BROOD-YEAR 2002 WINTER CHINOOK JUVENILE PRODUCTION INDICES WITH COMPARISONS TO ADULT ESCAPEMENT

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Brood-year 2002 winter Chinook juvenile production indices with comparisons to adult escapement

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Abstract— A dramatic increase in juvenile production occurred for brood-year 2002 winter Chinook salmon in the Sacramento River, CA, over that observed from 1995-2001. Estimated passage at Red Bluff Diversion Dam (RBDD) was 7,602,746 fry and pre-smolt/smolts combined. Estimated fry-equivalent passage was 8,114,841. 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 Fisheries division (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 RBDD fish ladders and the second using adult escapement estimates from the winter Chinook carcass survey. Rotary-screw trap JPI's were strongly correlated in trend to carcass survey JPE's ($r^2 = 0.98$, $P = 0.001$) and, to a lesser extent, fish ladder JPE's ($r^2 = 0.82$, $P = 0.012$). However, paired comparisons revealed a significant difference in production estimates existed between JPI's and fish ladder JPE's ($t = 3.14$, $P = 0.026$, df = 5). Moreover, fish ladder JPE's fell below the lower 90% confidence interval (C.I.) about the rotary-trap JPI in five of six years evaluated, indicating that fish ladder JPE's consistently underestimated juvenile winter Chinook production, relative to JPI's. Conversely, no significant difference was detected between rotary-trap JPI's and carcass survey JPE's ($t = 1.55$, $P = 0.197$, df = 4), and carcass survey JPE's fell within the 90% C.I. for rotary-trap JPI's in four of five years evaluated. We concluded that the NOAA Fisheries JPE model, using RBDD fish ladder escapement estimates, underestimated juvenile winter Chinook production and that JPE's were more robust using carcass survey escapement estimates. We further concluded that NOAA Fisheries should consider using rotary-screw trap JPI's rather than the JPE model to estimate juvenile production, for three primary reasons. First, the accuracy of fry-equivalent rotary-trap JPI's is not contingent upon accurate estimates of adult females, fecundity, sex ratios, egg-to-fry survival, egg viability, egg loss due to high water temperature or pre-spawn mortality, as is the JPE model. Secondly, the rotary-trap JPI does not suffer from the same or similar quantitative complexities as the NOAA Fisheries JPE model. Because of this, C.I.'s about JPI's are relatively narrow and provide fishery managers with robust estimates of fry-equivalent production on which to base management decisions. Lastly, the JPI provides information about reproductive success on the spawning grounds and life history strategies that can't be provided from carcass survey data.

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Introduction

Since listing under the federal Endangered Species Act, numerous measures have been implemented to protect winter Chinook salmon. One measure is to manage water exports from the Central Valley Project's Tracy Pumping Plant and State Water Project's Harvey Banks Delta Pumping Plant located in the southern Sacramento-San Joaquin Delta. Exports are managed to reduce entrainment of juvenile winter Chinook salmon migrating through the Delta. The United States Bureau of Reclamation and the California Department of Water Resources are authorized 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 numbers of winter Chinook entering the Delta. The model has used estimated counts of adult salmon using fishways (ladders) that provide passage over RBDD (Diaz-Soltero 1995, 1997; Lecky 1998, 1999, 2000), and more recently, carcass survey escapement estimates (McInnis 2002), as the primary variate. This juvenile production estimate (JPE) is then used to determine take at Delta pumping facilities.

The two survey methods (carcass surveys and RBDD ladder counts) that NOAA Fisheries has used to generate JPE's have, at times, produced very different estimates of escapement. The disparity between the escapement estimates is primarily due to the size composition of fish sampled by each survey (Snider et al. 2000). Adult females are generally larger than their male counterparts and are, therefore, located more frequently than males during the carcass survey, leading to skewed sex ratios (e.g., in 1999, the male to female ratio was 1:8.4). Because gender differentiation is questionable from the RBDD ladder counts, an assumed 1:1 sex ratio is used for estimates. These disparities in sex ratios between surveys can have large net effects on the estimated number of spawning females, which in turn, can have dramatic effects on the JPE. As a result, estimates of juvenile production using the JPE model with either survey technique may be subject to question.

Estimates of escapement are just one factor affecting the accuracy of JPE's. Another factor is that success on the spawning grounds is not addressed in the NOAA Fisheries JPE model. Many adult salmon may return to spawn, but if conditions are not conducive for producing juveniles then production will be less than the model would estimate. However, direct monitoring of juvenile 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 production 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 NOAA Fisheries JPE model.

Martin et al. (2001) determined that RBDD was an ideal location to monitor juvenile winter Chinook passage 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 abundance.

The objectives of this study were to (1) estimate the abundance of juvenile winter Chinook salmon 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.

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 clear 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 has impacted the river, the upper river remains mostly unrestricted below Shasta 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 channelization and loss of associated riparian vegetation.

Red Bluff Diversion Dam is located at river-kilometer 391 on the Sacramento River, approximately 3 km southeast of the city of Red Bluff. This diversion complex encompassed three major in-river structures associated with the diversion of water into the Tehama-Colusa Canal and Corning Canal systems; (1) the Red Bluff Research Pumping Plant (RPP), (2) RBDD and (3) a bypass outfall structure. This bypass outfall structure was designed to return juvenile salmon and other fish entrained into the plant or diverted into the canal system headworks back to the river, harmlessly. Red Bluff Diversion Dam is 226 m wide and has eleven gates measuring 18 m in width between ten concrete piers 2.4 m in width. Dam gates can be raised or lowered to impound and divert river flows into the canal. The RPP is located approximately 100 m downstream of RBDD (Figure 2) and consists of two Archimedes screw pumps and one internal helical pump. The in-river portion of the plant includes a long intake bay covered by a steel grid "trash rack" that prevents large debris from being entrained into the RPP. The trash rack is approximately 64 m long and 8 m tall. Pump intakes are located near the river bottom at a depth of approximately 4-6 m depending on river stage.

Methods

Fish Capture

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 traps along the transect varied throughout the study but generally sampled in river-margin (east and west river-margins) and mid-channel habitats simultaneously. Traps were positioned within these spatial zones unless sampling equipment failed, river depths were insufficient (i.e., < 1.2 m), or river hydrology restricted our ability to sample with all traps (e.g., water velocity < 0.6 m/s).

Sampling regimes

In general, traps were checked/serviced once daily. Traps sampled continuously throughout 24 h periods, except during high-flow events and periods of high winter Chinook abundance. During these occasions, traps were checked/serviced multiple times per day or continuously. When capture of winter Chinook juveniles exceeded 200/trap, a random sub-sample was taken to include approximately 100 Chinook salmon, 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 requirements. First, traps were structurally modified to only sample one-half of the normal volume of water. Secondly, because most winter Chinook emigrate during the nocturnal period, the nocturnal period was divided into two or four non-overlapping strata and one strata was randomly selected for sampling each day. Estimates were extrapolated to un-sampled strata by dividing catch by the strata-selection probability (i.e., $P = 0.25$ or 0.50). If further reductions in capture were needed to maintain permit compliance, we reduced the number of traps sampling or did not sample. Continuous sampling throughout the diurnal period was always conducted because very few fish were captured and, therefore, did not significantly impact our authorized take and incidental mortality limits.

We quantified sampling effort for among-week comparisons by assigning a value of 1.00 to a sample consisting of four traps sampling continuously for a 24 h period. Values less than 1.00 represent occasions where: (1) traps were structurally modified to sample one-half the normal volume of water, (2) we randomly sub-sampled the nocturnal period or (3) less than four traps were sampling. By standardizing effort direct comparisons among weeks could be made.

Data collection.— All fish captured were separated from debris, anesthetized, identified, enumerated, and fork lengths measured to the nearest 1 mm. Chinook salmon race was assigned using length-at-date criteria developed by Green[1] (1992).

Other data were collected at each trap check/servicing and included: (1) length of time trap sampled, (2) water velocity, (3) number of cone rotations during the sample, (4) depth of cone submerged, (5) debris type and quantity, (6) water temperature, and (7) water turbidity. Water velocity was measured using an Oceanic® Model 2030 flow torpedo. Water temperature was measured using an Onset Computer Corporation Optic StowAway® Temperature Logger. Water samples were analyzed in the laboratory using a Model 2100A Hach® Turbidimeter. The volume of water sampled was estimated from the (1) area of the cone submerged, (2) average velocity of water immediately in front of the trap at a depth of 0.6 m , and (3) duration of the sample. River volume (*Q*) was obtained from the California Data Exchange Center's Bend Bridge river gauge. The

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Generated by Sheila Greene, California Department of Water Resources, Environmental Services Office, Sacramento (8 May 1992) from a table developed by Frank Fisher, CDFG, Inland Fisheries Branch, Red Bluff (revised 2 February 1992). Fork lengths with overlapping run assignments are placed with the latter spawning run.

percent river volume sampled (*%Q*) by rotary-screw traps was estimated by the ratio of river volume sampled to total river volume passing RBDD.

Trap efficiency trials.— Fish were marked with either fluorescent spray-dye (Phinney 1967), bismark brown stain (Mundie and Taber 1983) or both (Gaines and Martin 1999, draft). Spray-dye marking equipment consisted of: (1) a 1.5 hp compressor and regulator valve capable of maintaining hose pressure of 150 pounds per square inch; (2) a sandblast gun fitted with a one quart canister and a 2.4 mm diameter siphon orifice; (3) and fluorescent, granulated pigment. Fish were stained in bismark brown staining solution prepared at a concentration of eight grams of bismark brown to 380 L of water. Fish were stained in solution for 45-50 minutes and removed.

Fish marked for trap efficiency trials were held for 6-24 hours before being released, generally 4 km upstream from RBDD. It was assumed that negligible mark-induced mortality occurred following the 6-24 h holding period (Gaines and Martin 1999, draft).

Passage Estimates

Winter Chinook passage was estimated by a model developed to predict daily trap efficiency (T_d). The model was developed by conducting 54 mark/recapture trials at RBDD and using $\%Q$ as the primary variate (Martin et al, 2001). 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 (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. $$\hat{T}_d = (0.0093545)(\%Q_d) - 0.0029842$$

$\hat{T}_d$ = Predicted trap efficiency on day d.

Weekly passage (Passage).— Population totals for numbers of Chinook salmon passing RBDD by 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. $$Var(\hat{P}) = (1 - \frac{n}{N})\frac{N^2}{n}s_{Pd}^2 + \frac{N}{n}\left[\sum_{d=1}^{n} \text{var}(\hat{P}_d) + 2\sum_{i \neq j} \text{cov}(\hat{P}_i, \hat{P}_j)\right]$$

The first term in Equation (7) is associated with sampling of days within the week.

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

The second term in Equation (7) is associated with estimating $\hat{P}_d$ within the day.

9. $$Var(\hat{P}_d) \doteq \frac{\hat{P}_d(1-\hat{T}_d)}{\hat{T}_d} + \text{var}(\hat{T}_d)\frac{\hat{P}_d(1-\hat{T}_d) + \hat{P}_d\hat{T}_d}{\hat{T}_d^3}$$

where

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

The third term in equation (7) is associated with estimating both $\hat{P}_i$ and $\hat{P}_j$ with the same trap efficiency model.

11. $$\text{cov}(\hat{P}_i, \hat{P}_j) = \frac{\text{cov}(\hat{T}_i, \hat{T}_j)\hat{P}_i\hat{P}_j}{\hat{T}_i\hat{T}_j}$$

where

12. $$Cov(\hat{T}_i, \hat{T}_j) = \text{var}(\hat{\alpha}) + x_i\,\text{cov}(\hat{\alpha}, \hat{\beta}) + x_j\,\text{cov}(\hat{\alpha}, \hat{\beta}) + x_i x_j\,\text{var}(\hat{\beta})$$

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

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

13. $$\hat{P} \pm t_{(\alpha/2;n-1)} \sqrt{\text{var}(\hat{P})}$$

Weekly JPI's were estimated by summing $\hat{P}$ across days.

14. $$JPI = \sum_{week=1}^{7} \hat{P}$$

Fry (≤ 45 mm FL) and pre-smolt/smolt (> 45mm 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 value. Fry-equivalent was estimated by the summation of fry passage and a weighted pre-smolt/smolt passage (59% fry-to-presmolt/smolt survival; Hallock undated). The rotary-trap JPI could then be directly compared to the NOAA Fisheries JPE.

To estimate daily passage for days that were not sampled, we used a mean daily passage from the sample immediately preceding and following the unsampled day. When consecutive days were not sampled, we calculated a mean daily passage for that period by noting the number of days not sampled and then calculating a mean daily passage using the same number of samples immediately preceding and following the unsampled period (i.e., if three consecutive days were not sampled, we calculated a mean daily passage for those samples using the three samples immediately preceding and following the unsampled period).

Results

Sampling effort.— Sampling began in April 2002, however, sampling effort was low until sufficient numbers of personnel were hired to staff the project. Trap damage and/or repair were the primary reasons when less than four traps were sampling. Weekly sampling effort averaged 0.35 and ranged from 0.00 to 1.00 (Table 1). During peak winter Chinook emigration (August through mid-October), sampling effort averaged 0.24 (range = 0.00-0.36). No samples were gathered in week 20 or week 38 due to RBDD operations associated with the impoundment and draw-down of Lake Red Bluff. Also no samples were gathered in week 25 or 51due to equipment damage and flood conditions, respectively.

Mark recapture trials.— Three mark/recapture trials were conducted to measure rotary-screw trap efficiency. The number of marked fish released per trial ranged from 340-805 and trap efficiencies ranged from 0.99 to 2.15%.

Patterns of abundance.— The abundance of brood-year 2002 (BY02) juvenile winter Chinook salmon passing RBDD was much greater than any brood-year previously monitored. The JPI for BY02 total winter Chinook abundance (fry and pre-smolt/smolts combined) was 7,602,746. The temporal distribution of BY02 outmigrants (Figure 3) was consistent with that observed by Martin et al. (2001) for BY95 through BY99. Newly emerged juveniles began to pass RBDD in early July (week 27) and fry (< 46 mm

FL) passage continued through late November (week 48). Relative abundance of fry increased from a low of less than 1.0% in week 27 to a high of 21.0% in week 39 (Figure 4). Weekly abundance of fry then declined from 18% in early October (week 40) to less than 1.0% in week 43. Passage of pre-smolt/smolt sized (46 - 200 mm FL) individuals began in week 34, increased through week 46, and then declined through week 50 (Figure 5). During this period, weekly relative abundance of pre-smolt/smolts increased from a low of less than 1.0% in week 34 to a high of approximately 15% in week 46. Weekly relative abundance declined from week 47 through week 49 and remained less than 5.0% through week 52 (Figure 5). Estimated passage of BY02 winter Chinook fry was 6,871,240. Weekly JPI's for fry ranged from 9,341 - 39,534 in July (weeks 27 - 30), 79,749 - 286,810 in August (weeks 31 - 34) and 516,894 - 1,422,148 in September (weeks 35 - 39, Table 2). Fry JPI's then declined rapidly from week 40 (1,266,066) through week 48 (34). No fry were captured after week 48. Weekly passage of pre-smolt/smolt sized individuals began in week 34 (mid-August) and peaked at 112,373 in week 46 (mid-November). Weekly JPI's remained above 13,000 through week 52. Total passage of pre-smolt/smolt sized individuals was 741,506 through December 31, 2002 (Table 3).

The length frequency distribution of BY02 winter Chinook juveniles captured at RBDD was bimodal (Figure 6) and consistent with distributions observed from BY95 - BY99. The first mode occurred at 33-39 mm FL and the second mode occurred at 46-64 mm FL (Figure 6). Over 90% of BY02 juvenile winter Chinook salmon passing RBDD were less than 46 mm FL and most were 30-39 mm FL. Conversely, pre-smolt/smolts (46-200 mm FL) represented less than 10% of total passage. Most pre-smolt/smolts were between 50 and 59 mm FL.

From week 27 through week 42, fry median fork lengths ranged from 34 - 37 mm (Figure 4). In week 43 fry median fork length increased to 40 mm and continued to increase, on average, one millimeter per week through week 45. Pre-smolt/smolt sized juveniles were first captured in week 14 and capture continued through week 17. However, these individuals were from the BY01 year class. First capture of BY02 pre-smolt/smolts occurred in week 34 and continued through week 52. Median fork lengths increased approximately one millimeter per week through week 45. From week 45 - 51, median pre-smolt/smolt fork lengths increased approximately five millimeters per week, on average (Figure 5).

The relationship between the proportion of pre-smolt/smolts passing RBDD and seasonal river discharge volume (July, August and September) described by Martin et al. (2001) was not supported by BY02 data. For example, the proportion of pre-smolt/smolts passing RBDD was lower in BY02 (< 10%) than for any brood-year from BY95 - BY99. Conversely, seasonal river discharge volume was less in BY02 than that for BY95 - BY99. The linear relationship between seasonal river discharge and the proportion of pre-smolt/smolts passing RBDD observed from BY95 through BY99 was greatly weakened with the addition of BY02 data (Figure 7). The strength of the relationship decreased from $r^2 = 0.84$ ($P = 0.029$, df = 4) to $r^2 = 0.21$ ($P = 0.359$, df = 5).

Comparison of JPI and JPE.— The fry-equivalent rotary-trap JPI for BY02 winter Chinook juveniles passing RBDD was 8,114,841. The BY02 fry-equivalent carcass survey and fish ladder JPE's were 6,978,583 and 5,270,598, respectively. Both JPE's fell within the 90% confidence interval about the rotary-trap JPI.

Data from BY95 through BY02 gathered from the three survey techniques (rotary trapping, carcass survey and ladder counts) was used to evaluate the linear relationship between winter Chinook fry-equivalent JPI's and JPE's. Limited contrasts were available because the winter Chinook carcass survey did not start until 1996 and rotary trapping at RBDD was not conducted in 2000 and 2001. Rotary-trap JPI's (BY96-BY99 and BY02) were significantly correlated to carcass survey JPE's ($r^2 = 0.98$, $P = 0.001$, df = 4; Figure 8a) and fish ladder JPE's (BY95-BY99, and BY02; $r^2 = 0.82$, $P = 0.013$, df = 5; Figure 8b). Martin et al. (2001) performed a similar analysis, less the BY02 estimates. With the addition of data from BY02, r^2 values increased and *p*-values decreased for both rotary-trap JPI to carcass survey JPE and rotary-trap JPI to fish ladder JPE relationships. However, paired comparisons revealed that significant differences existed between rotary-trap JPI's and fish ladder JPE's ($t = 3.14$, $P = 0.026$, df = 5). On average, the fish ladder JPE fell below the rotary-trap JPI -57% (range = -13 to -86%). Furthermore, the fish ladder JPE fell below the lower 90% confidence interval (C.I.) about the rotary-trap JPI in five of six years evaluated (Table 4). Conversely, no significant differences in mean production were detected between rotary-trap JPI's and carcass survey JPE's ($t = 1.55$, $P = 0.195$, df = 4), and carcass survey JPE's fell within the 90% C.I. for rotary-trap JPI's in four of five years evaluated. There was a tendency, however, for carcass survey JPE's to be less than rotary-trap JPI's. But, the magnitude was small relative to differences between rotary-trap JPI's and ladder JPE's (Table 4). On average the carcass survey JPE fell below the rotary-trap JPI by 13% (range = -59 to +14%).

Discussion

Winter Chinook abundance.— Juvenile winter Chinook passage at RBDD in BY02 was greater than that observed from BY95 through BY01. Total passage (fry and presmolt/smolts combined) of winter Chinook juveniles from July 1 through December 31, 2002 was greater than 7.6 million. The final estimate of passage will be higher because limited passage does occur after December 31. However, this period has represented 97% of total winter Chinook passage at RBDD, annually (Martin et al. 2001). It's important to note as well that juveniles passing after December 31, while few in number, are larger pre-smolt/smolt sized individuals and may survive and return as adults at a higher frequency than fry sized individuals passing RBDD earlier in the year.

Rotary-trap JPI's were standardized to fry-equivalent production values for among year comparisons of JPI's to JPE's. This was necessary because the JPE model does not account for the ratio of fry to pre-smolt/smolts in the population. In other words, the JPE characterizes production as exclusively fry, pre-smolt/smolts or smolts, rather than a combination of these different life stages. Because rotary-trap JPI's include a combination of life-stages, JPI's must be standardized to exclusively fry, pre-smolt/smolts or smolt passage for direct comparisons to JPE's. Winter Chinook juvenile passage at RBDD was predominantly fry (>90%), therefore, we adjusted pre-smolt/smolt numbers to “fry-equivalents”. Rotary-trap JPI’s were standardized to fry-equivalent passage estimates using the inverse of the JPE model’s fry-to-pre-smolt/smolt survival rate. Pre-smolt/smolt passage at RBDD was weighted by approximately 1.7 (59% fry to pre-smolt/smolt survival) for pre-smolt/smolt conversion to fry. Fry-equivalent rotary-trap JPI’s were then generated by summing fry passage to the weighted pre-smolt/smolt estimate.

The winter Chinook fry-equivalent rotary-trap JPI for BY02 was 8,114,841, an increase of 62% over the previous high of 5,000,416 in BY98, and 268% greater than the next highest brood-year (BY97; 2,205,163). Rotary-trap sampling at RBDD was not conducted in BY00 and BY01 and, therefore, comparison of the BY02 JPI to those years cannot be made. However, carcass survey JPE’s were available and, because they have supported rotary-trap JPI’s in previous years (Martin et al. 2001), some conclusions can be drawn. Both BY00 and BY01 were strong production years based on carcass survey JPE’s, especially BY01 (5,386,672). However, the rotary-trap JPI for BY02 was still much greater (45%) than the JPE for BY01.

Over 90% of juvenile winter Chinook passing RBDD were fry (<46 mm FL). Martin et al. (2001) determined that a strong inverse relationship ($r^2 = 0.84$, $P = 0.029$, N = 5) existed between upper river flows during the emergent period (July, August and September) and the proportion of pre-smolt/smolts passing RBDD. This may have important implications for management of winter Chinook juveniles in the upper river if survival rates differ between fry and pre-smolt/smolts rearing above and below RBDD. However, data from BY02 do not appear to support this relationship. For example, the proportion of fry emigrating past RBDD was greater for BY02 than BY95 - BY99 and seasonal river discharge was lower than that observed from BY95 - BY99 (Figure 7). The addition of the BY02 data point to the analysis performed by Martin et al. (2001) resulted in a decrease in r^2 from 0.84 to 0.21. The reader is cautioned about the interpretation of these data due to the small sample size (N = 6). Flows in the upper river are highly regulated through much of the winter Chinook emigration period primarily to meet agricultural and wildlife refuge water demands. Because demand for water is inconstant during this period, river flows may fluctuate considerably to accommodate water users. In our analysis, we pooled flow data during the emergent period (July, August and September) and this may mask much of the variability that occurred on a more stratified time-step. It may be that any relationship between upper river flows and pre-smolt/smolt passage would be better defined using a monthly time-step, rather than pooling flow data throughout the emergent period. Further analysis should be conducted to better define the relationship, if any, between upper river flows and juvenile passage.

Comparisons among JPI’s and JPE’s.— Martin et al. (2001) determined that the JPI from BY95 through BY99 was strongly correlated in trend with estimates of the number of spawning females from the carcass survey ($r^2 = 0.95$), and to a lesser extent, the number of spawning females estimated from the RBDD fish ladder ($r^2 = 0.57$). We performed a similar regression analysis, however, we contrasted rotary-trap JPI’s directly to carcass survey and fish ladder JPE’s rather than the number of female spawners. This alternative analysis had no effect on the test statistic because JPE’s are a direct function of the number of spawning females. We re-analyzed the data from BY95-BY99 with additional data from BY02 to determine if these relationships were static. The strength of the linear relationship between rotary-trap JPI's and carcass survey JPE's improved slightly with the addition of BY02 data (r^2 = 0.98, P = 0.001, df = 4). In contrast, the linear relationship between JPI's and fish ladder JPE's was not static and became much stronger with the addition of BY02 data, increasing the r^2 value from r^2 = 0.57 to r^2 = 0.83 (P = 0.013, df = 6). It's important to note that while carcass survey and fish ladder JPE's both supported rotary-trap JPI's in trend (i.e., as JPE's increase JPI's increase), only carcass survey JPE's supported rotary-trap JPI's in magnitude. Paired comparisons between rotary-trap JPI's and both carcass survey and fish ladder JPE's revealed that the mean rotary-trap JPI was significantly greater than the mean fish ladder JPE (P = 0.026). Conversely, no difference was detected between rotary-trap JPI's and carcass JPE's (P = 0.197), indicating that estimates of rotary-trap JPI's and carcass survey JPE's were similar.

The NOAA Fisheries sets limits on incidental mortality of winter Chinook salmon caused by entrainment of juveniles into the Central Valley Project's Tracy Pumping Plant and the State Water Project's Harvey O. Banks Delta Pumping Plant diversions. Historically, the NOAA Fisheries has limited entrainment to 2% of the annual JPE (NMFS 1997, Diaz-Soltero 1995 and 1997, Lecky 1998, 1999, and McInnis 2000, 2002). Therefore, accurate estimates of the number of juveniles entering the Delta are needed to minimize negative impacts on the population due to these facilities.

To determine the number of juveniles entering the Delta, the JPE model initially estimates fry production in the upper river. In an effort to provide more accurate estimates of fry production, several refinements to the JPE model were implemented in 2001. For example, the model now uses escapement estimates generated from the carcass survey rather than escapement estimates generated from RBDD ladder counts, as in the past. Secondly, several assumptions (constants) used in the JPE calculation, such as fecundity, sex ratio and pre-spawn mortality, are now treated as variables, and directly estimated from the carcass survey and adult trapping each year. The net effect of these changes may improve the accuracy of JPE's.

However, difficulties exist when indirectly estimating juvenile production from adult returns. Escapement estimates from carcass survey data in large river systems are inherently variable and the accuracy of estimates from the Sacramento River winter Chinook carcass survey is uncertain. Moreover, confidence intervals about escapement estimates may be unreliable if mark/recapture model assumptions are violated, specifically the assumptions of equal catchability and that marked fish are randomly distributed among unmarked fish. The assumption of equal catchability may not have been met because there were large areas of the survey reach where water depth was too great to observe carcasses, and as evidenced by sex ratios skewed toward females, suggesting a bias towards larger fish. Female spawners are generally larger than their male counterparts and Zhou (2002) determined that rates of carcass recovery generally increased with fish size. However, any bias toward females should not affect the accuracy of the JPE because the estimate of females is the primary variate in the JPE model. In other words, if the carcass survey only sampled females, rather than both sexes, the estimate of the female population should not differ from an estimate of total escapement (males and females) and applying the observed sex-ratio. The assumption that marked carcasses were randomly distributed with unmarked carcasses was likely violated and it's probable that this assumption may never be met. For example, where should marked carcasses be released for recapture? If marked carcasses are released where they were found, they will likely be recaptured on the next survey because most carcasses were observed in large static pools or eddies where water velocities were too low to distribute them further, artificially inflating recapture efficiencies. If marked carcasses were released into fast moving water, few would be recovered, resulting in low recapture efficiencies and unstable escapement estimates. Therefore, the JPE methodology of using escapement estimates as the primary variate in a juvenile production model may need further refinement.

Aside from the uncertainty of escapement estimates, other problems may exist when applying the JPE model. For example, the model does not account for inter-year variability in egg-to-fry survival (Botsford and Brittnacher 1998; Major and Mighell 1969; Wales and Coots 1955), environmental conditions (Bigelow 1996, Reiser and White 1988, Heming 1981), losses due to pollution (Arkoosh et al. 1988), degraded water quality (Bradford 1994), density dependent and/or independent factors, infectious disease (Arkoosh 1988) and behavioral patterns. Many of these factors are expected to influence juvenile production and survival on a year-to-year basis, while others may be year specific depending on environmental and/or anthropogenic-induced conditions.

Moreover, the NOAA Fisheries JPE model uses a fixed egg-to-fry survival rate of 25%. Certainly, egg-to-fry survival is variable among years and should be treated as a variable rather than a fixed constant. Also, egg-to-fry survival rates have never been measured in the Sacramento River and are, therefore, unknown. And egg-to-fry survival rates do not address or account for egg viability, another factor that is variable among years.

The JPE model may also produce "boundless" estimates of fry production (i.e., confidence intervals so wide that they don't provide any certainty about the estimate). All model variables used to estimate fry production have an associated variance and, therefore, covariances must be combined to produce confidence intervals (C.I.'s) about the JPE. The combination of variances and covariances may lead to wide C.I.'s and the quantitative complexity of the calculations may be intractable.

In contrast, the rotary-trap JPI only indexed fish that hatched on the spawning grounds above our sampling location and survived to emigrate past RBDD, primarily as fry. The accuracy of JPI's was not contingent upon accurate estimates of many JPE variables and assumptions, such as total escapement, sex ratios, fecundity, egg-to-fry survival rates, egg viability, egg loss due to high water temperature or pre-spawn mortality. However, calculation of fry-equivalent JPI's does require the limited use of one JPE assumption (59% fry to pre-smolt/smolt passage), and any error in this rate of survival would result in inaccuracy of the JPI. We used the inverse of the survival rate to "back-calculate" fry production from pre-smolt/smolt passage. In doing so, we minimized the effect of possible error in the survival rate because it was only applied to the proportion of pre-smolt/smolt passing RBDD, approximately 25% of the population, on average.

Fry-equivalent JPI's only required the estimation of a single variable, trap efficiency. We have modeled trap efficiency by conducting 54 mark/recapture trials at RBDD (Martin et al. 2001). The model and our quantitative methodologies have been independently and critically reviewed, and supported for use in the upper Sacramento River by biological statisticians at the School of Fisheries, University of Washington, Seattle, WA., Western EcoSystems Technology, Cheyenne, WY. and by statisticians at California State University, Chico, CA.

Rotary-trap JPI's could also be used to determine limits of incidental take at Delta pumping facilities, similar to the JPE model, by incorporating two JPE assumptions. Those assumptions are 59% fry to pre-smolt/smolt survival, previously discussed, and 52% survival of smolts entering the Delta. If fry-equivalent rotary-trap JPI's at RBDD were more accurate than fry-equivalent JPE's, and applying the same JPE assumptions addressing survival from fry to smolts, it's intuitive that rotary-trap JPI estimates of smolt abundance entering the Delta would also be more accurate. Therefore, it may be preferable to use rotary-trap JPI's from RBDD, rather than the JPE model, to determine take at Delta pumping facilities. However, it's important to realize that the accuracy of juvenile production estimates using either method is uncertain. Each method merely provides an *estimate* of juvenile production, and the absolute abundance of juvenile winter Chinook at any point along their migratory path is unknown. Furthermore, both survey techniques are necessary to effectively monitor winter Chinook salmon recovery efforts. The carcass survey is needed for evaluation of the adult population and to determine if recovery criteria are being met. Rotary-trapping at RBDD is necessary to evaluate the reproductive success of those returning adults. Hence, it is emphasized that JPE's and JPI's are resultant derivatives of these independent surveys which are operated to achieve other management objectives.

In summary, the accuracy of fry equivalent rotary-trap JPI's at RBDD is not contingent upon accurate estimates of adult females, fecundity, sex ratios, egg-to-fry survival, egg viability, egg loss due to high water temperature or pre-spawn mortality as the JPE is. Secondly, JPI's do not suffer from the same or similar quantitative complexities as the NOAA Fisheries JPE model. Therefore, C.I.'s about rotary-trap JPI's are relatively narrow and provide fishery managers with robust estimates of juvenile production on which to base management decisions. Lastly, the rotary-trap JPI provides information about reproductive success on the spawning grounds that can't be provided from the carcass survey alone. For example, large numbers of adults may return to spawn, but produce few offspring. If this were to occur, the JPE model would overestimate juvenile production, leading to greater take of endangered winter Chinook at Delta pumping facilities.

Conclusions and Management Recommendations

- The rotary-trap JPI was found to be useful for evaluating year-class strengths in winter Chinook production and for supportive evidence of adult escapement.

- We conclude that NOAA Fisheries JPE model, based on the winter Chinook carcass survey, was a satisfactory replacement for RBDD ladder counts.

- Further analysis should be conducted to more clearly define the relationship between river discharge and the proportion of pre-smolt/smolts passing RBDD, as this may be a useful tool for managing fry distributions in the upper river.

- The NOAA Fisheries should consider using rotary-trap JPI's from RBDD to determine take at Delta pumping facilities because: (1) the accuracy of JPI's is only contingent upon the accuracy of a single variable (trap efficiency), rather than multiple variables, and (2) C.I.s are easily calculated and relatively narrow, providing fishery managers with robust estimates of juvenile production on which to base management decisions.

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Table 1.— Sampling effort was quantified by assigning a value of 1.00 to a sample consisting of four rotary-screw traps sampling continuously for a 24 hour period. Values less than 1.00 represent occasions where less than four traps were sampling, we randomly sub-sampled periods of the day or night, or when traps were structurally modified to sample only one-half their normal volume of water. 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 prevent exceeding our authorized take limitations for winter Chinook salmon.

Week	Sampling effort	Week	Sampling effort
14 (April)	0.04	34	0.25
15	0.21	35 (September)	0.12
16	0.25	36	0.23
17	0.29	37	0.13
18 (May)	0.25	38	0.00
19	0.32	39	0.32
20	0.00	40 (October)	0.27
21	0.04	41	0.27
22 (June)	0.14	42	0.28
23	0.27	43	0.79
24	0.13	44 (November)	0.88
25	0.00	45	0.88
26 (July)	0.32	46	0.95
27	0.45	47	1.00
28	0.50	48 (December)	0.98
29	0.16	49	0.98
30	0.20	50	0.79
31 (August)	0.36	51	0.00
32	0.33	52	0.14
33	0.27		

Table 2.— Weekly juvenile production indices (JPI) and median fork length for winter Chinook fry passing Red Bluff Diversion Dam (RK391), Sacramento River, CA. Sampling was conducted using rotary-screw traps from April 1 through December 31, 2002. This period represents the last three months of BY01 and the first six months of BY02. Sampling effort was not sufficient to produce robust JPI's for weeks 14 and 15 and no winter Chinook fry were captured from week 16 - 26. Results include weekly JPI's, 75% and 90% confidence intervals and median fork length.

		Fry production				
			90% C.I.		75% C.I.	
Week	Median FL (mm)	Rotary-trap JPI	Lower	Upper	Lower	Upper
			Brood-year 2001			
14	-	-	-	-	-	-
15	-	-	-	-	-	-
16	-	0	0	0	0	0
17	-	0	0	0	0	0
18	-	0	0	0	0	0
19	-	0	0	0	0	0
20	-	0	0	0	0	0
21	-	0	0	0	0	0
22	-	0	0	0	0	0
23	-	0	0	0	0	0
24	-	0	0	0	0	0
25	-	0	0	0	0	0
			Brood-year 2002			
26	-	0	0	0	0	0
27	34.0	9,341	3,037	15,645	5,167	13,515
28	35.0	24,958	11,510	38,406	16,055	33,861
29	35.0	41,524	19,984	63,064	27,264	55,784
30	35.0	39,534	18,005	61,063	25,281	53,787
31	35.0	79,749	38,365	121,133	52,352	107,146
32	35.0	150,122	73,752	226,492	99,562	200,682
33	35.0	169,069	77,220	260,918	108,262	229,876
34	35.0	286,810	143,364	430,256	191,844	381,776
35	36.0	516,894	324,589	709,199	389,581	644,207
36	36.0	443,251	293,351	593,151	344,012	542,490

Table 2.— (continued).

		Fry production				
			90% C.I.		75% C.I.	
Week	Median FL (mm)	JPI	Lower	Upper	Lower	Upper
37	36.0	837,552	526,442	1,148,662	631,586	1,043,518
38	-	877,632	545,001	1,210,263	657,418	1,097,846
39	36.0	1,422,148	826,966	2,017,330	1,028,116	1,816,180
40	36.0	1,266,066	677,646	1,854,486	876,511	1,655,621
41	36.0	490,151	270,690	709,612	344,860	635,442
42	37.0	153,491	69,795	237,187	98,081	208,901
43	40.0	27,548	16,996	38,100	20,563	34,533
44	42.0	20,600	14,743	26,457	16,722	24,478
45	43.0	11,198	7,626	14,770	8,833	13,563
46	44.0	2,720	1,851	3,589	2,144	3,296
47	45.0	848	441	1,255	579	1,117
48	45.0	34	0	101	0	79
49	-	0	0	0	0	0
50	-	0	0	0	0	0
51	-	0	0	0	0	0
52	-	0	0	0	0	0
Total		6,871,240	3,961,375	9,781,138	4,944,794	8,797,697

Table 3.— Weekly juvenile production indices (JPI) and median fork length for winter Chinook pre-smolt/smolts (46-200 mm FL) passing Red Bluff Diversion Dam (RK391), Sacramento River, CA. Sampling was conducted using rotary-screw traps from April 1 through December 31, 2002. This period represents the last three months of BY01 and the first six months of BY02. Sampling effort was not sufficient to produce robust JPI's for weeks 14 and 15, but did provide pertinent fork length data. Results include weekly JPI's, 75% and 90% confidence intervals and median fork length.

		Pre-smolt/smolt production				
			90% C.I.		75% C.I.	
Week	Median FL (mm)	Rotary-trap JPI	Lower	Upper	Lower	Upper
		Brood-year 2001				
14	110.0	-	-	-	-	-
15	127.5	-	-	-	-	-
16	128.0	325	130	520	196	454
17	141.5	301	110	492	175	427
18	-	0	0	0	0	0
19	-	0	0	0	0	0
20	-	0	0	0	0	0
21	-	0	0	0	0	0
22	-	0	0	0	0	0
23	-	0	0	0	0	0
24	-	0	0	0	0	0
25	-	0	0	0	0	0
		Brood-year 2002				
26	-	0	0	0	0	0
27	-	0	0	0	0	0
28	-	0	0	0	0	0
29	-	0	0	0	0	0
30	-	0	0	0	0	0
31	-	0	0	0	0	0
32	-	0	0	0	0	0
33	-	0	0	0	0	0
34	46.0	1,875	614	3,136	1,040	2,710
35	47.0	3,577	1,742	5,412	2,362	4,792

Table 3.—(continued).

		Pre-smolt/smolt production				
			90% C.I.		75% C.I.	
Week	Median FL (mm)	JPI	Lower	Upper	Lower	Upper
36	48.0	3,383	1,906	4,860	2,405	4,361
37	50.0	10,548	5,984	15,112	7,526	13,570
38	-	14,560	8,661	20,459	10,655	18,465
39	52.5	18,879	9,048	28,710	12,370	25,388
40	50.0	35,136	19,298	50,974	24,651	45,621
41	51.0	60,604	30,232	90,976	40,496	80,712
42	51.0	60,662	28,184	93,140	39,161	82,163
43	52.0	37,102	24,073	50,131	28,476	45,728
44	53.0	74,204	54,066	94,342	60,872	87,536
45	54.0	90,017	63,927	116,107	72,744	107,290
46	57.0	112,373	87,586	137,160	95,963	128,783
47	60.0	81,461	61,210	101,712	68,054	94,868
48	62.0	46,659	36,123	57,195	39,684	53,634
49	62.5	14,415	11,120	17,710	12,234	16,596
50	64.0	13,071	9,605	16,537	10,777	15,365
51	77.0	24,724	19,306	30,142	21,137	28,311
52	72.0	28,256	23,181	33,331	24,871	31,641
Total		731,506	495,866	967,146	575,479	887,533

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 the 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 temperature, and (4) 25% egg-to-fry survival. From BY00 through BY02, assumptions 1 - 3 were estimated annually from the carcass survey data gathered on the spawning grounds, through aerial redd surveys and from Livingston Stone National Fish Hatchery. 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	-	-	764,082	792
1996	469,183	384,124	818,096	550,872	571	406,160	421
1997	2,205,163	1,876,018	3,555,314	1,386,346	1,437	297,143	308
1998	5,000,416	4,617,475	6,571,241	4,676,143	4,847	1,141,299	1,183
1999	1,366,161	1,052,620	2,652,305	1,568,684	1,626	411,948	427
2000	-	-	-	4,126,949	3,530	1,284,742	1,099
2001	-	-	-	5,386,672	4,607	1,451,158	1,241
2002	8,114,841	4,798,472	11,431,210	6,978,583	5,670	5,270,598	4,673

[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. (1997, 1998, and 1999, and Bruce Oppenheim, NOAA Fisheries, pers comm 2000, 2001, 2002).

[c] Fish ladder JPE obtained from Diaz-Soltero 1995 and 1997, Lecky 1998, 1999, and Bruce Oppenheim, NOAA Fisheries, pers comm 2000, 2001, 2002.

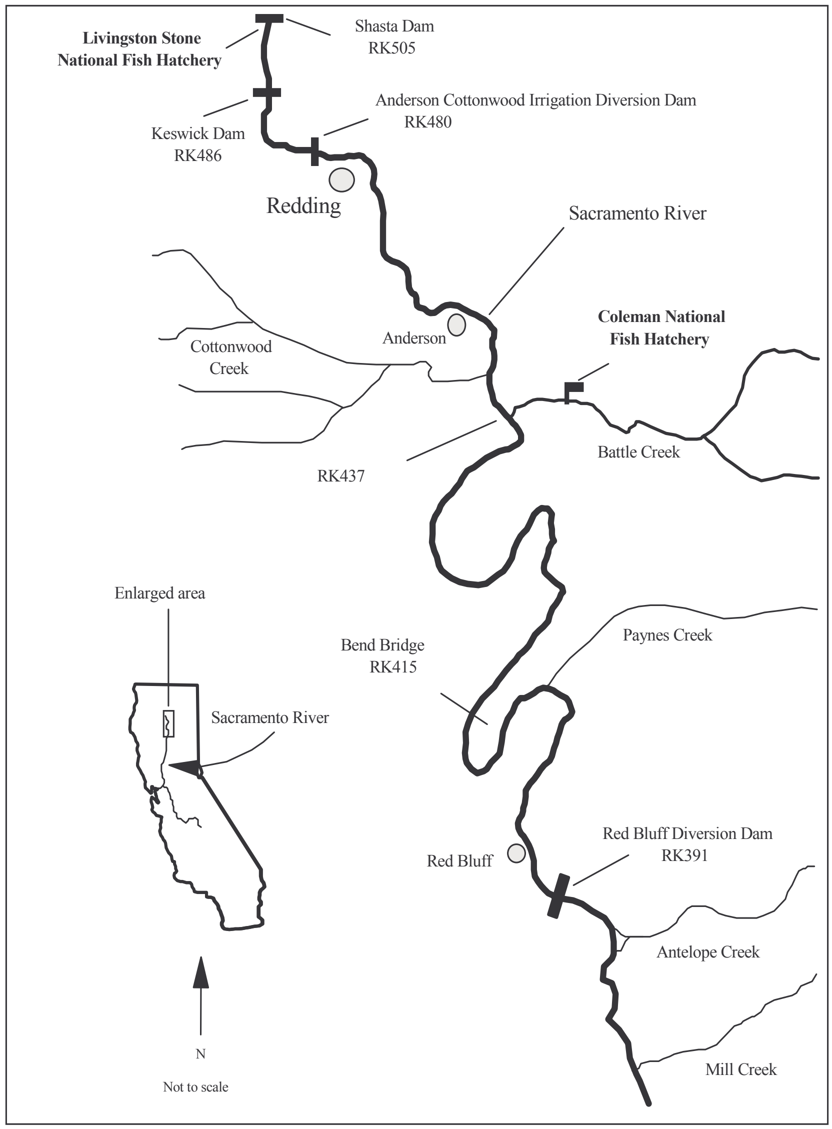

Figure 1. Location of Red Bluff Diversion Dam on the Sacramento River, CA, at river kilometer 391 (RK391).

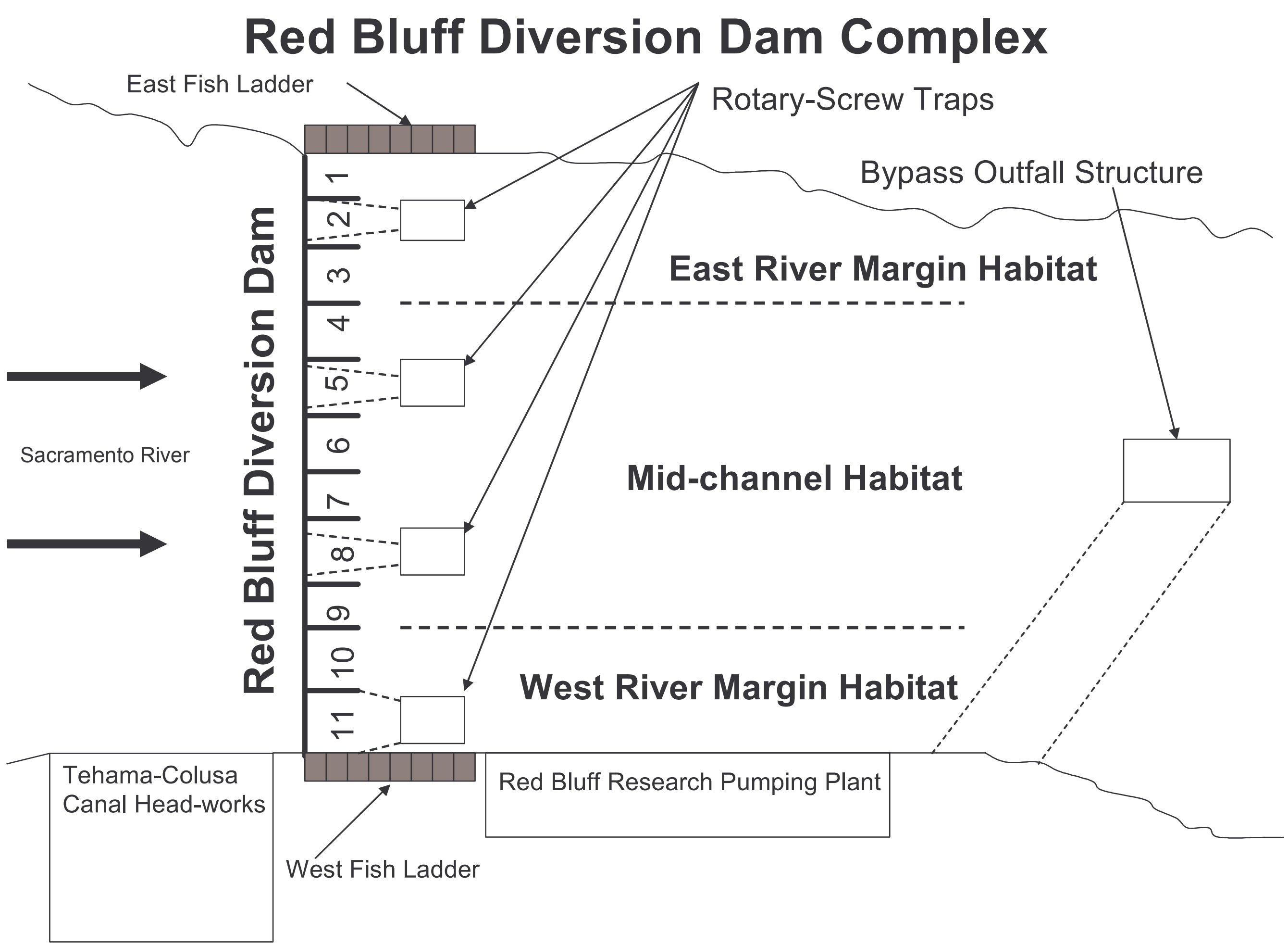

Figure 2. Rotary-screw trap sampling transect at Red Bluff Diversion Dam Complex (RK391) on the Sacramento River, CA.

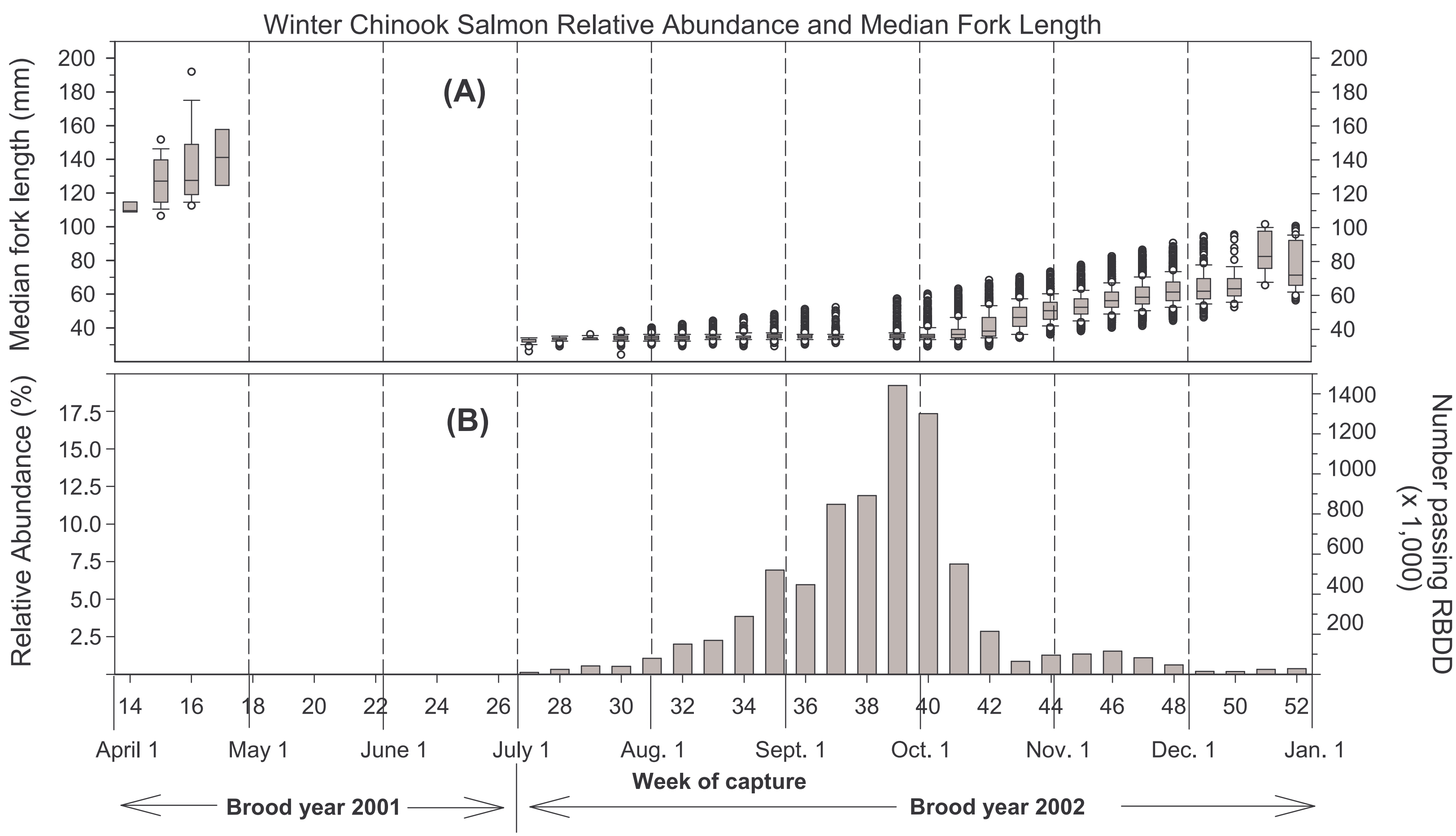

Figure 3. Median fork length (A) and estimated abundance (B) of BY02 winter Chinook salmon (fry and pre-smolt/smolts combined) passing Red Bluff Diversion Dam (RK391), Sacramento River, CA. Winter Chinook juveniles were captured by rotary-screw traps for the period April 1 through December 31, 2002. Box plots display weekly median fork lengths, 10^{th}, 25^{th}, 75^{th} and 90^{th} percentiles and outliers.

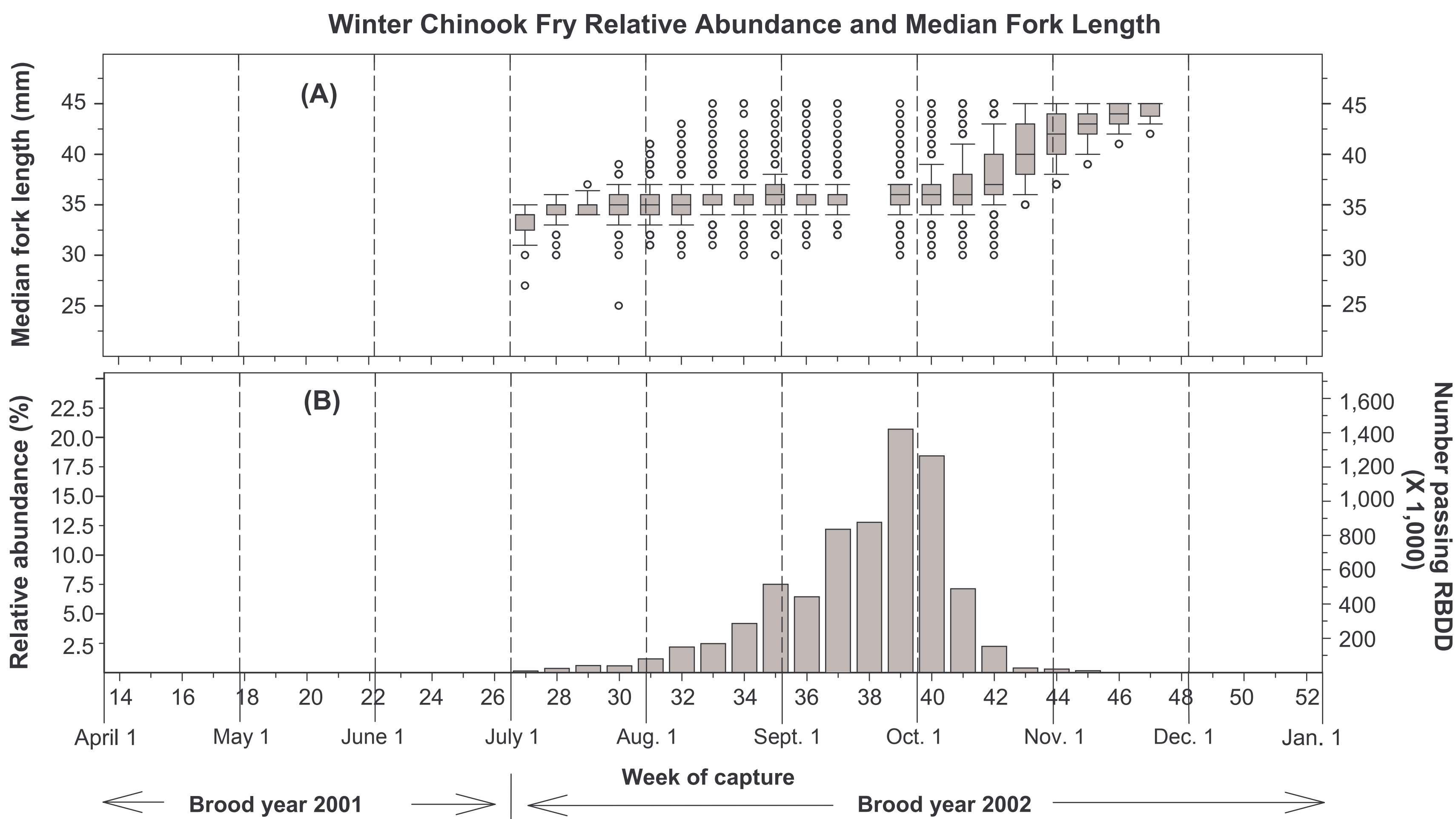

Figure 4. Median fork length (A) and estimated abundance (B) of winter Chinook fry (<46 mm FL) passing Red Bluff Diversion Dam (RK391), Sacramento River, CA. Winter Chinook juveniles were captured by rotary-screw traps for the period April 1 through December 31, 2002. Box plots display weekly median fork lengths, 10th, 25th, 75th and 90th percentiles and outliers.

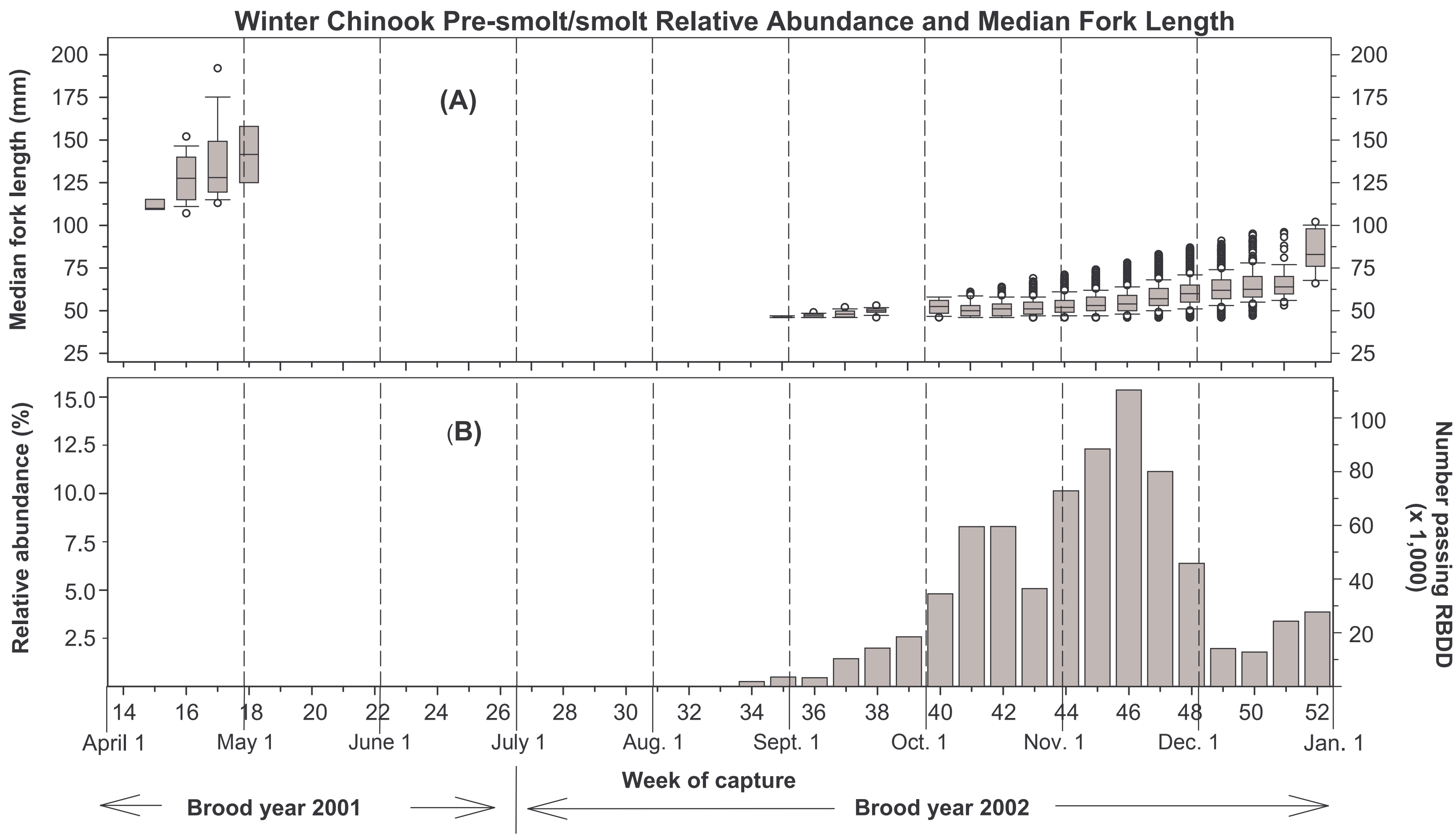

Figure 5. Median fork length (A) and estimated abundance (B) of winter Chinook pre-smolt/smolts (46-200 mm FL) passing Red Bluff Diversion Dam (RK391), Sacramento River, CA. Winter Chinook pre-smolt/smolts were captured by rotary-screw traps for the period April 1 through December 31, 2002. Box plots display weekly median fork lengths, 10th, 25th, 75th and 90th percentiles and outliers.

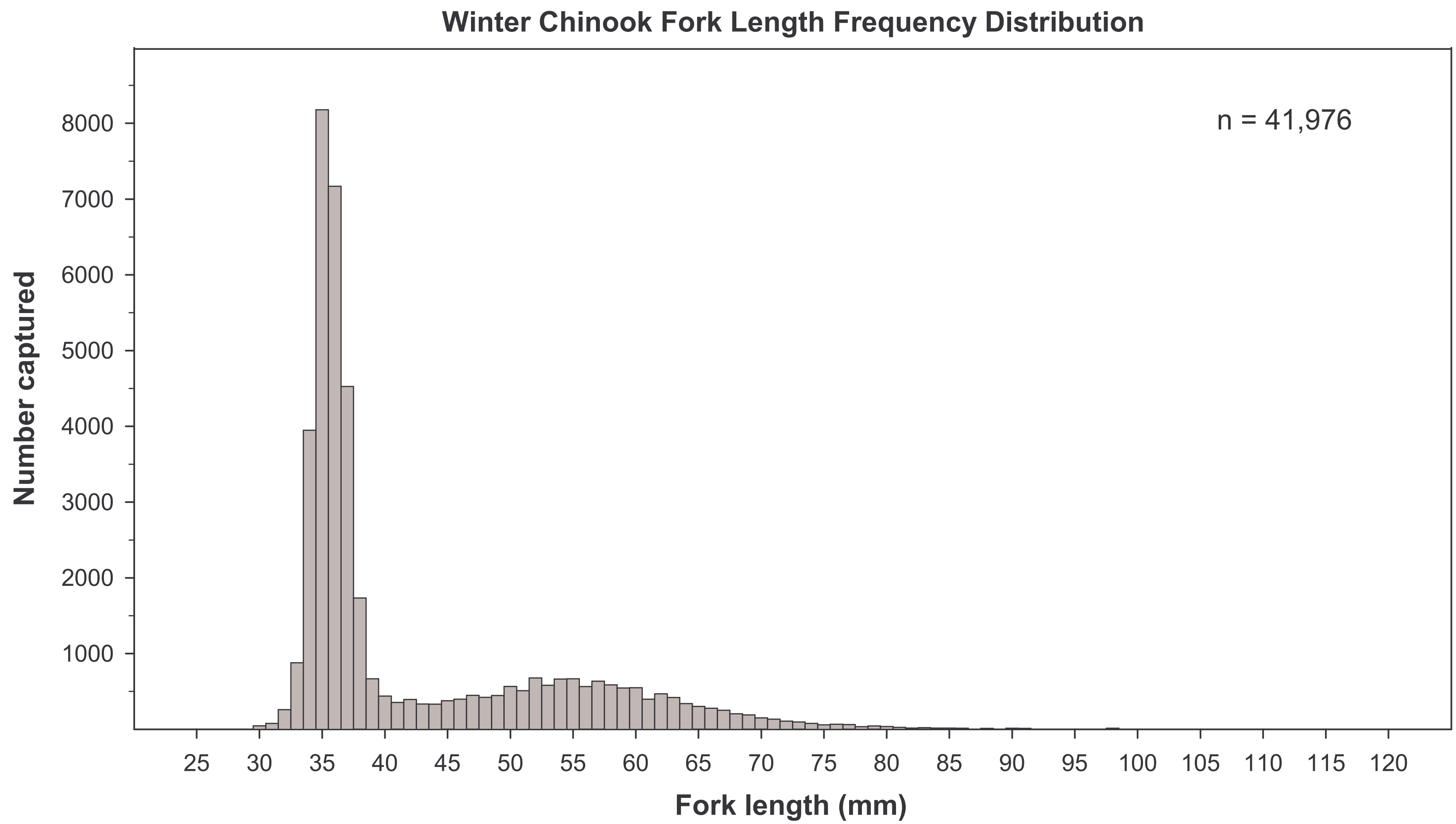

Figure 6. Fork length frequency distribution for BY02 winter Chinook salmon captured by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Fork length data was expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from April 1 through December 31, 2002.

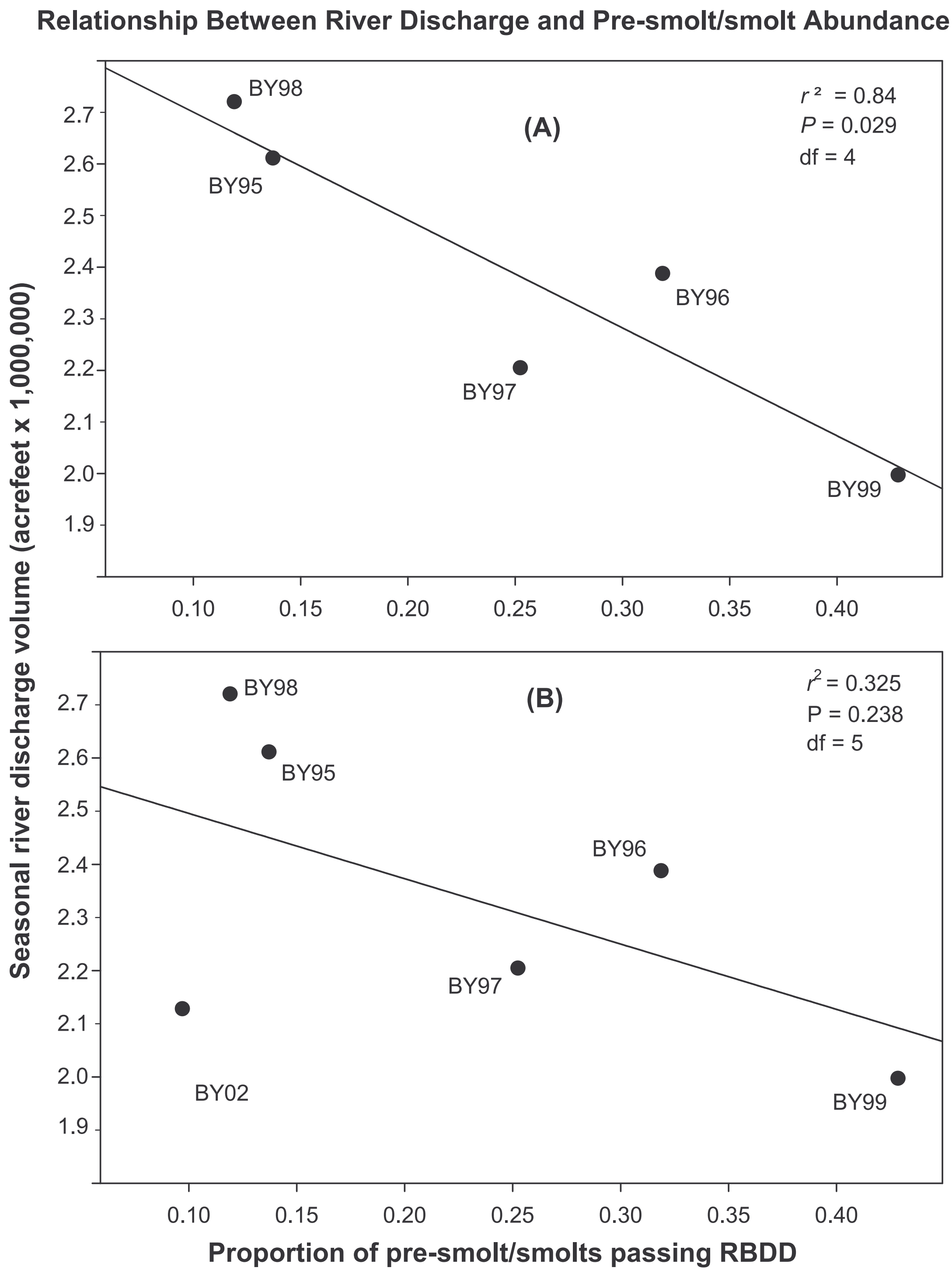

Figure 7. Linear relationship between seasonal river discharge (July, Aug. and Sept.) and the relative proportion (in percent) of winter Chinook pre-smolt/smolts passing Red Bluff Diversion Dam (RK391), Sacramento River, CA. Figure A depicts a strong correlation (r^2 = 0.840) using data from BY95 - 99 (figure reproduced from Martin et al. 2001). Figure B depicts a much weakened relationship (r^2 = 0.325) with the addition of BY02 data to the regression model.

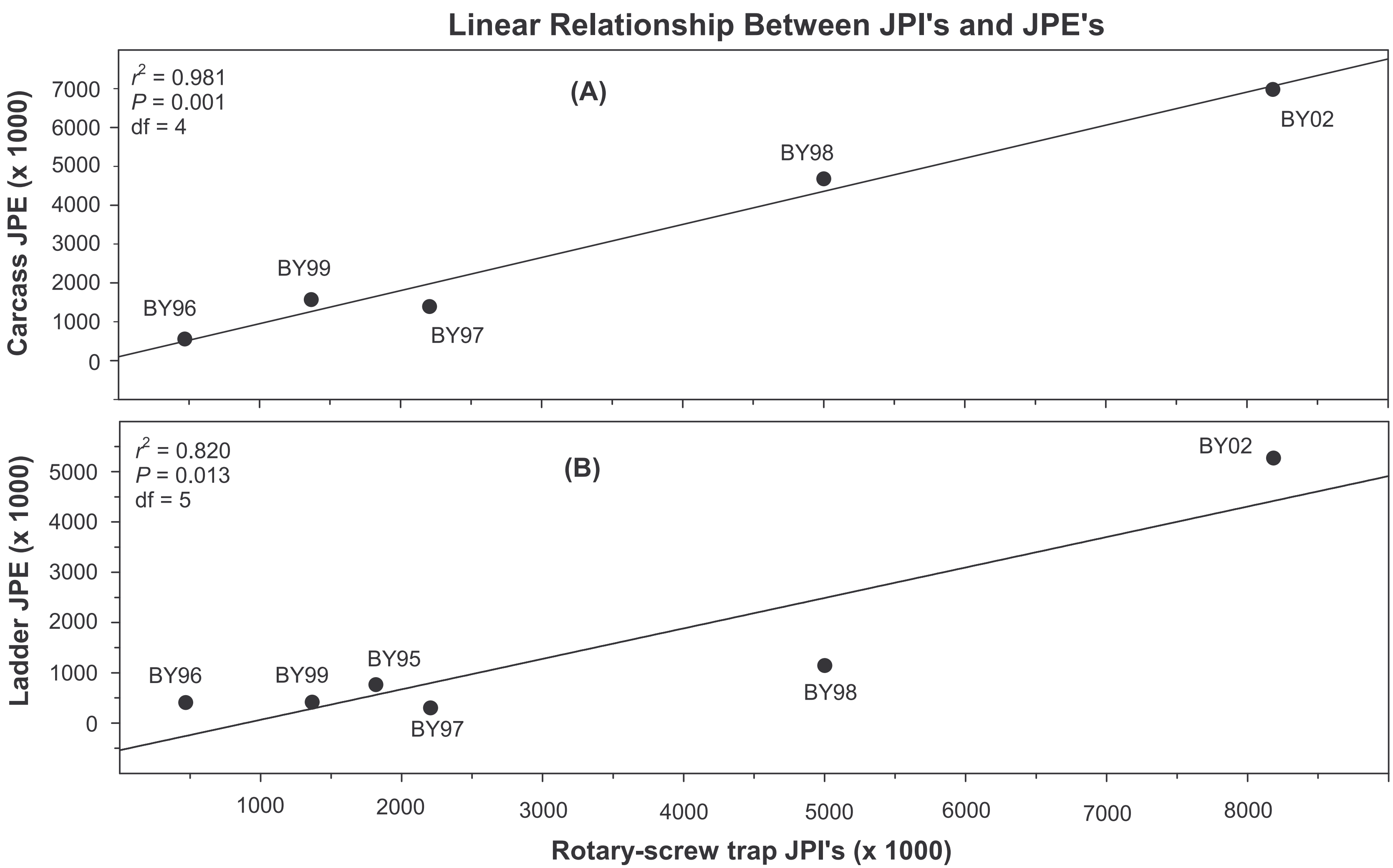

Figure 8. Linear relationship between rotary-screw trap juvenile production indices (JPI) and (A) carcass survey derived juvenile production estimates (JPE) and (B) RBDD ladder count derived JPE's.