BROOD-YEAR 2005 WINTER CHINOOK JUVENILE PRODUCTION INDICES WITH COMPARISONS TO JUVENILE PRODUCTION ESTIMATES DERIVED FROM ADULT ESCAPEMENT

Prepared for:
California Bay-Delta Authority
Final Annual Report 2005
Project Number ERP-01-N44

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February 2007

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The correct citation for this report is:

Poytress, W. R. 2007. Brood-year 2005 winter Chinook juvenile production indices with comparisons to juvenile production estimates derived from adult escapement. Report of U.S. Fish and Wildlife Service to California Bay-Delta Authority, San Francisco, CA.

Brood-year 2005 winter Chinook juvenile production indices with comparisons to juvenile production estimates derived from adult escapement

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Abstract.— Brood-year 2005 juvenile winter-run Chinook salmon passage at Red Bluff Diversion Dam (RBDD) was 8,361,493 fry and pre-smolt/smolts combined, representing a 9% increase in that observed during the passage of this cohort in brood-year 2002. Fry-equivalent production was 8,941,241 representing the highest estimate of juvenile production monitored by the project since its inception. 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 were correlated strongly in trend, albeit less than in previous years, to carcass survey JPE's (r^2 = 0.89, P < 0.001, df = 7) and to a lesser extent rotary trap JPI's were correlated to fish ladder JPE's (r^2 = 0.67, P = 0.007, df = 8). Paired comparisons revealed a significant difference in production estimates between JPI's and fish ladder JPE's (t = 3.92, P = 0.004, df = 8) with fish ladder JPE's falling below the lower 90% confidence interval (C.I.) about the rotary trap JPI in 2005. Conversely, no significant difference was detected between rotary trap JPI's and carcass survey JPE's (t = -0.10, P = 0.927, df = 7), yet the 2005 carcass survey JPE *exceeded* the upper 90% C.I. about the rotary trap JPI for the first time. In comparison, the 2005 NOAA Fisheries JPE model overestimated juvenile winter-run Chinook salmon production by 35% using carcass survey data while underestimating juvenile production by 69% using RBDD fish ladder escapement estimates.

Table of Contents

List of Tables

Table **Page**

List of Figures

Figure **Page**

List of Figures continued

Figure **Page**

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 estimated to be entering the Delta 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, 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 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. 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

[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).

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 (Reiser and White 1988, Botsford and Brittnacher 1998). The overall result being the production of fewer juveniles than the JPE 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) 2005 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 July 1, 2005 through June 30, 2006. The report, therefore, includes JPI's for the complete 2005 brood-year emigration period. 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 has 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 is composed of eleven, 18 m wide fixed-wheel gates. 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 generally 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 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 checked/serviced once daily. During periods of high winter Chinook abundance, elevated river flows, or heavy debris loads traps were checked/serviced multiple times per day or continuously to reduce 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 with fork lengths (FL) measured (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 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

[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.

from the California Data Exchange Center's Bend Bridge gauging station (http://cdec2.water.ca.gov/cgi-progs/queryFx?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 4 km upstream from RBDD. 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.

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 110 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. $$\hat{T}_d = (0.007162)(\%Q) + 0.001383$$

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. $$Var(\hat{P}) = (1-\frac{n}{N})\frac{N^2}{n}s_{\hat{P}_d}^2 + \frac{N}{n}\left[\sum_{d=1}^{n}Var(\hat{P}_d) + 2\sum_{i\neq j}^{n}Cov(\hat{P}_i,\hat{P}_j)\right]$$

The first term in eq. 7 is associated with sampling of days within the week.

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

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

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

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 (> 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 throughout the 2005 brood-year emigration period ranged from 0.00 to 1.00 ($\bar{x}$ = 0.62, N = 52 weeks; Table 1). Weekly sampling effort ranged from 0.00 to 1.00 ($\bar{x}$ = 0.87, N = 26 weeks) between July and December, the period of greatest juvenile winter Chinook emigration, and 0.00 to 0.93 ($\bar{x}$ = 0.38, N = 26 weeks) during the latter half of the emigration period (Table 1).

Trap efficiency trials.—Five mark-recapture trials were conducted primarily using fry sized naturally produced Chinook during 2005/2006 to estimate rotary-screw trap efficiency (Table 2). Sacramento River discharge sampled during the trials ranged from 8,639 to 12,317 cfs. Estimated *%Q* during trap efficiency trials ranged from 1.83% to 3.20% ($\bar{x}$ = 2.44 %; Table 2).

Trials were conducted with RBDD gates lowered (N = 1), RBDD gates raised (N = 4), rotary traps modified to sample with half cones (N = 2), unmodified (standard cone; N = 3), and while sampling with 4 traps (N = 5). All trials were conducted using Chinook sampled from rotary traps, and trap efficiencies ranged from 0.88 to 2.53% ($\bar{x}$ = 1.55%). The number of marked fish released per trial ranged from 1,437 to 1,610 ($\bar{x}$ = 1,543) and the number of marked fish recaptured after release ranged from 14 to 38 ($\bar{x}$ = 24). All fish were released at sunset and 98% of recaptures occurred within the first 24 hours and 100% within 48 hours.

Fork lengths of fish marked and released ranged from 31 to 46 mm ($\bar{x}$ = 36.3 mm). Fork lengths of recaptured marked fish ranged from 33 to 46 mm ($\bar{x}$ = 36.5 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 = 0.646).

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 was unchanged from that in 2004 (Poytress et al. 2006) with the addition of 5 trials conducted during brood-year 2005 ($r^2 = 0.41$; Figure 3).

Patterns of Abundance.—Brood-year 2005 winter Chinook juvenile passage at RBDD was 8,361,493 fry and pre-smolt/smolts combined (Table 3). Peak passage of winter Chinook juveniles occurred predominantly during weeks 38 through 41, the latter half of September and first half of October (Figure 4b).

Brood-year 2005 fry size class (<46 mm FL) juveniles began to pass RBDD during week 28 (mid-July) and weekly passage increased progressively throughout September (Table 3). Weekly juvenile passage increased from 868 to 4,064 in July, 6,049 to 241,575 in August, 474,250 to 2,083,214 in September and then generally declined through November. The peak weekly passage estimate occurred in week 39 and comprised 28% of the annual estimate (Figure 5b).

Brood-year 2005 pre-smolt/smolt sized (>45 mm FL) juveniles began to emigrate past RBDD in week 34 (late August). Weekly passage increased consistently through week 43 and peaked sharply in week 45 (early November) at 226,612 (Table 3). Weekly passage generally declined through week 52 of 2005 with minor increases in passage through week 18 (May) of 2006 (Figure 6b).

Weekly median fork length of brood-year 2005 winter Chinook increased slowly from 34.5 mm in week 28 to 37.0 mm in week 42 (Table 3). Median fork lengths increased rapidly from 42.0 mm in week 43 to 68.0 mm in week 51 and steadily increased, thereafter, to 128.0 mm in week 16 (Figure 4a). Brood-year 2005 fry winter Chinook median fork lengths ranged from 34.5 mm in week 28 to 45.0 mm in week 48 (Figure 5a). Brood-year 2005 pre-smolt/smolt median fork length ranged from 47.5 to 54.0 mm from week 34 to 45, increasing by 0.59 mm per week on average (Figure 6a). From week 46 to 51, however, average weekly median fork length increase was 2.0 mm per week from 58.0 to 68.0 mm. The length frequency distribution of brood-year 2005 juveniles captured at RBDD was composed primarily of 33.0 to 39.0 mm FL individuals (85%; Figure 7), representing 90.1% of total passage. Pre-smolt/smolt sized individuals represented 7.0% of brood-year 2005 winter Chinook juveniles captured at RBDD and 9.9% of total passage (Table 3). Estimated passage of brood-year 2005 pre-smolt/smolts passing after December 31, 2005 was 0.5% of total annual passage.

Comparison of JPI and JPE. —The fry-equivalent rotary trap JPI for brood-year 2005 was 8,941,241. The NOAA Fisheries brood-year 2005 fry-equivalent carcass survey and fish ladder JPE's were 12,109,474 and 2,766,151, respectively. Neither the carcass survey JPE nor the fish ladder JPE fell within the 90% C.I. about the rotary trap JPI (Table 4). In direct comparison, the carcass survey JPE was 35% greater while the fish ladder JPE was 69% less than the JPI.

We combined data from 1995 to 2004 with brood-year 2005 JPE's and JPI's to evaluate the linear relationship between the estimates. Eight 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. Nine observations were available to evaluate using RBDD ladder data (1995-1999, 2002-

2005). Rotary trap JPI's were significantly correlated *in trend* to carcass survey JPE's (r^2 = 0.89, P < 0.0005, df = 7; Figure 8a) and to a lesser extent fish ladder JPE's (r^2 = 0.67, P = 0.0073, df = 8; 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 = 3.92, P = 0.004, df = 8). Moreover, the 2005 fish ladder JPE fell below the lower 90% C.I. about the rotary trap JPI, similar to the trend seen in the previous seven out of eight years (Table 4). On average, fish ladder JPE's were 61% 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 = -0.10, P = 0.927, df = 7), even though the 2005 carcass survey JPE *exceeded* the 90% C.I. about the rotary trap JPI by 0.62% for the first time since evaluations have been conducted. On average, carcass survey JPE's were 3% less than rotary trap JPI's (range = -37 to +17%).

Discussion

Sampling effort.—Weekly sampling effort was highly variable in 2005 (Table 1). Effort was reduced during the peak period of winter Chinook passage by reducing the amount of water volume sampled by the rotary trap cones. Modification of rotary trap cones (Gaines and Poytress 2004) was performed to reduce reliance on sub-sampling techniques and to reduce capture of Endangered winter Chinook salmon while maintaining the accuracy of passages estimates. Traps were modified during weeks 39 through 42 in the two mid-channel habitat traps (Figure 2). From July through December 2005, the foremost winter Chinook emigration period, rotary-screw traps sampled 24 h daily on 166 of 184 days. Six days were not sampled in mid September due to RBDD operations associated with the annual draw-down of Lake Red Bluff. The remaining twelve days were not sampled due to high discharge and debris flow conditions associated with rain events, primarily during the last two weeks of December (Figure 9). Sampling effort between January and June of 2006 was highly variable with eight complete weeks unsampled due to high river discharge and associated debris (Figure 9).

Trap efficiency modeling.—On 3 occasions in 2005 and 2 occasions in the first half of 2006, we measured the efficiency of our rotary-screw traps by conducting mark-recapture trials. Data from trials were combined with data from 105 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 unchanged from that reported in Poytress et al. 2006. Trials were not conducted as frequently as in recent years (Gaines and Poytress 2004, Poytress et al. 2006) due primarily to high river discharge events. However, there continued to be substantial variability in trap efficiency that was not explained by %Q.

Patterns of abundance.—Brood-year 2005 winter Chinook juvenile passage at RBDD, from July 1, 2005 through June 30, 2006, was 8,361,493 fry and pre-smolt/smolts combined, representing the highest value of juvenile passage since the program's inception (Martin et al 2001, Poytress et al. 2006). Peak passage, representing 69% of the annual total estimate, occurred within a four week period in the last half of September and first half of October. Weekly passage values during the peak abundance period were estimated to be between 1,041,994 and 2,115,018 individuals per week (Table 3). Overall, estimated passage of brood-year 2005 winter Chinook represented approximately 137% more juveniles passing RBDD than that observed in 2004 and 58% more than was observed in 2003 (Poytress et al. 2006). In comparison to brood-year 2002, estimated passage was 9.2% greater in 2005 representing a juvenile cohort replacement rate of 1.09.

Interestingly, between October and December (week 45), the first storm event of the fall season produced a rise in discharge volume and increased turbidity (Figure 9) resulting in a substantial increase of pre-smolt/smolt winter Chinook passage (Table 3). Passage associated with this single event equated to 27% of the total estimated pre-smolt/smolt passage for the year providing evidence that initial storm events may be an important cue for juvenile winter Chinook migration out of the upper Sacramento River.

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 2005, fry size class individuals composed 90% of passage and therefore the calculation of 1.7 fry:1 pre-smolt smolt (based on estimated 59% fry to smolt survival; Hallock undated) calculation had a nominal effect 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 production values ($t = 3.93$, $P = 0.004$, df = 8). Furthermore, it appears that fish ladder JPE's continued to *greatly* 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 2005 data ($t = -0.10$, $P = 0.927$, df = 7).

Poytress et al. (2006) indicated that the rotary-screw trap JPI was strongly correlated in trend to carcass survey JPE's ($r^2 = 0.95$), and to a lesser extent, fish ladder JPE's ($r^2 = 0.78$). For the second consecutive year the addition of new data resulted in a weakening of the relationship for the carcass survey ($r^2 = 0.89$, df = 6; Figure 8a) *and* the fish ladder JPE’s ($r^2 = 0.67$, df = 7; Figure 8b). Moreover, the 2005 JPE *exceeded* the 90% C.I. about the JPI for the first time in eight years of evaluation, albeit slightly (0.62%). As a note, the brood-year 2005 NOAA Fisheries JPE model returned to using an average annual fecundity value derived from winter Chinook propagated at the Livingston Stone National Fish Hatchery (Bruce Oppenheim, NOAA Fisheries, personal comment). Interestingly, the carcass survey JPE was found to be 35% greater than the rotary trap JPI in 2005, whereas the 2004 JPE was found to be 26% less than the 2004 JPE using an alternate fecundity value. Overall, by direct comparison the 2005 NOAA Fisheries JPE model using carcass survey data overestimated juvenile production by 35%

and underestimated juvenile production by 69% using RBDD fish ladder escapement estimates.

Acknowledgments

Funding for this project was provided by the California Bay-Delta Authority (contract # ERP-01-N44). Numerous individuals helped with development and implementation of this project including, but not limited to, Oliver "Towns" Burgess, Felipe Carrillo, Nicholas Demetras, Melissa Dragan, Jessica Fischer, Josh Gruber, James Hoang, Tammy Knecht, Edwin Martin, Andy Popper, Gregory True and Kara Yetishefsky. Logistical and programmatic support was provided by Karen Mayhew, Deon Pollett, Jim Smith, Angela Taylor, Keenan True, Beverly Wesemann and especially Tom Kisanuki. We sincerely appreciate the support provided by the U.S. Bureau of Reclamation and all Red Bluff Diversion Dam staff, especially Robert Bagshaw, Ed Henderson, and Paul Freeman. The author received valuable advice on various aspects of the project from Phillip Gaines and Craig Martin.

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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 <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. Modifying traps to sample less water volume was implemented to reduce catch and associated impact on winter Chinook salmon during periods of peak migration and river discharge. A winter Chinook brood-year (BY) is identified as beginning on July 1 and ending on June 30.

Sampling effort			
Week	BY 2005	Week	BY 2005
27 (Jul)	1.00	1 (Jan)	0.00
28	0.96	2	0.00
29	0.96	3	0.39
30	1.00	4	0.88
31 (Aug)	1.00	5 (Feb)	0.43
32	1.00	6	0.48
33	1.00	7	0.93
34	1.00	8	0.75
35 (Sep)	1.00	9 (Mar)	0.21
36	1.00	10	0.00
37	0.71	11	0.18
38	0.32	12	0.93
39	0.75	13 (Apr)	0.71
40 (Oct)	0.75	14	0.00
41	0.75	15	0.00
42	0.93	16	0.68
43	1.00	17	0.82
44 (Nov)	1.00	18 (May)	0.29
45	0.86	19	0.43
46	1.00	20	0.00
47	1.00	21	0.00
48 (Dec)	0.96	22 (Jun)	0.00
49	1.00	23	0.11
50	1.00	24	0.21
51	0.57	25	0.71
52	0.00	26	0.71

Table 2.—Summary of results from mark-recapture trials conducted in 2005 ($N = 3$) and 2006 ($N = 2$) to evaluate 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	2005	1,437	35.59	14	36.71	0.97	2.16	4	No	Lowered
2	2005	1,587	35.87	14	36.07	0.88	1.83	4	Yes	Raised
3	2005	1,577	35.71	21	36.57	1.33	2.33	4	Yes	Raised
4	2006	1,610	37.40	33	36.29	2.05	3.20	4	No	Raised
5	2006	1,503	37.17	38	36.65	2.53	2.68	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, 2005 through June 30, 2006 (Brood-year 2005). 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 2005			
26	0	-	0	-	0	-	0
27	0	-	0	-	0	-	0
28	868	34.5	0	-	868	34.5	868
29	2,044	36	0	-	2,044	36	2,044
30	4,064	36	0	-	4,064	36	4,064
31	6,049	35	0	-	6,049	35	6,049
32	9,399	35	0	-	9,399	35	9,399
33	13,304	35	0	-	13,304	35	13,304
34	44,961	36	211	47.5	45,172	36	45,320
35	241,575	36	578	47	242,155	36	242,559
36	474,250	36	2,614	49	476,864	36	478,694
37	566,535	35	2,726	47	569,260	35	571,165
38	1,032,278	36	9,718	48	1,041,994	36	1,048,801
39	2,083,214	36	31,805	49	2,115,018	36	2,137,281
40	1,483,109	36	27,233	49	1,510,342	36	1,529,403
41	1,091,328	36	46,886	49	1,138,213	36	1,171,033
42	284,964	36	48,228	52	333,192	37	366,950
43	96,754	38	62,066	54	158,820	42	202,266
44	33,605	42	60,773	54	94,379	49	136,921
45	62,321	43	226,612	54	288,932	51	447,564
46	1,795	44	37,494	58	39,290	57	65,536

Table 3.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
47	828	44	28,874	60	29,701	59	49,912
48	36	45	23,512	60	23,547	60	40,003
49	0	-	69,837	63	69,837	63	118,725
50	0	-	7,884	67	7,884	67	13,401
51	0	-	51,551	68	51,551	68	87,637
52	0	-	48,133	–	48,133	–	81,826
1	0	-	7,572	–	7,572	–	12,871
2	0	-	7,572	–	7,572	–	12,871
3	0	-	7,538	82	7,538	82	12,814
4	0	-	8,688	100.5	8,688	100.5	14,767
5	0	-	2,908	80.5	2,908	80.5	4,943
6	0	-	1,551	81	1,551	81	2,637
7	0	-	1,291	110.5	1,291	110.5	2,195
8	0	-	1,356	115	1,356	115	2,305
9	0	-	577	98	577	98	981
10	0	-	540	–	540	–	918
11	0	-	540	–	540	–	918
12	0	-	222	107	222	107	376
13	0	-	718	117	718	117	1,222
14	0	-	98	–	98	–	168
15	0	-	98	–	98	–	168
16	0	-	185	128	185	128	315
17	0	-	14	–	14	–	24
18	0	-	14	–	14	–	24
19	0	-	0	–	0	–	0
20	0	-	0	–	0	–	0
21	0	-	0	–	0	–	0
22	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
23	0	-	0	–	0	–	0
24	0	-	0	-	0	-	0
25	0	-	0	-	0	-	0
BY total	7,533,282		828,217		8,361,493		8,941,241

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 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 BY05, 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 [d]	# 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 [d]	3,758,790	2,673,168	4,846,169	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

[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 (2000-2005), 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..).

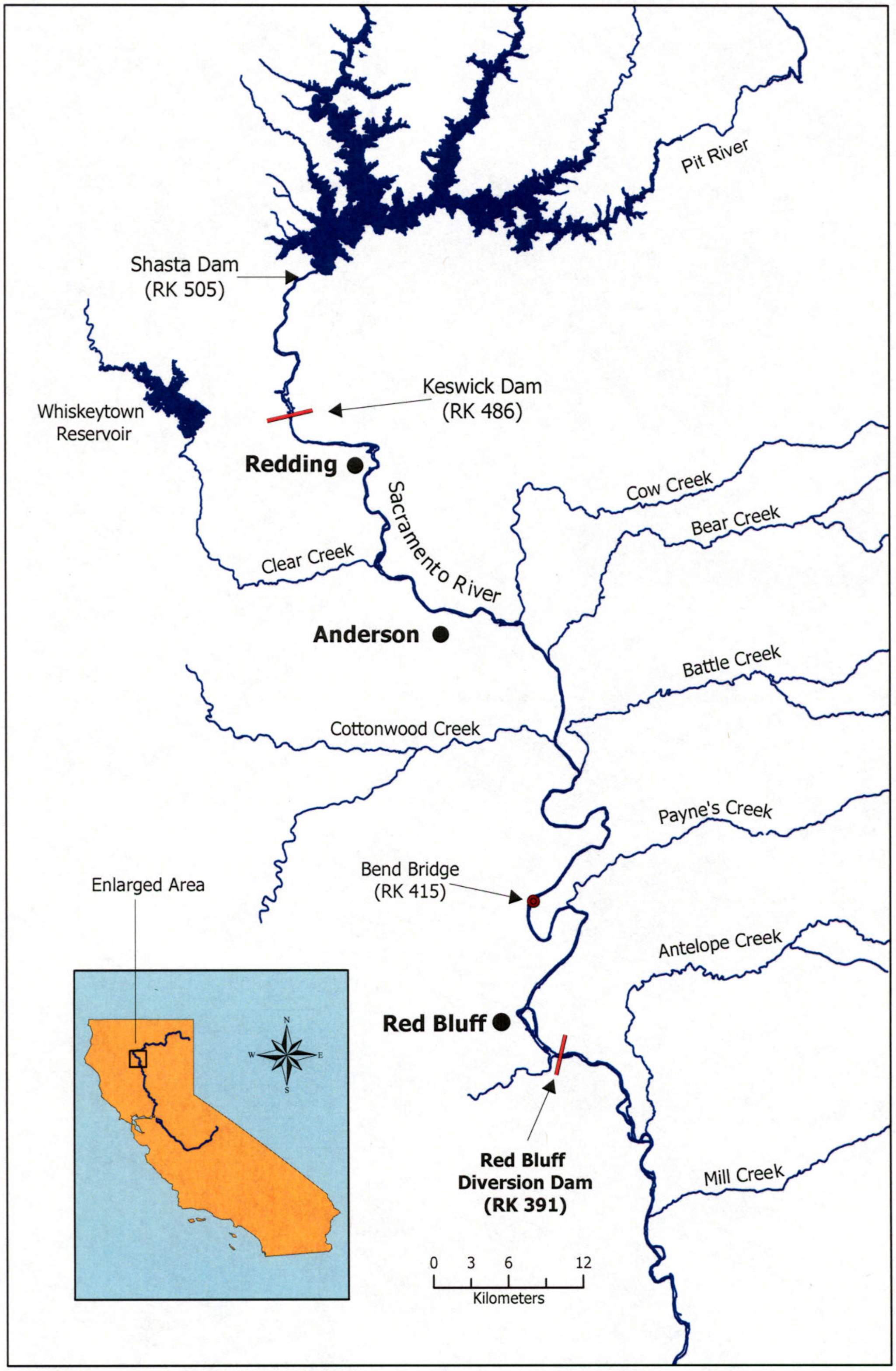

Figure 1. Location of Red Bluff Diversion Dam on the Sacramento River, CA, at river kilometer 391 (RK 391).

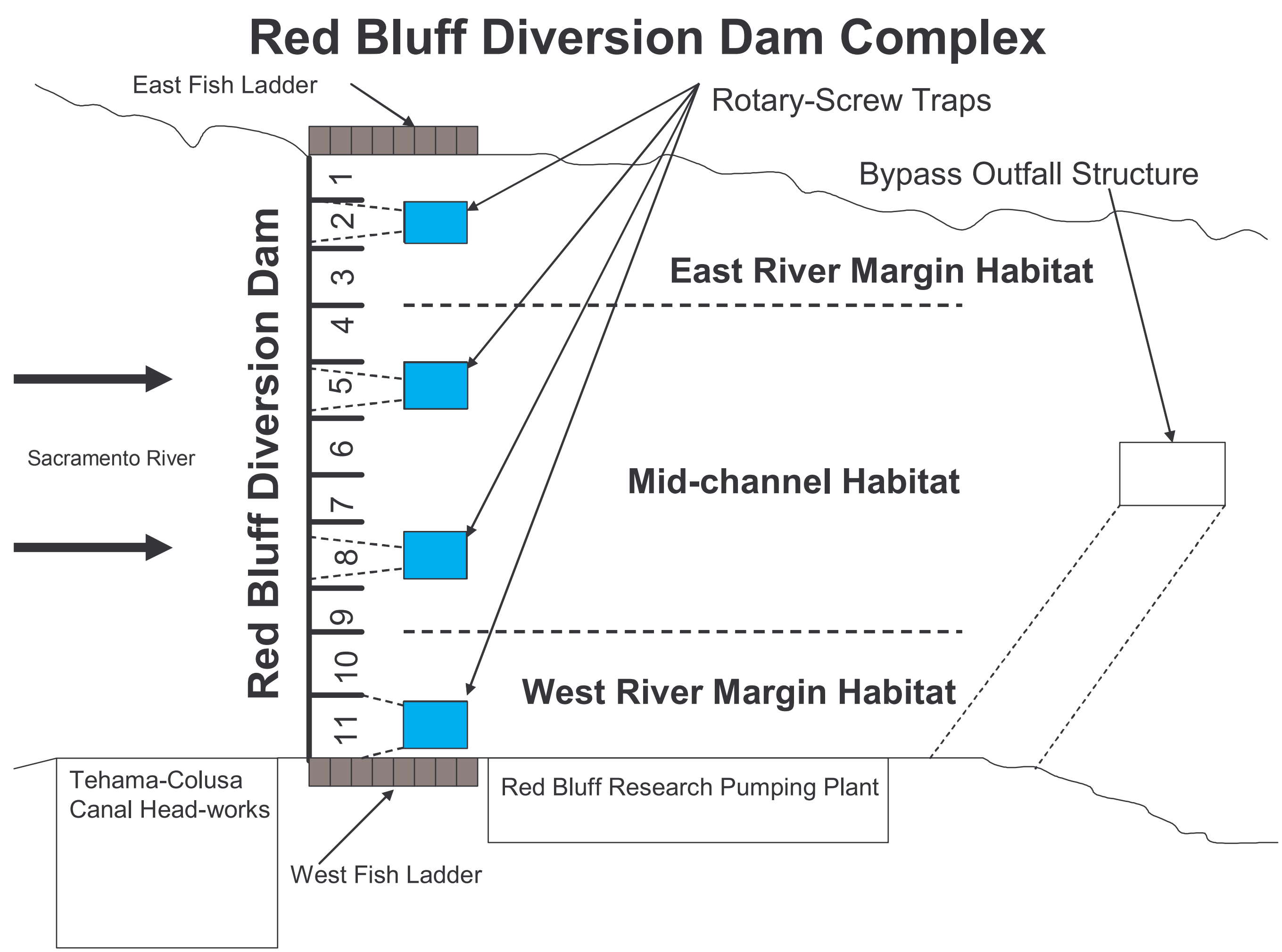

Figure 2. Rotary-screw trap sampling transect at Red Bluff Diversion Dam Complex (RK391) on the Sacramento River, CA.

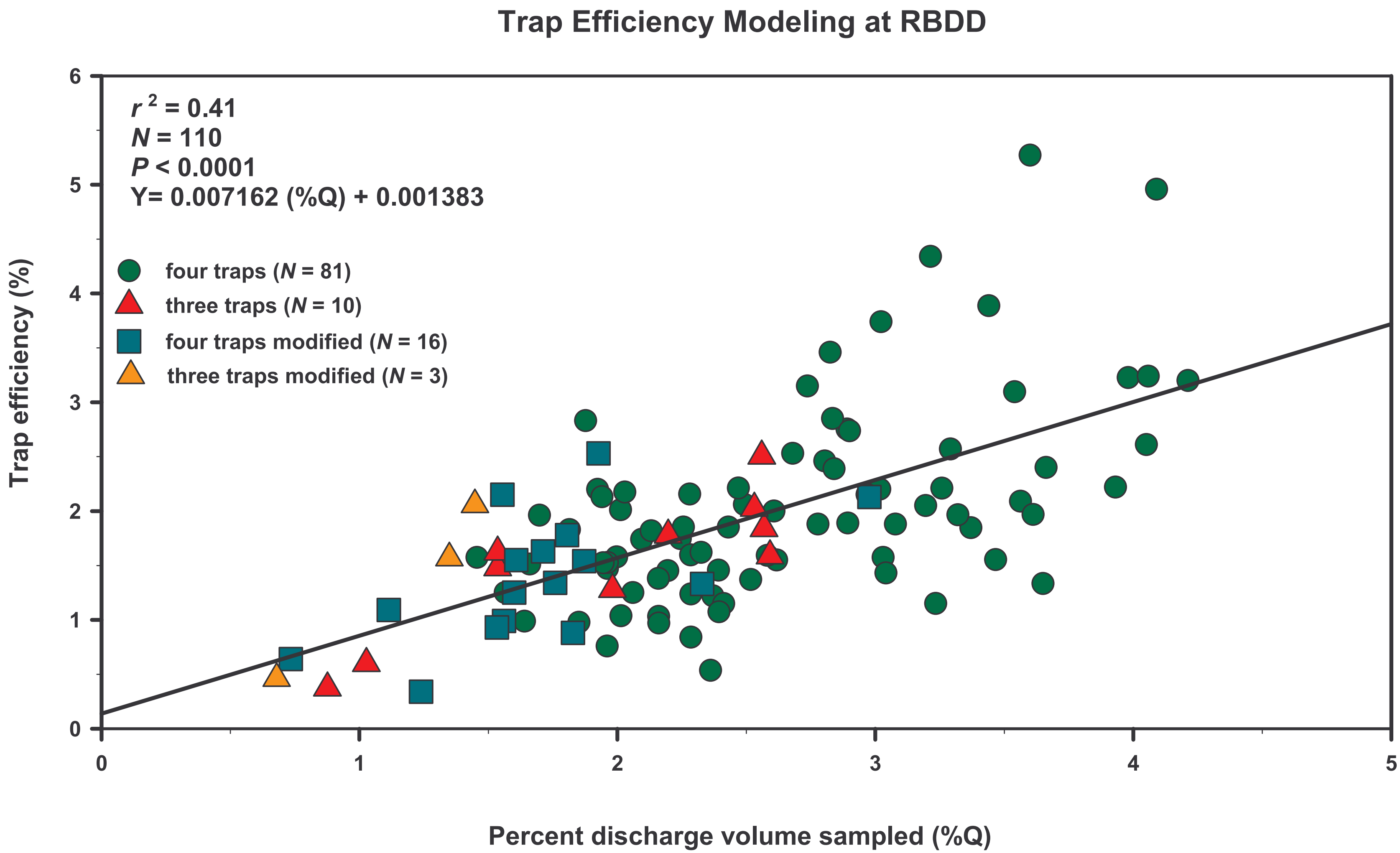

Figure 3. Trap efficiency model for combined 2.4 m diameter rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four traps (N = 81), three traps (N = 10), or with traps modified to sample one-half the normal volume of water (N = 19).

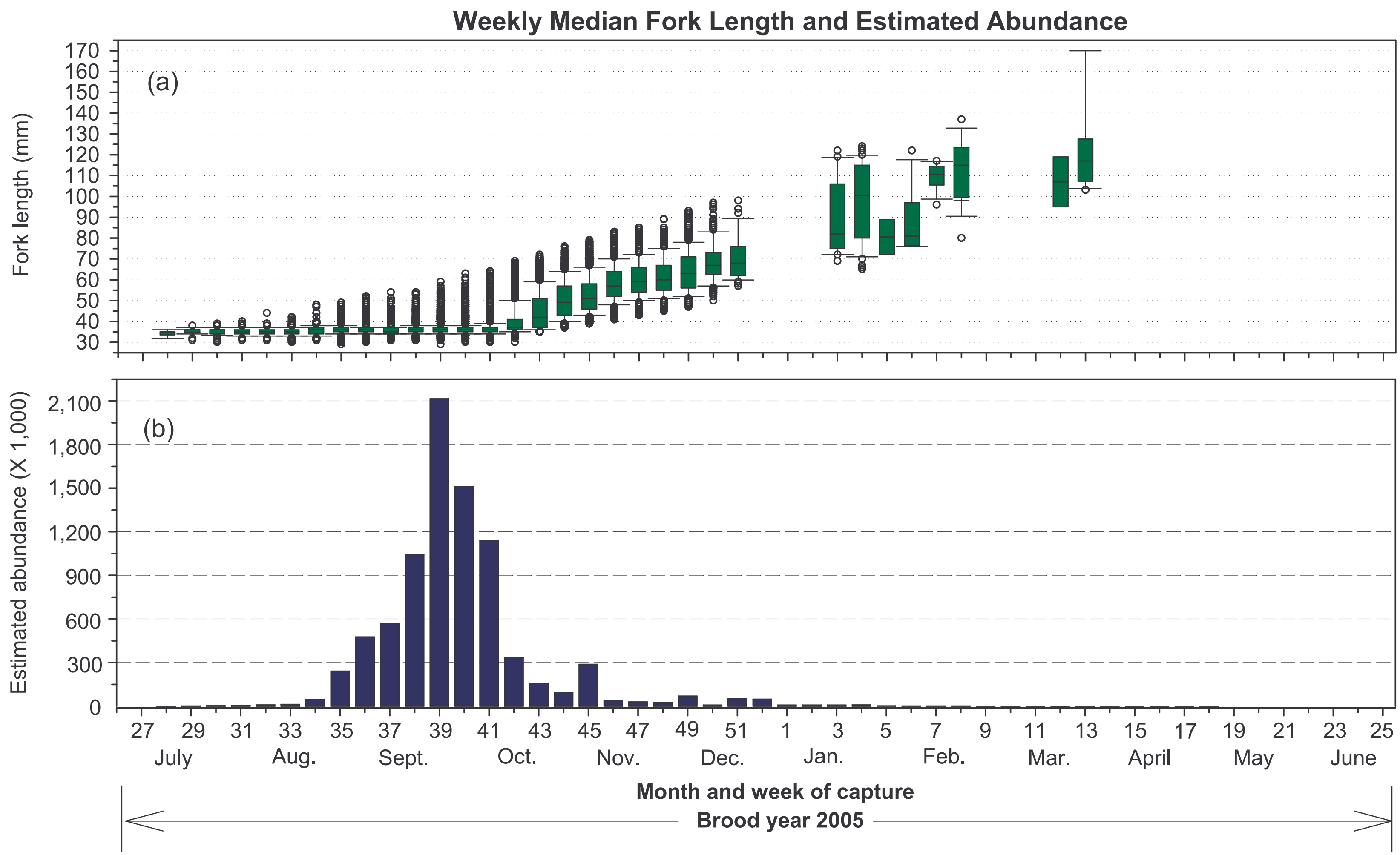

Figure 4. Weekly median fork length (a) and estimated abundance (b) of juvenile winter Chinook salmon passing Red Bluff Diversion Dam (RK391), Sacramento River, CA. Winter Chinook salmon were sampled by rotary-screw traps for the period July 1, 2005 through June 30, 2006. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

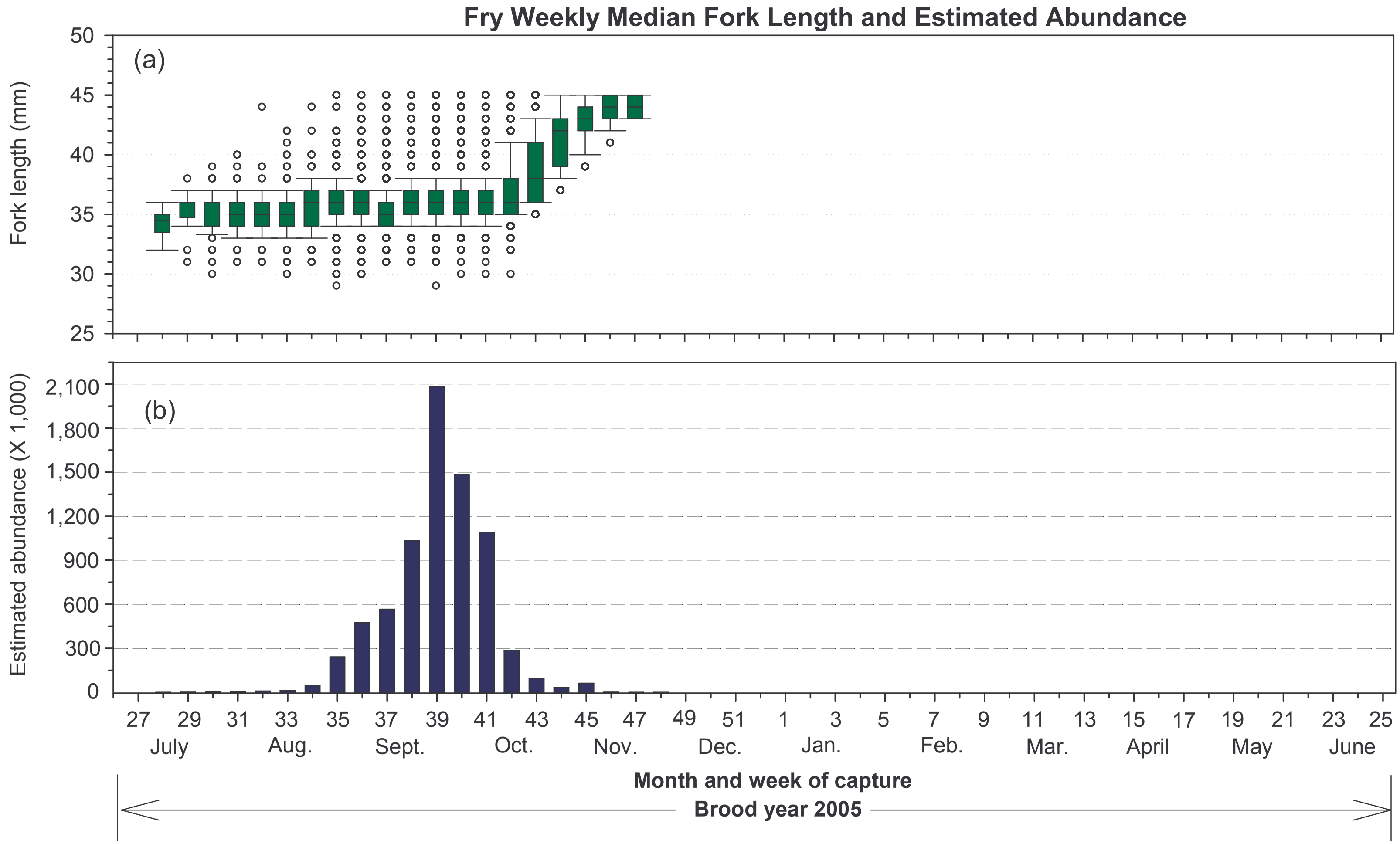

Figure 5. Weekly median fork length (a) and estimated abundance (b) of winter Chinook salmon fry (< 46 mm FL) passing Red Bluff Diversion Dam (RK391), Sacramento River, CA. Winter Chinook juveniles were sampled by rotary-screw traps for the period July 1, 2005 through June 30, 2006. Box plots display weekly median fork length, 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles and outliers.

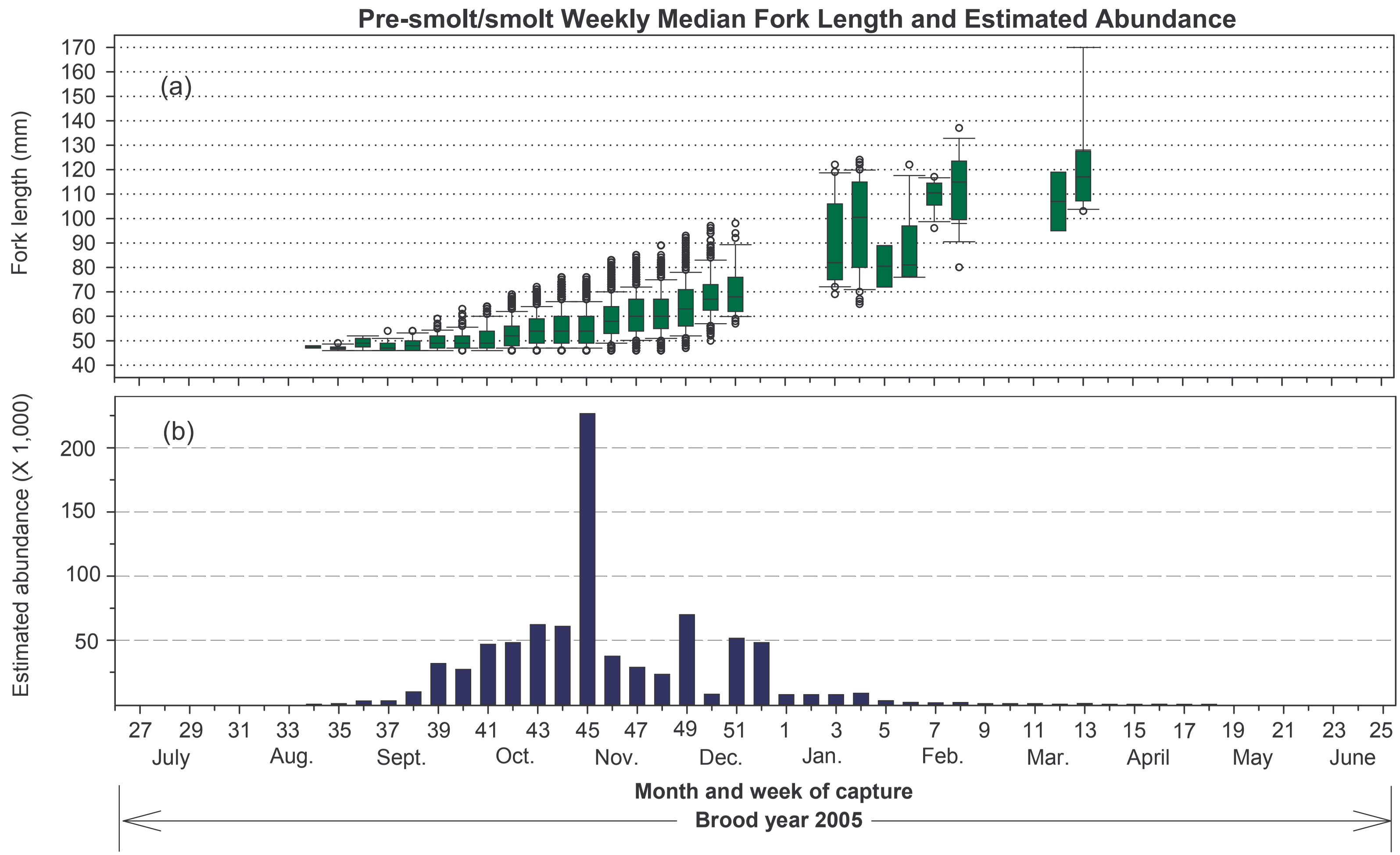

Figure 6. Weekly median fork length (a) and estimated abundance (b) of winter Chinook pre-smolt/smolts (> 45 mm FL) passing Red Bluff Diversion Dam (RK391), Sacramento River, CA. Winter Chinook juveniles were sampled by rotary-screw traps for the period July 1, 2005 through June 30, 2006. Box plots display weekly median fork length, 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles and outliers.

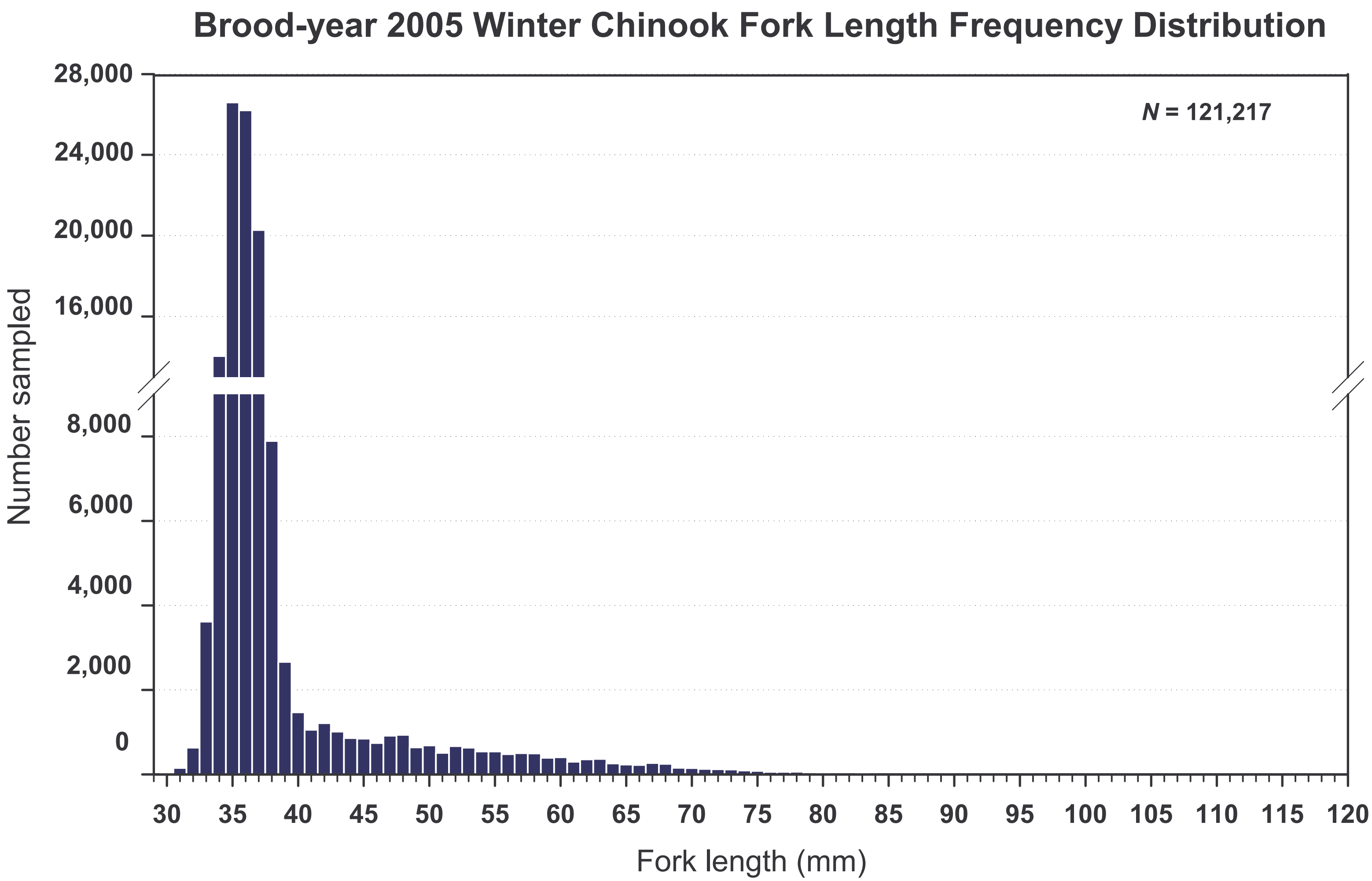

Figure 7. Fork length frequency distribution of brood-year 2005 juvenile winter Chinook salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Fork length data was expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from July 1, 2005 through June 30, 2006.

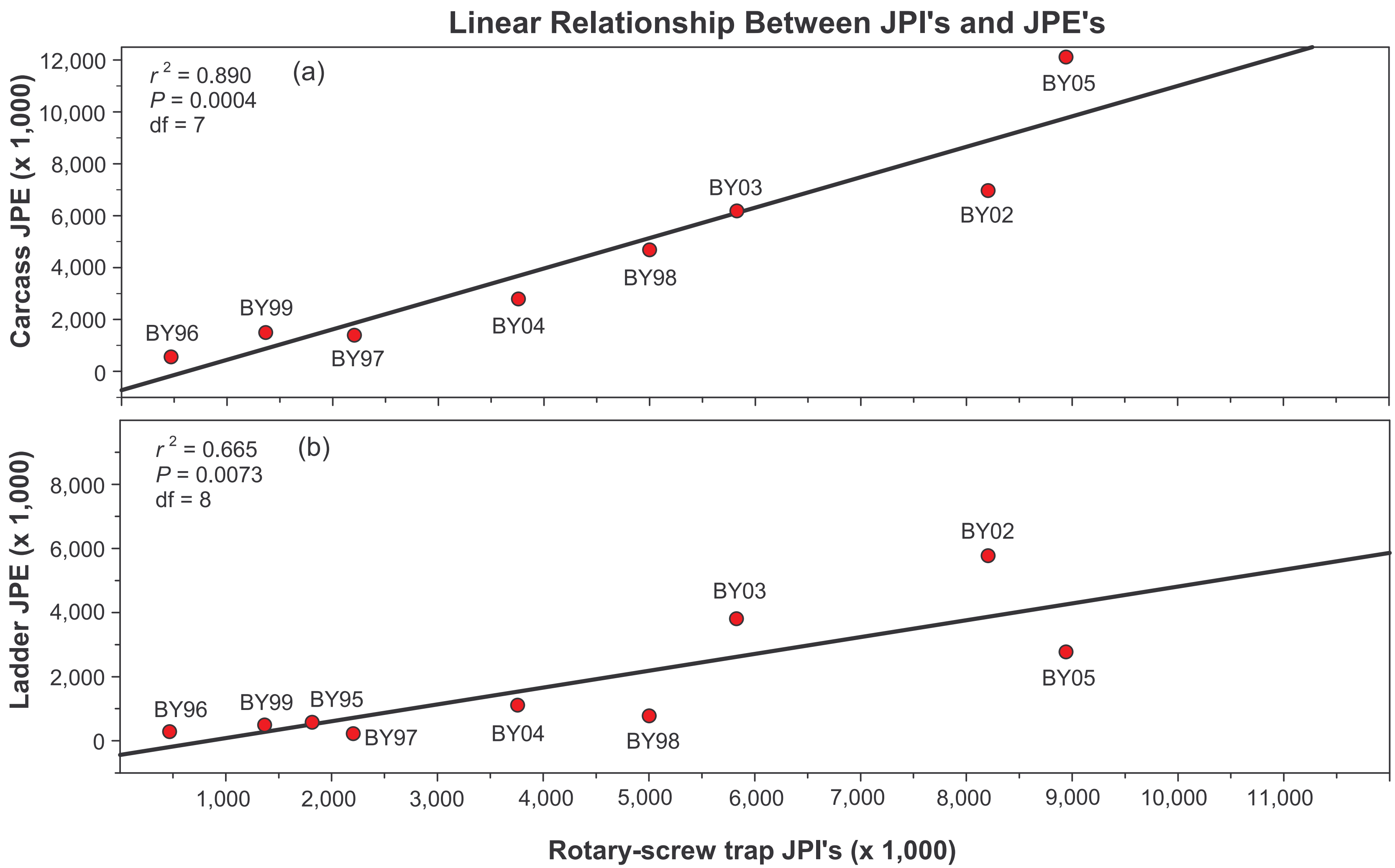

Figure 8. Linear relationship between rotary-screw trap juvenile production indices (JPI) and (a) carcass survey derived juvenile production estimates (JPE) and (b) RBDD ladder count derived JPE's.

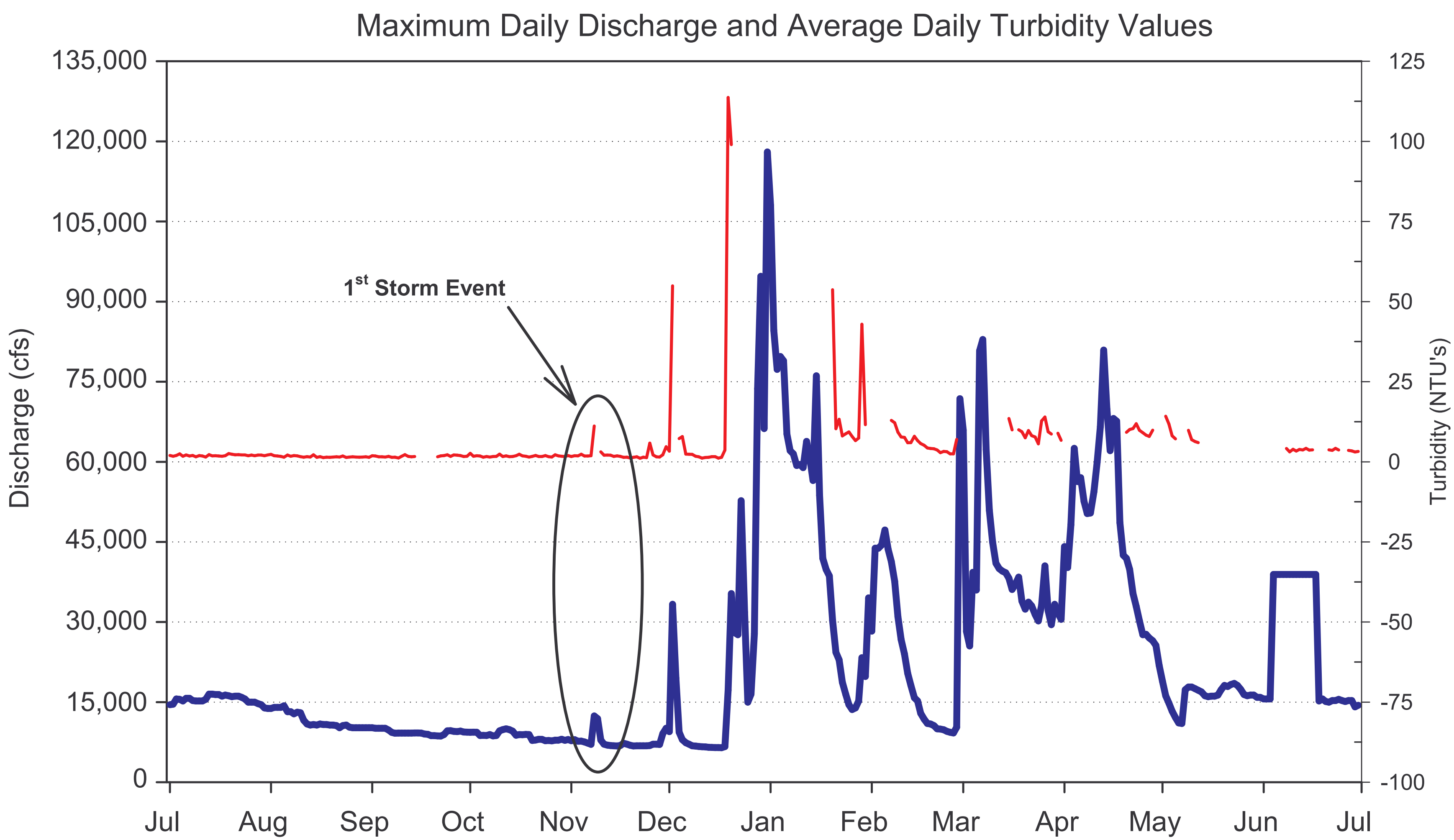

Figure 9. Maximum daily discharge (thick line) calculated from the California Data Exchange Center's Bend Bridge gauging station and average daily turbidity values (thin line) from rotary-screw traps at RBDD for the period July 1, 2005 through June 30, 2006. Circled area added to emphasize conditions related to passage event representing 27% of annual winter Chinook pre-smolt passage.