials were conducted in 2004 and six trials were conducted in the first half of 2005 to estimate rotary-screw trap efficiency (Table 2). Sacramento River discharge sampled during the trials ranged from 5,810 to 16,900 cfs. Estimated *%Q* during trap efficiency trials ranged from 1.35% to 4.21% ($\bar{x}$ = 2.65 %; Table 2).

Trials were conducted with RBDD gates lowered (*N* = 6), RBDD gates raised (*N* = 21), rotary traps modified to sample with half cones (*N* = 8), unmodified (standard cone; *N* = 19), and while sampling with 4 traps (*N* = 24) and with 3 traps (*N* = 3). All trials were conducted using Chinook sampled from rotary traps, and trap efficiencies ranged from 1.15 to 4.34% ($\bar{x}$ = 2.20%). The number of marked fish released per trial ranged from 691 to 2,074 ($\bar{x}$ = 1,460) and the number of marked fish recaptured after release ranged from 10 to 50 ($\bar{x}$ = 30). All fish were released at sunset and 95% of recaptures occurred within the first 24 hours, 98.5% within 48 hours, 99.6% within 72 hours and 100% within 96 hours.

Fork lengths of fish marked and released ranged from 30 to 102 mm ($\bar{x}$ = 46.6 mm). Fork lengths of recaptured marked fish ranged from 30 to 102 mm ($\bar{x}$ = 46.5 mm). The fork lengths of fish marked and released in mark-recapture trials was commensurate with the fork lengths of fish captured by rotary-screw traps. A paired comparison of mean length of marked fish released (46.6 mm FL) was not statistically greater than the mean length of marked fish recaptured (46.5 mm FL; $P = 0.727$, df = 26).

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* ($P < 0.0001$). The strength of the relationship improved slightly from $r^2 = 0.40$ (Gaines and Poytress 2004) to $r^2 = 0.41$ (Figure 3) with the addition of 21 trials conducted in 2004 and 6 trials conducted in 2005.

Patterns of abundance.— The information presented below was prepared in a manner to convert to a biologically based reporting period from the previous calendar year reporting period. As such, note the emigration cycle for winter Chinook juveniles begins on July 1 and ends on June 30, for a given brood-year. This annual report, therefore, contains results for two different brood-years, the second half of BY03 (January 1, 2004 through June 30, 2004) and all of BY 04 (July 1, 2004 through June 30, 2005). Where appropriate, data from 2002 and 2003 have been included for comparison.

Brood-year 2003.— Passage of BY03 winter Chinook juveniles occurred from January 1, 2004 through May 27, 2004. Estimated passage during this period was 28,943 and represented less than one half of one percent of BY03 total passage (fry and pre-smolt/smolts combined), and 3.6% of pre-smolt/smolt passage. Passage generally declined throughout the period with weekly passage estimates ranging from 3,609 in week one to 102 in week twenty-two (Table 3). Weekly median fork length of BY03 pre-smolt/smolts ranged from 76 to 162 mm from week one through week twenty-two, increasing an average of 3.9 mm per week.

Brood-year 2004.— Brood-year 2004 winter Chinook juvenile passage at RBDD was 3,515,486 fry and pre-smolt/smolts combined (Table 3). This represents approximately 33% less juveniles passing RBDD than that observed in 2003 and 54% less than was observed in 2002.

Brood-year 2004 newly emerged juveniles began to pass RBDD in mid-July (week 28) and weekly passage increased steadily through late September (week 39; Fig. 4b). Weekly fry passage increased from 71 to 3,360 in July, 5,021 to 136,590 in August and peaked at 805,532 in mid-September (week 37). Weekly passage then generally declined through late November. No fry were captured after week 47. Total estimated passage of BY04 winter Chinook fry was 3,167,901, representing 90% of BY 04 total passage (Table 3). The temporal emigration pattern of BY04 fry was consistent with the pattern observed for BY03 (Figure 5b), with passage of newly emerged fry beginning in early July and peak passage occurring in the latter half of September (Table 3).

Brood-year 2004 pre-smolt/smolt sized (>45 mm FL) juveniles began to emigrate past RBDD in late August (week 35), increased in number weekly and peaked in abundance in the latter half of October (week 43) at 78,264 (Table 3). Weekly passage generally declined throughout the remainder of the brood-year with small increases in passage through week 19 (Figure 6b).

Weekly median fork length of BY04 fry increased slowly from 31.0 mm in week 28 to 36.0 mm in week 42 (Figure 4a). Fork lengths increased rapidly from 36.0 mm to 39.0 mm in week 43 and steadily increased, thereafter, to 45.0 mm in week 47 (Figure 5a). Brood-year 2004 pre-smolt/smolt median fork length ranged from 46.0 to 52.0 mm from week 35 to 43, increasing by 0.75 mm per week on average (Figure 6a). From week 44 to 52, however, average weekly median fork length increase was 2.6 mm per week from 54.0 to 75.0 mm. The length frequency distribution of BY04 juveniles was positively skewed and strongly influenced by 33.0 to 37.0 mm FL individuals (Figure 7a), similar to the distribution observed for BY03 (Figure 7b) and BY 02 winter Chinook (Figure 7c). Only 10.0% of BY04 winter Chinook juveniles passing RBDD were pre-smolt/smolt sized individuals (15.1% for BY03 and 10.2% for BY02). Estimated passage of BY03 pre-smolt/smolts passing after December 31, 2003 was 0.5% of total passage.

Comparison of JPI and JPE. — The fry-equivalent rotary trap JPI for BY04 was 3,758,790. The BY04 fry-equivalent carcass survey and fish ladder JPE's were 2,786,832 and 1,105,900, respectively. Only the carcass survey JPE fell within the 90% C.I. about the rotary trap JPI (Table 4).

We combined data from 1995 to 2003 with BY04 JPE's and JPI's to evaluate the linear relationship between the estimates. Seven observations were available to evaluate using the carcass survey data because the winter Chinook carcass survey did not start until 1996 and rotary trapping at RBDD was not conducted in 2000 and 2001. Eight observations were available to evaluate using RBDD ladder data (1995-1999, 2002-2004). Rotary trap JPI's were significantly correlated *in trend* to carcass survey JPE's ($r^2 = 0.95$, $P < 0.0002$, df = 6; Figure 8a) and to a lesser extent fish ladder JPE's ($r^2 = 0.78$, $P = 0.0034$, df = 7; Figure 8b). However, paired comparisons revealed a significant difference in fry-equivalent production estimates between rotary trap JPI's and fish ladder JPE's ($t = 4.35$, $P = 0.003$, df = 7). Moreover, the 2004 fish ladder JPE's fell below the lower 90% C.I. about the rotary trap JPI, similar to the trend seen in the previous seven years (Table 4). On average, fish ladder JPE's were 60% less than rotary trap JPI's (range = -29 to -90%). Conversely, no significant difference was detected among rotary trap JPI's and carcass survey JPE's ($t = 1.71$, $P = 0.138$, df = 6), and carcass survey JPE's fell within the 90% C.I. about the rotary trap JPI in six of seven years evaluated. On average, carcass survey JPE's were 7% less than rotary trap JPI's (range = -37 to +17%).

Discussion

Sampling effort.— Weekly sampling effort was greater by 11% in 2004 than 2003 (Table 1). From July through December 2004, the peak winter Chinook emigration period, rotary-screw traps sampled 24 h daily on 169 of 184 days. Seven days were not sampled in mid September due to RBDD operations associated with the annual draw-down of Lake Red Bluff. In contrast, only 159 of 184 days were sampled for the same period in 2003.

Trap efficiency modeling.— On 21 occasions in 2004 and 6 occasions in the first half of 2005, we measured the efficiency of our rotary-screw traps using mark-recapture trials. Data from trials were combined with data from 78 previously conducted trials to model the relationship between trap efficiency and %Q at RBDD (Figure 3). Trap efficiency was moderately correlated with %Q ($r^2 = 0.41$). The relationship was slightly improved from that reported in Gaines and Poytress 2004, likely due to the addition of multiple data points to the upper limit of percent river discharge sampled. These data points were added as a result of low discharge conditions exhibited during trials conducted in 2005. However, there was substantial variability in trap efficiency that was not explained by %*Q*.

Patterns of abundance.— Brood-year 2004 winter Chinook juvenile passage at RBDD, from July 1, 2004 through June 30, 2005, was 3,515,486 fry and pre-smolt/smolts combined, approximately 33% less and 54% less than that observed for BY03 and BY 02, respectively. 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 (Gaines and Martin 2002). It is possible that differential survival exists between these subpopulations 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). 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.

Comparisons of JPI's and JPE's.— Gaines and Poytress (2004) determined that the rotary-screw trap JPI was strongly correlated in trend to carcass survey JPE's (r^2 = 0.98), and to a lesser extent, fish ladder JPE's (r^2 = 0.85). Interestingly, the addition of BY04 data resulted in a diminished relationship for the carcass survey (r^2 = 0.95, df = 6; Figure 8a) *and* the fish ladder JPE's (r^2 = 0.78, df = 7; Figure 8b). For the BY04 JPE model, NOAA Fisheries employed a standard fecundity value (3,500 eggs/female) used in previous years (McInnis 1993, Grover 1995, Diaz-Soltero 1995). In more recent years, an average annual fecundity value derived from winter Chinook propagated at the Livingston Stone National Fish Hatchery (LSNFH) had been used to estimate fecundity in the model (Bruce Oppenheim, pers. comm.). The values obtained from LSNFH winter Chinook spawning records from brood-years 2000-2003 averaged 4,794 eggs/female, representing a 37% greater number of eggs/female than the standard value used in the 2004 JPE model. The change in the fecundity estimate may have contributed greatly to the disparities between the 2004 JPI and JPE's.

Fish ladder JPE's were not supportive of JPI's with respect to the magnitude of fry-equivalent production values (t = 4.36, P = 0.003, df = 7). Furthermore, it appears that fish ladder JPE's consistently underestimate juvenile production, relative to JPI's and carcass survey JPE's (Table 4). In contrast, rotary-screw trap JPI's and carcass survey JPE's have historically been strongly correlated. Moreover, significant differences in the magnitude of JPI's and carcass survey JPE's were not detected with the addition of 2004 data (t = 1.71, P = 0.138, df = 6). The reader should be cautioned that our conclusions were based on small sample sizes in both the carcass survey (N = 7) and fish ladder (N = 8) comparisons between JPI's and JPE's. We concluded that the 2004 NOAA Fisheries JPE model, using carcass survey and RBDD fish ladder escapement estimates underestimated juvenile production by 26% and 71%, respectively.

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Literature Cited

Arkoosh, M.R., E. Casillas, E. Clemons, A.N. Kagley, R. Olson, P. Reno, R.E. Stein. 1998. Effect of pollution on fish diseases: potential impacts on salmonid populations. Journal on Aquatic Animal Health 10:182-190.

Bigelow, P.E. 1996. Evaluation of the Sacramento River spawning gravel restoration project and winter-run chinook salmon redd survey, 1987-1993. Final report. U.S. Fish and Wildlife Service, Northern Central Valley Fish and Wildlife Office, Red Bluff, CA.

Botsford, L.W. and J.G. Brittnacher. 1998. Viability of Sacramento River winter-run chinook salmon. Conservation Biology 12: 65-79.

Bradford, M.J. 1994. Trends in the abundance of chinook salmon (*Oncorhychus tshawytscha*) of the Nechako River, British Columbia. Canadian Journal of Fisheries and Aquatic Science 51: 965-973.

CDFG. 1996. Sacramento River winter-run chinook salmon. Annual report prepared for the Fish and Game Commission, May 1996. California Department of Fish and Game, Sacramento, CA.

Diaz-Soltero, H. 1997. Estimated number of winter-run Chinook salmon juveniles that will enter the Delta during the 1996-97 season. February 10, 1997 letter from the National Marine Fisheries Service to the U.S. Bureau of Reclamation and California Department of Water Resources.

Diaz-Soltero, H. 1995. Estimated number of winter-run Chinook salmon juveniles that will enter the Delta during the 1995-96 season. October 30, 1995 letter from the National Marine Fisheries Service to the U.S. Bureau of Reclamation and California Department of Water Resources.

Gaines, P.D. and C.D. Martin. 2002. Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing the Red Bluff Diversion Dam, Sacramento River. Red Bluff Research Pumping Plant Report Series, Volume 14. U.S. Fish and Wildlife Service, Red Bluff, CA.

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

Gaines, P.D. and W.R. Poytress. 2003. Brood-year 2002 winter Chinook juvenile production indices with comparisons to adult escapement. U.S. Fish and Wildlife Service report to California Bay-Delta Authority. San Francisco, CA.

Grover, J. 1995. Family group composition and 1995 release plan for brood year 1994 winter-run chinook salmon juveniles from Coleman National Fish Hatchery. January 11, 1995 letter from the United States Fish and Wildlife Service to the National Marine Fisheries Service.

Hallock, R.J. 1991. The Red Bluff diversion dam. Pages 96-104 *in* A. Lufkin, editor. California's salmon and steelhead. The struggle to restore an imperiled resource. University of California Press, Berkeley.

Hallock, R.J. Undated. The status of inland habitat and factors adversely impacting salmon resources. Anadromous Fisheries Program, California Department of Fish and Game, Red Bluff, CA.

Heming, T.A. 1981. Effects of temperature on utilization of yolk by chinook salmon (*Oncorhychus tshawytscha*) eggs and alevins. Canadian Journal of Fisheries and Aquatic Science 39: 184-190.

Lecky, J.H. 2000. Estimated number of winter-run chinook salmon juveniles that will enter the Delta during the 1999-00 season. February 18, 2000 letter from the National Marine Fisheries Service to the U.S. Bureau of Reclamation and California Department of Water Resources.

Lecky, J.H. 1999. Estimated number of winter-run chinook salmon juveniles that will enter the Delta during the 1998-99 season. February 26, 1999 letter from the National Marine Fisheries Service to the U.S. Bureau of Reclamation and California Department of Water Resources.

Lecky, J.H. 1998. Estimated number of winter-run chinook salmon juveniles that will enter the Delta during the 1997-98 season. April 27, 1998 letter from the National Marine Fisheries Service to the U.S. Bureau of Reclamation and California Department of Water Resources.

Major, R. L. and J.L. Mighell. 1969. Egg-to-migrant survival of spring chinook salmon (*Oncorhychus tshawytscha*) in the Yakima River, Washington. Fishery Bulletin 67 (2) 347-359.

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

McInnis, R. 2002. Estimated number of winter-run Chinook salmon juveniles that will enter the Delta during the 2001-02 season. February 22, 2002 letter from the National Marine Fisheries Service to the U.S. Bureau of Reclamation and California Department of Water Resources.

McInnis, R. 1993. Estimated number of winter-run Chinook salmon juveniles that will enter the Delta during the 1993-94 season. September 30, 1993 letter from the National Marine Fisheries Service to the U.S. Bureau of Reclamation and California Department of Water Resources.

Mundie, J.H. and R.E. Traber. 1983. Movements of coho salmon *Onchorhynchus kisutch* fingerlings in a stream following marking with a vital stain. Canadian Journal of Fisheries and Aquatic Science 40:1318-1319.

Reiser, D.W. and R.G. White. 1998. Effects of two sediment size-classes on survival of steelhead and chinook salmon eggs. North American Journal of Fisheries Management 8:432-437.

Snider, B., B. Reavis, and S. Hill. 2000. 1999 upper Sacramento River winter-run Chinook salmon escapement survey May-August 1999. Stream Evaluation Program Technical Report No. 00-1. California Department of Fish and Game, Habitat Conservation Division, Sacramento, CA.

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

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

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

Yoshiyama, R.M., F.W. Fisher , and P.B. Moyle. 1998. Historical abundance and decline Of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18:487-521.

Zhou, S. 2002. Size-dependent recovery of Chinook salmon in carcass surveys. Transactions of the American fisheries Society 131:1194-1202.

Table 1.—Sampling effort was quantified by assigning a value of 1.00 to a sample consisting of four, 2.4-m diameter rotary-screw traps sampling 24h daily, seven days weekly. Weekly values less than 1.00 represent occasions where less than four traps were sampling, we randomly sub-sampled periods of the day or night, traps were structurally modified to sample only one-half the normal volume of water or when less than seven days were sampled. Trap damage and repair was the primary reason when less than four traps were sampling. Sub-sampling and modifying traps to sample less water volume were implemented to reduce catch and associated impact on winter Chinook salmon during periods of peak river discharge. A winter Chinook brood-year (BY) is identified as beginning on July 1 and ending on June 30.

	Sampling effort				Sampling effort		
Week	BY02	BY03	BY04	Week	BY02	BY03	BY04
27 (Jul)	0.48	1.00	1.00	1 (Jan)	0.00	0.36	0.50
28	0.50	0.93	0.93	2	0.00	0.41	0.61
29	0.02	0.82	0.82	3	0.27	0.50	0.62
30	0.21	1.00	1.00	4	0.32	0.50	0.73
31 (Aug)	0.36	1.00	1.00	5 (Feb)	0.48	0.43	0.32
32	0.32	0.96	1.00	6	0.50	0.50	0.79
33	0.32	1.00	1.00	7	0.29	0.36	1.00
34	0.23	1.00	1.00	8	0.32	0.00	0.96
35 (Sep)	0.11	1.00	1.00	9 (Mar)	0.84	0.00	0.75
36	0.29	0.86	1.00	10	1.00	0.43	1.00
37	0.21	0.32	0.18	11	0.54	0.61	0.96
38	0.00	0.36	1.00	12	0.68	0.64	0.54
39	0.50	0.89	1.00	13 (Apr)	0.75	0.75	0.86
40 (Oct)	0.36	1.00	1.00	14	0.57	0.75	1.00
41	0.36	1.00	1.00	15	1.00	0.86	0.93
42	0.43	1.00	0.86	16	0.43	0.46	0.39
43	0.75	1.00	0.75	17	0.05	0.36	1.00
44 (Nov)	0.88	0.86	1.00	18 (May)	0.16	0.64	0.55
45	0.88	1.00	1.00	19	0.75	0.14	0.41
46	0.98	1.00	1.00	20	0.00	0.71	0.00
47	1.00	1.00	1.00	21	0.00	1.00	0.00
48 (Dec)	1.00	1.00	0.93	22 (Jun)	0.68	1.00	0.00
49	0.96	1.00	0.93	23	1.00	1.00	0.79
50	0.57	0.43	0.86	24	1.00	0.71	1.00
51	0.07	1.00	1.00	25	0.96	0.86	1.00
52	0.11	0.00	0.50	26	0.43	0.93	1.00

Table 2.—Summary results from mark-recapture trials conducted in 2002 ($N = 3$), 2003 ($N = 18$), 2004 ($N = 21$), and 2005 ($N = 6$) to determine rotary-screw trap efficiency at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Results include the number of fish released, the mean fork length at release (Release FL), the number recaptured, the mean fork length at recapture (Recapture FL), combined trap efficiency (TE %), percent river volume sampled by rotary-screw traps (%Q), number of traps sampling during trials, 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	2002	805	68.73	8	70.38	0.99	1.56	4	Yes	Lowered
2	2002	743	69.67	16	72.13	2.15	1.55	4	Yes	Lowered
3	2002	340	76.46	7	76.71	2.06	1.41	3	Yes	Lowered
4	2003	5,143	36.76	33	37.00	0.64	0.73	4	Yes	Raised
5	2003	2,942	36.70	10	37.80	0.34	1.24	4	Yes	Raised
6	2003	3,106	37.77	29	36.79	0.93	1.53	4	Yes	Raised
7	2003	3,256	37.42	15	37.27	0.46	0.68	3	Yes	Raised
8	2003	2,019	37.01	22	37.18	1.09	1.11	4	Yes	Raised
9	2003	1,456	37.04	31	37.87	2.13	2.98	4	Yes	Raised
10	2003	1,168	37.07	28	38.07	2.40	3.66	4	No	Raised
11	2003	1,053	37.43	22	37.55	2.09	3.56	4	No	Raised
12	2003	1,067	38.15	17	38.29	1.59	2.59	3	No	Raised
13	2003	1,119	37.08	14	37.07	1.25	2.06	4	No	Lowered
14	2003	1,283	36.66	26	37.46	2.03	2.53	3	No	Lowered
15	2003	1,197	37.26	30	36.90	2.51	2.56	3	No	Lowered
16	2003	1,012	35.54	18	36.17	1.78	2.20	3	No	Raised
17	2003	1,017	36.88	28	37.18	2.75	2.89	4	No	Raised
18	2003	1,064	37.57	20	36.50	1.88	3.08	4	No	Raised
19	2003	999	37.23	22	36.82	2.20	3.02	4	No	Raised
20	2003	1,017	38.13	16	39.38	1.57	3.03	4	No	Raised
21	2003	1,209	37.99	26	36.81	2.15	2.97	4	No	Raised
22	2004	2,074	37.11	26	37.12	1.25	1.60	4	Yes	Raised

Table 2.— (continued)

Trial#	Year	Number released	Release FL (mm)	Number recaptured	Recapture FL (mm)	TE (%)	%Q	Number of traps sampling	Traps modified	RBDD Gate Configuration
23	2004	2,018	38.37	36	37.39	1.78	1.81	4	Yes	Raised
24	2004	2,024	37.66	33	37.24	1.63	1.71	4	Yes	Raised
25	2004	1,999	37.93	31	38.00	1.55	1.61	4	Yes	Raised
26	2004	2,017	37.77	27	37.00	1.34	1.76	4	Yes	Raised
27	2004	2,009	37.22	31	37.81	1.54	1.87	4	Yes	Raised
28	2004	1,401	38.26	18	39.61	1.28	1.98	3	No	Raised
29	2004	815	38.79	15	40.93	1.84	2.57	3	No	Raised
30	2004	1,304	72.92	33	71.73	2.53	1.93	4	Yes	Raised
31	2004	814	75.51	18	75.11	2.21	3.26	4	No	Raised
32	2004	867	80.16	10	78.30	1.15	3.23	4	No	Lowered
33	2004	1,096	81.17	27	79.89	2.46	2.80	4	No	Lowered
34	2004	888	76.24	28	78.93	3.15	2.74	4	No	Lowered
35	2004	691	76.41	12	75.73	1.74	2.09	4	No	Lowered
36	2004	1,096	36.53	41	36.00	3.74	3.02	4	No	Lowered
37	2004	1,153	36.57	50	35.64	4.34	3.21	4	No	Lowered
38	2004	1,023	36.00	14	35.36	1.37	2.52	4	No	Raised
39	2004	1,153	35.82	50	35.29	4.34	3.21	4	No	Raised
40	2004	2,006	36.01	31	35.10	1.55	2.62	4	No	Raised
41	2004	1,918	36.07	36	35.44	1.88	2.78	4	No	Raised
42	2004	1,682	36.43	24	35.04	1.43	3.04	4	No	Raised
43	2005	1,283	36.63	41	37.41	3.20	4.21	4	No	Raised
44	2005	1,971	36.59	31	36.00	1.57	1.35	3	Yes	Raised
45	2005	1,763	36.58	46	36.67	2.61	4.05	4	No	Raised
46	2005	1,216	36.58	27	36.52	2.22	3.93	4	No	Raised
47	2005	1,328	36.33	43	35.58	3.24	4.06	4	No	Raised
48	2005	1,949	57.05	50	61.38	2.57	3.29	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, 2002 through June30, 2004. This period represents all of BY02, BY03, and BY04. 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 appx. 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 2002				
26	0	-	0	-	0	-	0
27	9,346	34	0	-	9,346	34	9,346
28	24,760	35	0	-	24,760	35	24,760
29	29,495	35	0	-	29,495	35	29,495
30	34,230	35	0	-	34,230	35	34,230
31	70,725	35	0	-	70,725	35	70,725
32	141,478	35	0	-	141,478	35	141,478
33	181,460	35	0	-	181,460	35	181,460
34	119,875	35	632	46	120,507	35	120,950
35	266,042	36	1,864	47	267,906	36	269,211
36	412,209	36	3,096	48	415,305	36	417,473
37	790,025	36	5,217	50	795,242	36	798,894
38	1,114,945	-	9,698	-	1,124,643	-	1,131,431
39	1,439,865	36	14,179	52.5	1,454,044	36	1,463,967
40	1,495,953	36	38,975	50	1,534,928	36	1,562,207
41	515,277	36	49,209	51	564,486	37	598,930
42	167,042	37	63,548	51	230,591	39	275,073
43	27,477	40	37,030	52	64,507	47	90,428
44	20,607	42	74,223	53	94,830	51	146,786
45	11,459	43	86,668	54	98,127	53	158,795
46	2,768	44	114,163	57	116,931	57	196,846
47	853	45	82,286	60	83,139	59	140,743

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	32	45	46,236	62	46,268	62	78,635
49	0	-	14,455	62.5	14,455	62.5	24,575
50	0	-	4,335	64	4,335	64	7,366
51	0	-	21,629	77	21,629	77	36,693
52	0	-	24,719	72	24,719	72	41,935
1	0	-	21,629	-	21,629	-	36,693
2	0	-	21,269	-	21,629	-	36,693
3	0	-	13,332	95	13,332	95	22,667
4	0	-	3,529	82	3,529	82	5,998
5	0	-	3,953	114	3,953	114	6,722
6	0	-	4,021	109.5	4,021	109.5	6,836
7	0	-	3,956	97	3,956	97	6,726
8	0	-	2,003	111	2,003	111	3,406
9	0	-	1,024	118	1,024	118	1,740
10	0	-	571	128	571	128	971
11	0	-	1,250	120	1,250	120	2,123
12	0	-	4,679	115	4,679	115	7,951
13	0	-	2,686	116	2,686	116	4,569
14	0	-	2,062	123	2,062	123	3,507
15	0	-	3,076	129	3,076	129	5,230
16	0	-	791	131	791	131	1,349
17	0	-	0	-	0	-	0
18	0	-	0	-	0	-	0
19	0	-	0	-	0	-	0
20	0	-	0	-	0	-	0
21	0	-	0	-	0	-	0
22	0	-	0	-	0	-	0
23	0	-	0	-	0	-	0

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
BY02 total	6,875,923		782,353		7,658,276		8,205,609
			Brood-year 2003				
26	0	-	0	-	0	-	0
27	765	33	0	-	765	33	765
28	1,735	34	0	-	1,735	34	1,735
29	6,226	35	0	-	6,226	35	6,226
30	9,727	34	0	-	9,727	34	9,727
31	22,033	35	0	-	22,033	35	22,033
32	50,472	36	0	-	50,472	36	50,472
33	67,863	36	0	-	67,863	36	67,863
34	100,309	37	601	46.5	100,909	37	101,330
35	273,113	37	35,585	47	276,699	37	279,209
36	237,617	37	1,992	48	239,609	37	241,003
37	159,532	37	4,606	49.5	164,138	37	167,361
38	989,000	36	7,299	49	996,301	36	1,001,406
39	1,059,358	36	11,693	49	1,071,051	36	1,079,237
40	555,461	36	16,197	51	571,656	37	582,994
41	364,550	36	44,469	52	409,021	37	440,150
42	387,386	37	63,946	51	451,331	37	496,096
43	121,865	37	45,142	52	167,006	38	198,606
44	28,751	40	41,846	52	70,597	48	99,890
45	25,836	43	224,601	54	250,439	52	407,660
46	9,169	44	95,474	54	104,641	53	171,474
47	2,526	45	73,537	57	76,062	57	127,537
48	368	45	34,893	59	35,261	59	59,687

Table 3.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
49	0	-	63,413	61	63,413	61	107,804
50	0	-	14,205	63	14,205	63	24,148
51	0	-	11,058	64	11,058	64	18,797
52	0	-	8,381	-	8,381	-	14,247
1	0	-	3,609	76	3,609	76	6,135
2	0	-	2,981	80	2,981	80	5,069
3	0	-	0	-	0	-	0
4	0	-	533	119	533	119	907
5	0	-	7,060	100.5	7,060	100.5	12,002
6	0	-	411	111	411	111	699
7	0	-	0	-	0	-	0
8	0	-	2,028	-	2,028	-	3,448
9	0	-	2,028	-	2,028	-	3,448
10	0	-	3,763	110	3,763	110	6,396
11	0	-	3,940	107	3,940	107	6,696
12	0	-	1,028	111	1,028	111	1,745
13	0	-	830	112	830	112	1,408
14	0	-	188	112	188	112	320
15	0	-	156	143	156	143	267
16	0	-	89	133	89	133	151
17	0	-	197	117	197	117	335
18	0	-	0	-	0	-	0
19	0	-	0	-	0	-	0
20	0	-	0	-	0	-	0
21	0	-	0	-	0	-	0
22	0	-	102	162	102	162	173
23	0	-	0	-	0	-	0
24	0	-	0	-	0	-	0

Table 3.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
25	0	-	0	-	0	-	0
26	0	-	0	-	0	-	0
BY03 total	4,473,680		795,881		5,269,561		5,826,672
			Brood-year 2004				
27	0	-	0	-	0	-	0
28	71	31	0	-	71	31	71
29	1,483	36	0	-	1,483	36	1,483
30	3,360	35	0	-	3,360	35	3,360
31	5,021	35	0	-	5,021	35	5,021
32	18,462	35	0	-	18,462	35	18,462
33	37,441	35	0	-	37,441	35	37,441
34	64,508	36	160	46.5	64,669	36	64,781
35	136,280	36	308	46	136,590	36	136,805
36	337,493	36	1,028	47	338,523	36	339,245
37	799,414	35.5	6,111	49.5	805,532	36	809,809
38	710,292	35	4,545	50.5	714,837	35	718,017
39	353,191	35	4,847	50	358,037	35	361,430
40	174,072	35	6,841	50	108,910	35	185,699
41	265,099	35	26,847	50	291,943	35	310,734
42	166,694	36	56,014	50	222,708	37	261,918
43	85,538	39	78,264	52	163,801	47	218,586
44	6,630	43	32,479	54	39,109	52	61,845
45	2,033	43	21,216	55.5	23,247	55	38,098
46	623	44.5	15,104	59	15,726	59	26,299
47	196	45	38,506	61	38,701	61	65,656
48	0	-	5,795	64	5,795	64	9,851
49	0	-	12,509	67	12,509	67	21,265

Table 3.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
50	0	-	12,447	69	12,447	69	21,162
51	0	-	822	72	822	72	1,395
52	0	-	9,369	75	9,369	75	15,926
1	0	-	591	78	591	78	1,004
2	0	-	3,402	78	3,402	78	5,784
3	0	-	220	83.5	220	83.5	374
4	0	-	76	78	76	78	127
5	0	-	314	86	314	86	533
6	0	-	73	105.5	73	105.5	123
7	0	-	60	128.5	60	128.5	103
8	0	-	6,144	115	6,144	115	10,445
9	0	-	989	87.5	989	87.5	1,679
10	0	-	507	106.5	507	106.5	860
11	0	-	172	123	172	123	293
12	0	-	163	126	163	126	277
13	0	-	388	111.5	388	111.5	661
14	0	-	211	145.5	211	145.5	359
15	0	-	335	125.5	335	125.5	569
16	0	-	128	160	128	160	217
17	0	-	88	148	88	148	150
18	0	-	298	149	298	149	508
19	0	-	216	159	216	159	365
20	0	-	0	-	0	-	0
21	0	-	0	-	0	-	0
22	0	-	0	-	0	-	0
23	0	-	0	-	0	-	0
24	0	-	0	-	0	-	0
25	0	-	0	-	0	-	0

Table 3.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
26	0	-	0	-	0	-	0
BY04 total	3,167,901		347,585		3,515,486		3,758,790

Table 4.— Comparisons between juvenile production estimates (JPE) and rotary trapping juvenile production indices (JPI). Fish ladder JPE and carcass survey JPE were derived from the estimated adult female escapement from fish ladder counts at Red Bluff Diversion Dam and the upper Sacramento winter Chinook carcass survey, respectively. 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 BY04, assumptions 1-3 were estimated from 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	[d]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	2,786,832	3,185	1,105,900	1,264

[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 (2000-2004), 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 2002-2004; 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] Updated from Gaines and Poytress (2004) to include sampling from January 1, 2004 - June 30, 2004.

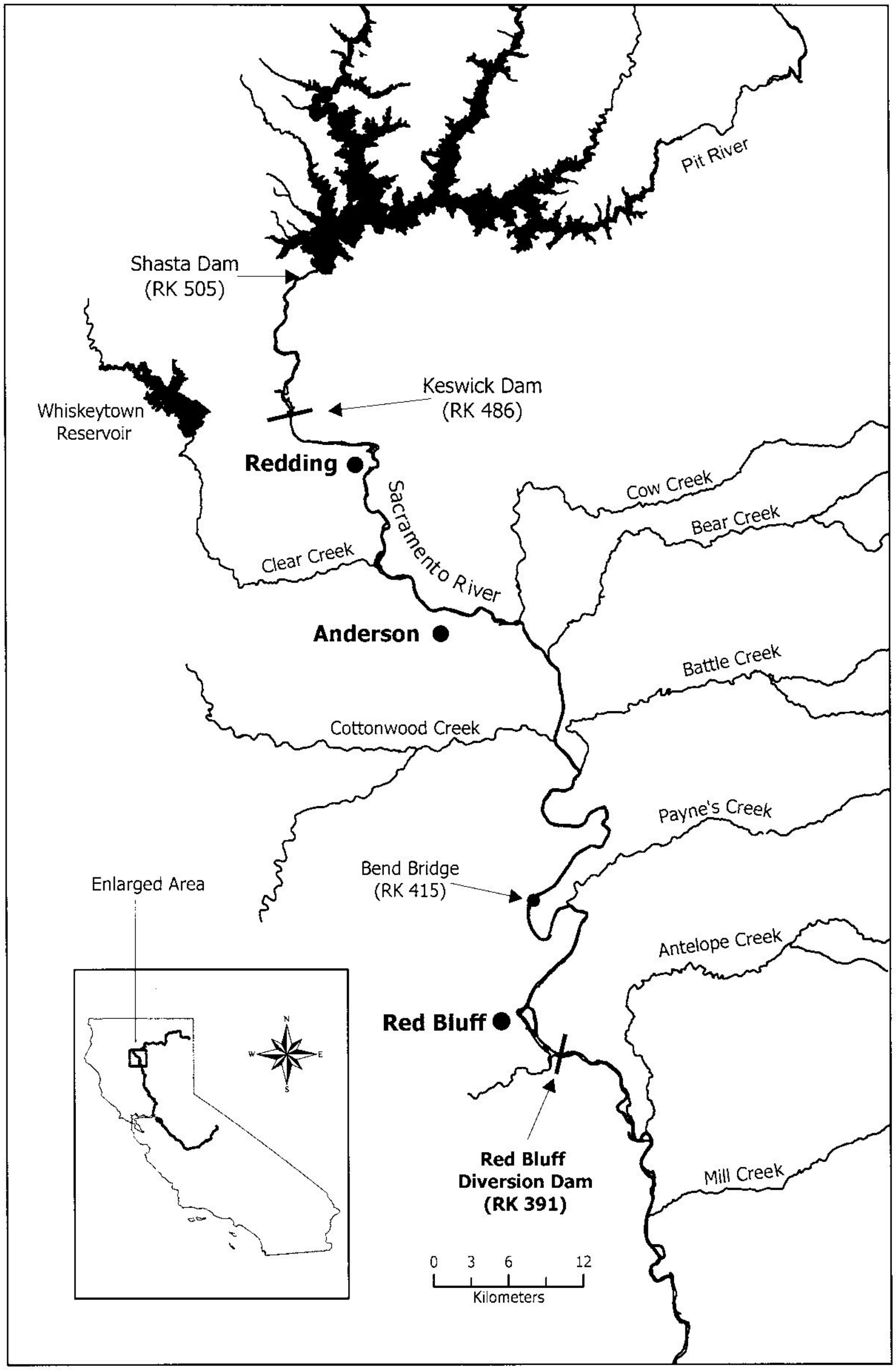

Figure 1. Location of Red Bluff Diversion Dam on the Sacramento River, CA, at river kilometer 391 (RK 391).

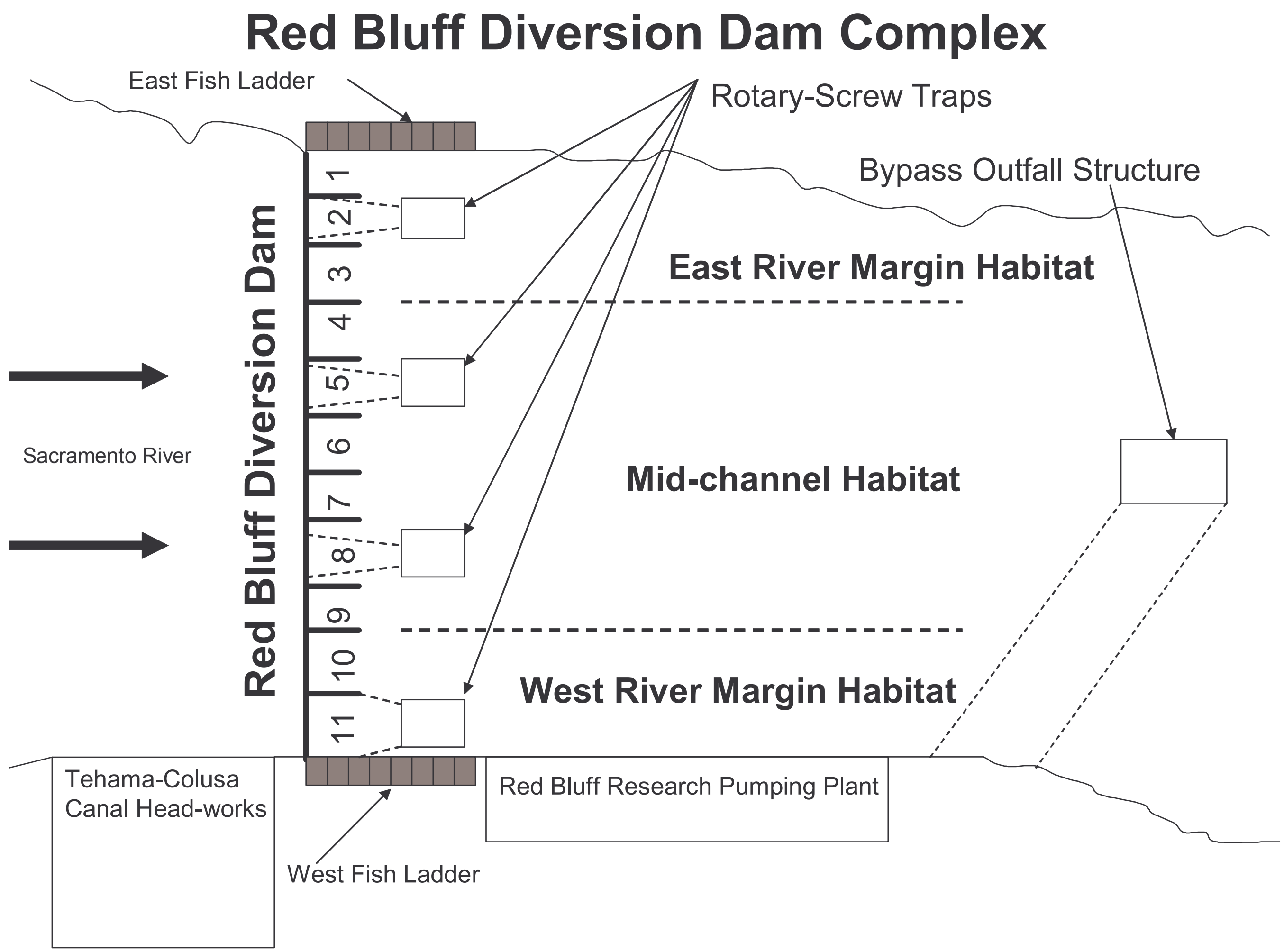

Figure 2. Rotary-screw trap sampling transect at Red Bluff Diversion Dam Complex (RK391) on the Sacramento River, CA.

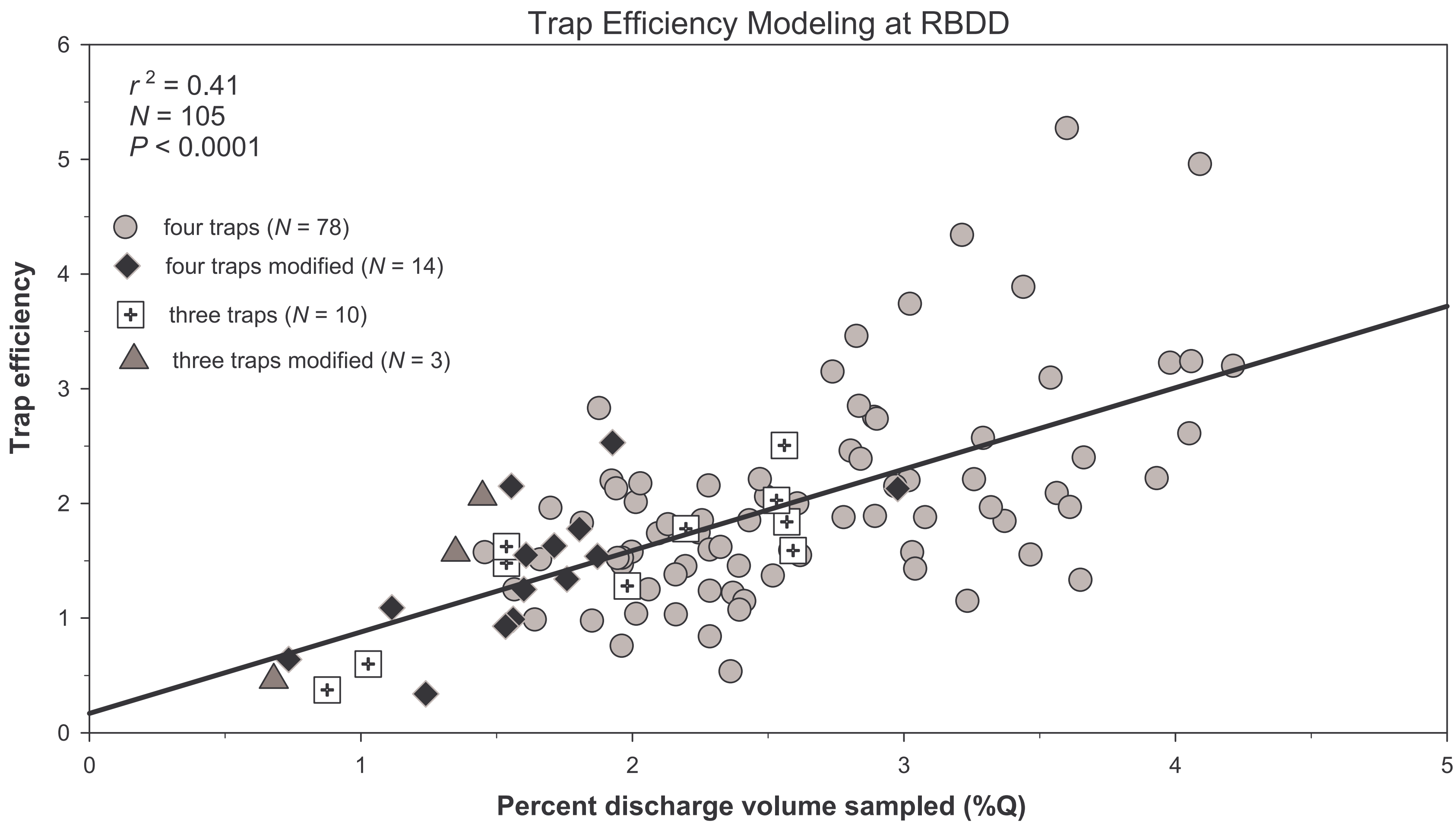

Figure 3. Trap efficiency model for combined 2.4 m diameter rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four traps (*N* = 78), three traps (*N* = 10), or with traps modified to sample one-half the normal volume of water (*N* = 17).

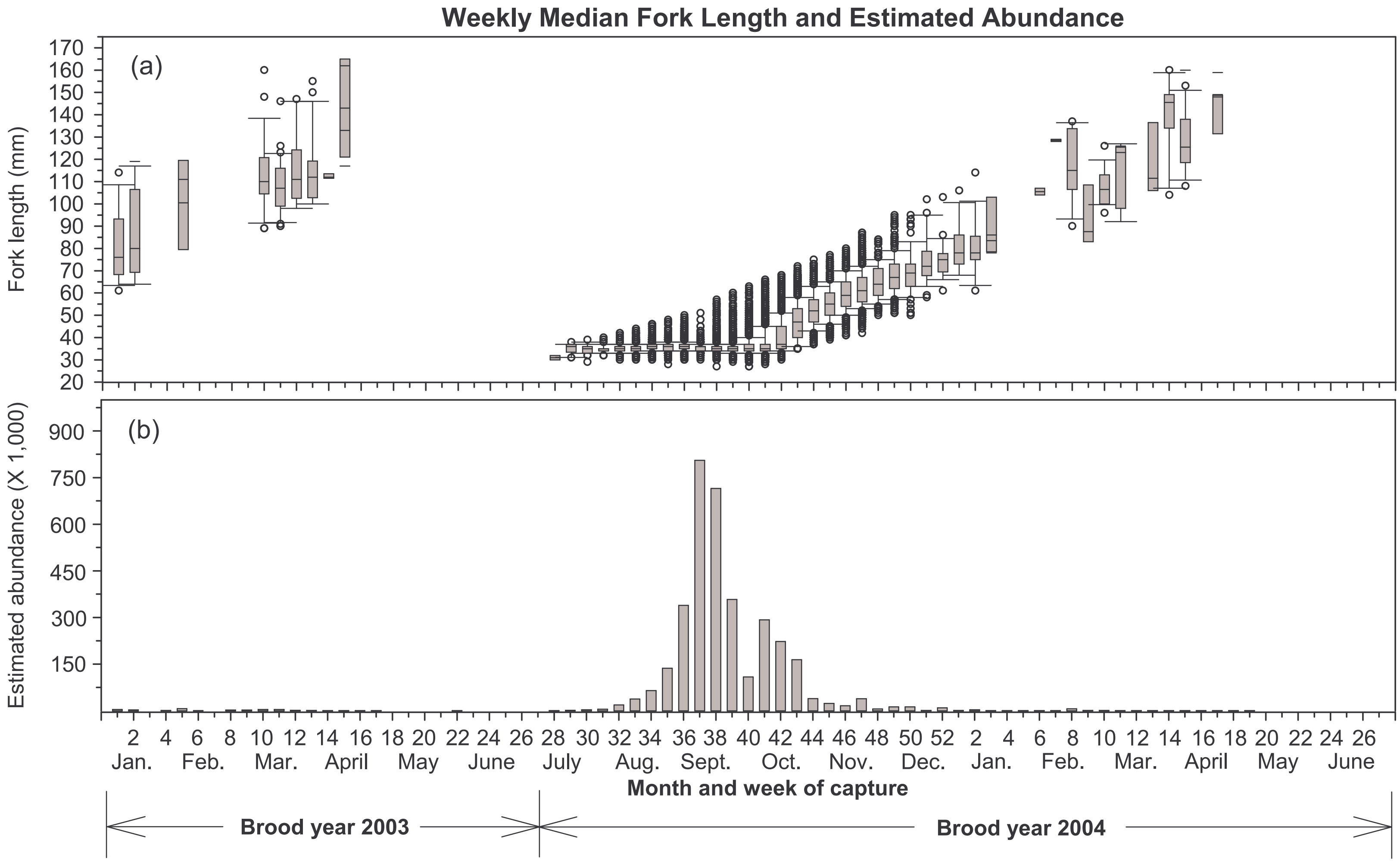

Figure 4. Weekly median fork length (a) and estimated abundance (b) of juvenile winter Chinook salmon passing Red Bluff Diversion Dam (RK391), Sacramento River, CA. Winter Chinook salmon were captured by rotary-screw traps for the period January 1, 2004 through June 30, 2005. Box plots display weekly median fork length, 10th, 25th, 75th and 90th percentiles and outliers.

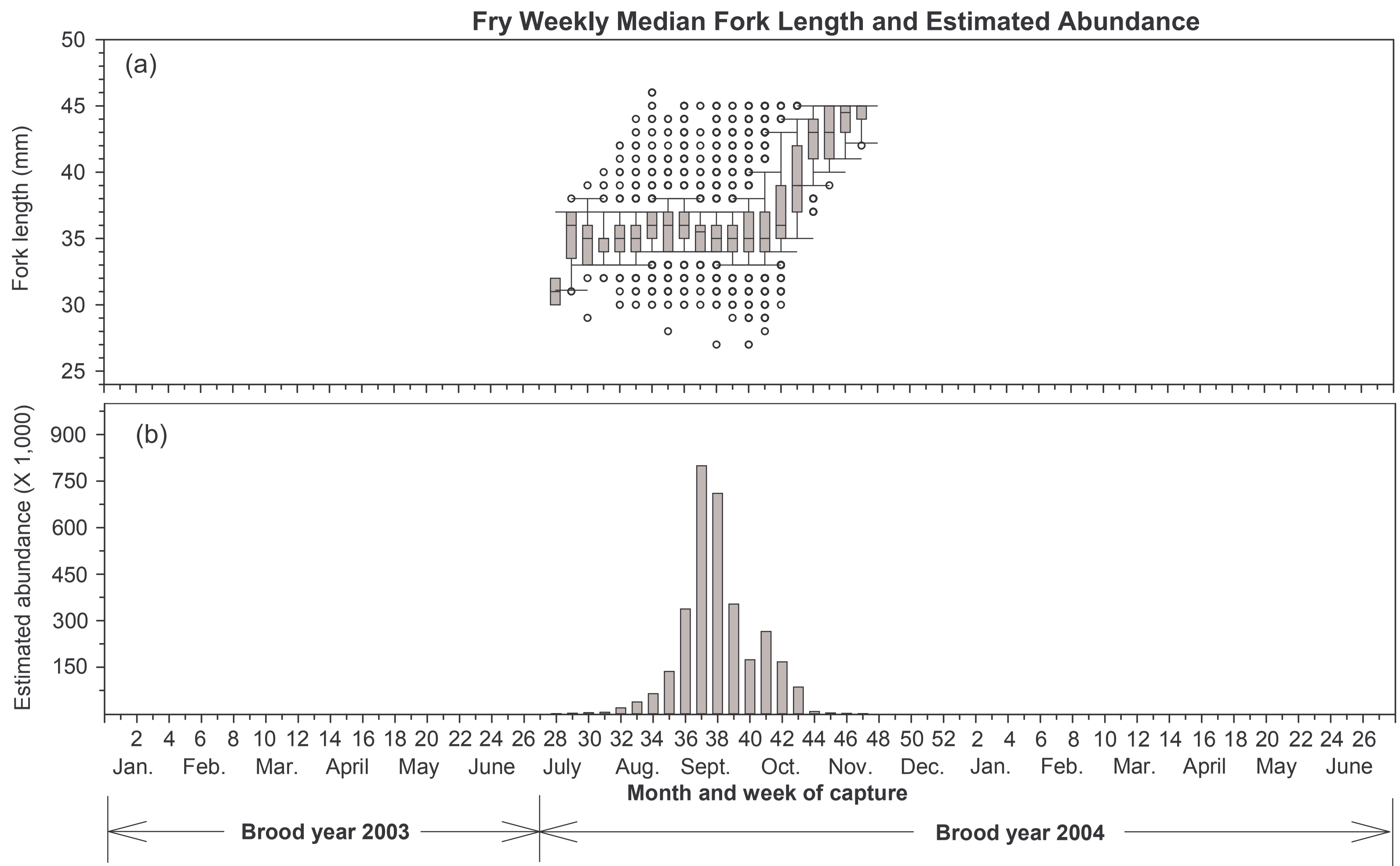

Figure 5. Weekly median fork length (a) and estimated abundance (b) of winter Chinook salmon fry (< 46 mm FL) passing Red Bluff Diversion Dam (RK391), Sacramento River, CA. Winter Chinook juveniles were captured by rotary-screw traps for the period January 1, 2004 through June 30, 2005. Box plots display weekly median fork length, 10^{th}, 25^{th}, 75^{th} and 90^{th} percentiles and outliers.

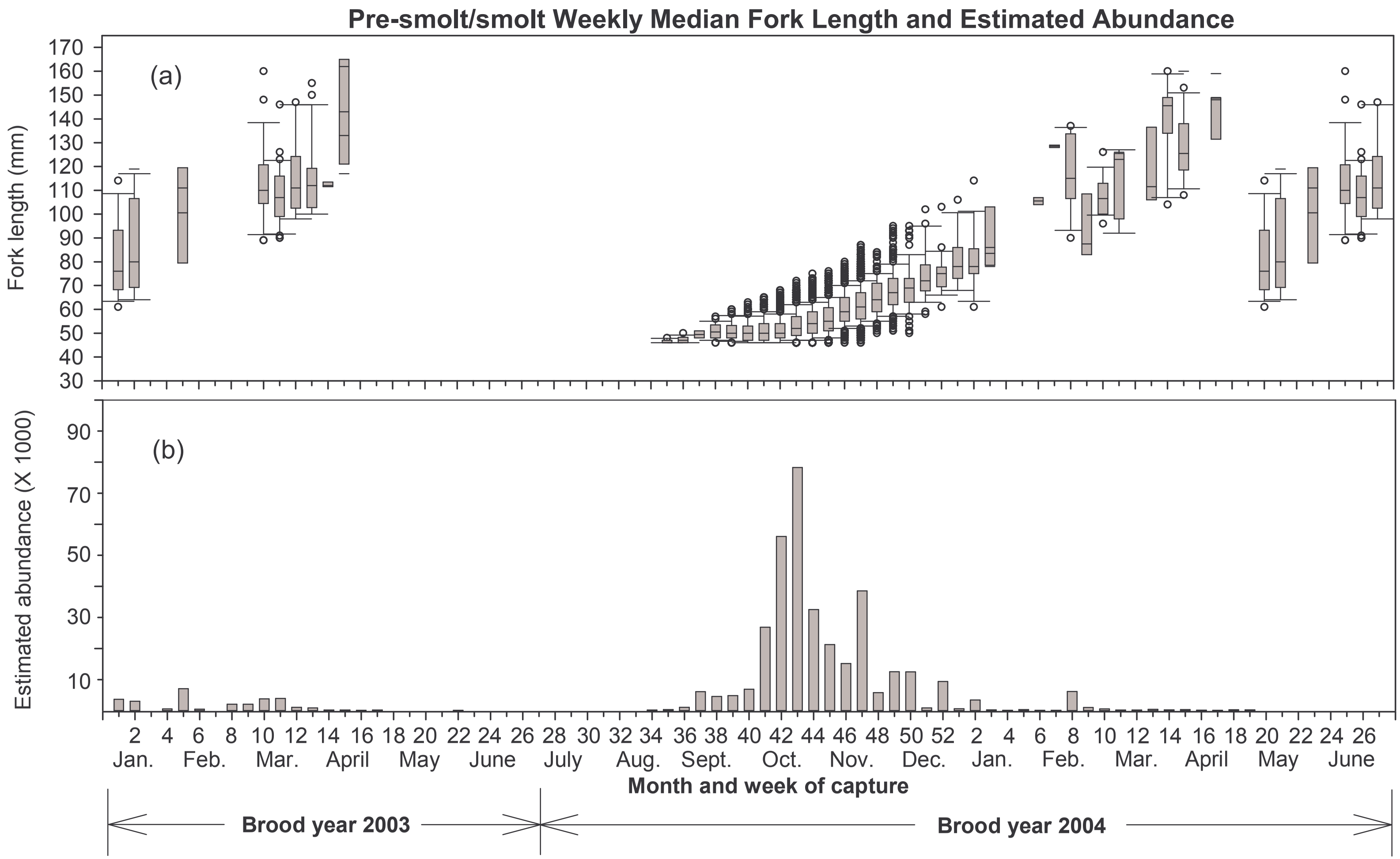

Figure 6. Weekly median fork length (a) and estimated abundance (b) of winter Chinook pre-smolt/smolts (> 45 mm FL) passing Red Bluff Diversion Dam (RK391), Sacramento River, CA. Winter Chinook juveniles were captured by rotary-screw traps for the period January 1, 2004 through June 30, 2005. Box plots display weekly median fork length, 10^{th}, 25^{th}, 75^{th} and 90^{th} percentiles and outliers.

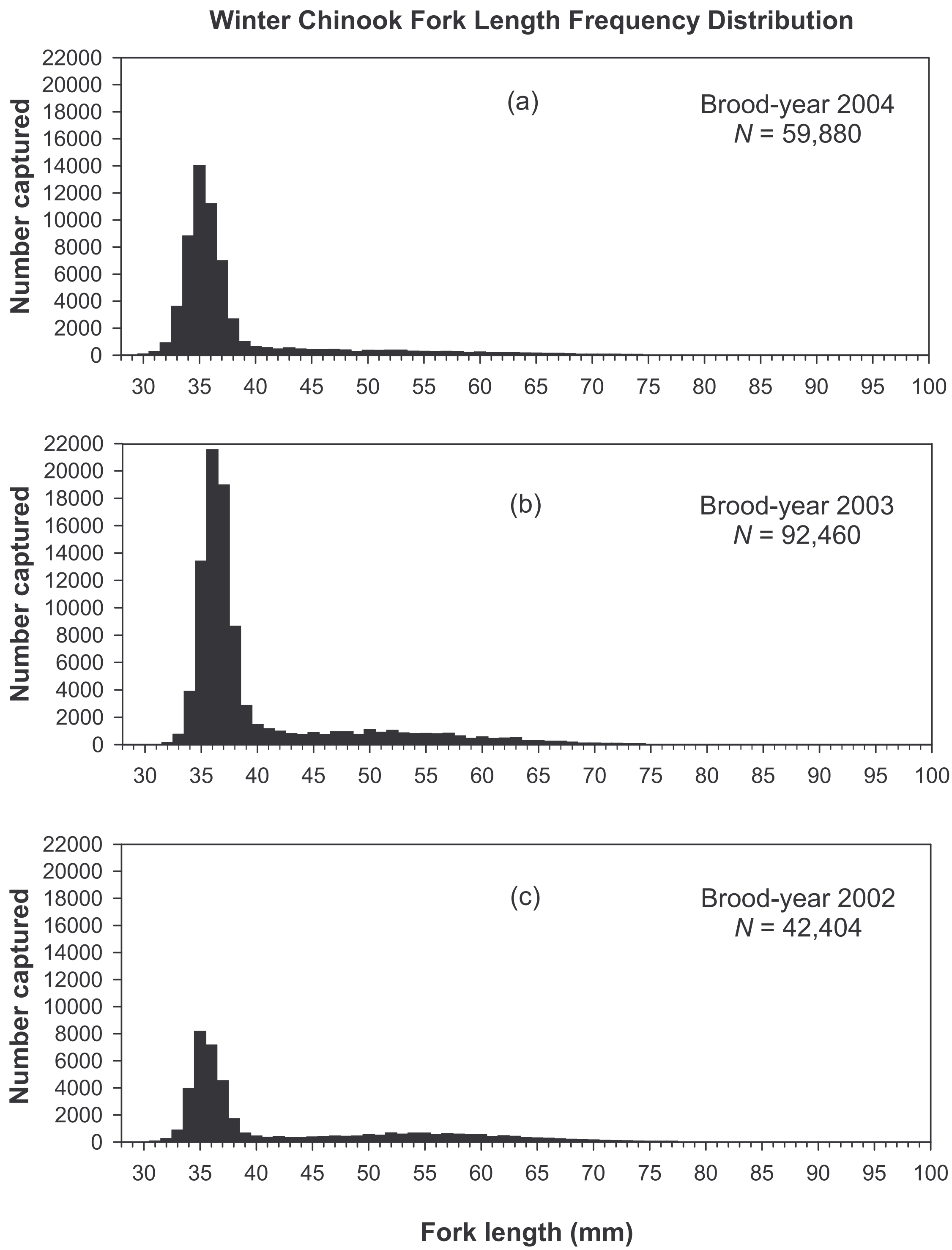

Figure 7. Fork length frequency distributions for (a) brood-year 2004, (b) brood-year 2003 and (c) brood-year 2002 juvenile winter Chinook salmon captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Fork length data was expanded to unmeasured individuals when subsampling protocols were implemented. Sampling was conducted from July 1, 2002 through June 30, 2005.

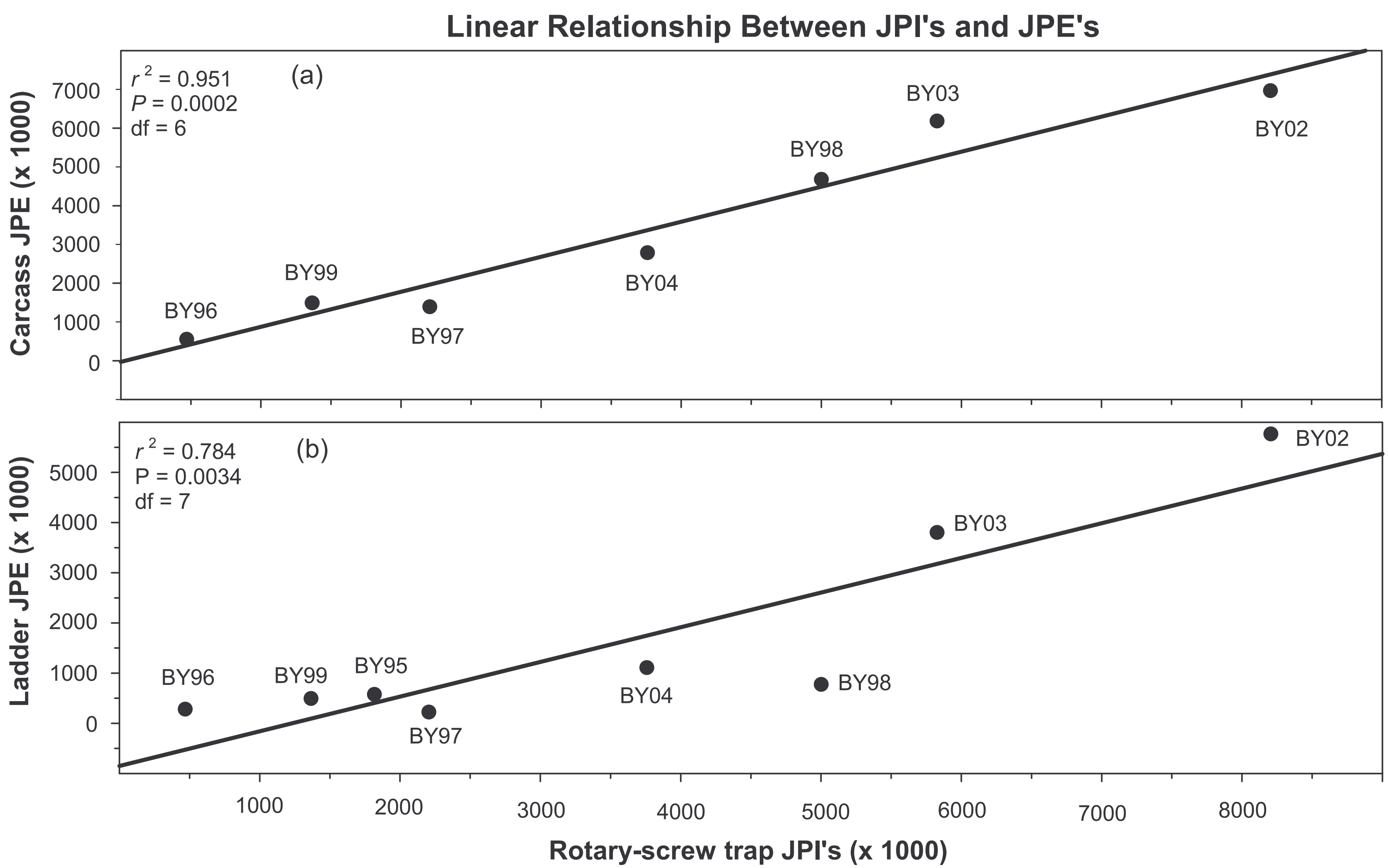

Figure 8. Linear relationship between rotary-screw trap juvenile production indices (JPI) and (a) carcass survey derived juvenile production estimates (JPE) and (b) RBDD ladder count derived JPE's.