BROOD-YEAR 2003 WINTER CHINOOK JUVENILE PRODUCTION INDICES WITH COMPARISONS TO ADULT ESCAPEMENT

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Prepared by:
Phillip D. Gaines
and
William R. Poytress

U.S. Fish and Wildlife Service
Red Bluff Fish and Wildlife Office
10950 Tyler Road
Red Bluff, CA 96080

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Brood-year 2003 winter Chinook juvenile production indices with comparisons to adult escapement

Phillip D. Gaines and William R. Poytress

U.S. Fish and Wildlife Service
Red Bluff Fish and Wildlife Office

Abstract.— Brood-year 2003 winter Chinook salmon juvenile passage at Red Bluff Diversion Dam (RBDD) was 5,945,585 fry and pre-smolt/smolts combined, approximately 23% less than that observed for brood-year 2002. Fry-equivalent passage was 6,536,854. 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 (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 ($r^2 = 0.98$, $P < 0.001$, df = 5) and, to a lesser extent, fish ladder JPE's ($r^2 = 0.85$, $P = 0.003$, df = 6). However, paired comparisons revealed a significant difference in production estimates existed between JPI's and fish ladder JPE's ($t = 3.81$, $P = 0.009$, df = 6). Moreover, fish ladder JPE's fell below the lower 90% confidence interval (C.I.) about the rotary-trap JPI in six of seven 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 ($t = 1.85$, $P = 0.124$, df = 5), and carcass survey JPE's fell within the 90% C.I. for rotary-trap JPI's in five of six 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.

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Introduction

Numerous measures have been implemented to protect and conserve federally endangered winter Chinook salmon, *Onchorhyncus tshawytscha*. One measure is to creatively 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 Chinook salmon annually migrating through the Delta seaward. The United States Bureau of Reclamation and the California Department of Water Resources are authorized by the NOAA Fisheries for incidental take of up to two percent of the annual winter Chinook population at these facilities (CDFG 1996). The NOAA Fisheries uses a juvenile production model to estimate abundance of the juvenile population entering the Delta. The production model uses estimated adult escapement as the primary variate. Historically, the model has used adult escapement estimates derived from counts of fish using the fishways (ladders) at Red Bluff Diversion Dam (Diaz-Soltero 1995, 1997; Lecky 1998, 1999, 2000), and more recently, escapement estimates derived from the winter Chinook carcass survey (McInnis 2002).

The two survey methods (carcass surveys and RBDD ladder counts) have at times produced greatly dissimilar juvenile production estimates (JPE's). The incongruence between the estimates is primarily due to the size composition of fish sampled by each survey technique (Snider et al. 2000). Adult females are generally larger and may be more easily recognized and recovered, than their male counterparts, leading to skewed sex-ratios. For example, in 1999 the carcass survey male to female ratio was 1:8.4. Because gender differentiation is questionable at the RBDD ladders, an assumed 1:1 sex ratio is used for estimates. 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 dramatic effects on the JPE.

Another factor contributing to the incongruence in JPE's among survey techniques is the annual variability in migration timing. The gates at RBDD are only closed during a portion of the spawning migration, and only while the gates are closed are the fish ladders operational. Therefore, the majority of 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 - 48%, based on data from 1969-1985 when gates at RBDD were closed year-round (Snider et al. 2000).

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 question. Estimated escapement is just one factor affecting the accuracy of JPE's. Another factor, not addressed directly in the JPE model, is success on the spawning grounds. Many adult salmon may return to spawn, but if conditions are not conducive for successful reproduction, fewer juveniles would be produced than the model would predict. However, 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 and 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 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.

This annual report addresses, in detail, our juvenile winter Chinook monitoring activities at RBDD for the period January 1, 2003 through December 31, 2003. The report also includes juvenile monitoring data gathered from 1995 - 2002, for comparison. This report will be submitted to the California Bay-Delta Authority to comply with contractual reporting requirements for project ERP-01-N44.

Study Area

The Sacramento River is the largest river system in California, flowing south through 600 km (400 miles) of the state (Figure 1). It originates in northern California near Mt. Shasta as a mountain stream, widens as it drains adjacent slopes of the Coast, Klamath, Cascade, and Sierra Nevada mountain ranges, and reaches the ocean at the San Francisco Bay. Although agricultural and urban development 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 (RK391) on the Sacramento River, approximately 3 km southeast of the city of Red Bluff. The dam is 226 m wide and has eleven fixed-wheel gates 18 m wide. Between gates are concrete piers 2.4 m in width. Gates can be raised allowing for run-of-the-river conditions, or lowered to impound and divert river flows into the Tehama-Colusa Canal.

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 across 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 (< 1.2 m), or river hydrology restricted our ability to sample with all traps (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 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 restrictions. The specific sub-sampling protocol implemented was contingent upon the number of winter Chinook captured. 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 stratum 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 by assigning a value of 1.00 to a sample consisting of all 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 (nearest 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 opening 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 cone at a depth of 0.6 m, and (3) duration of the sample. River volume (Q)

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

was obtained from the California Data Exchange Center's Bend Bridge gauging station. The 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 granulated pigments using spray-dye techniques (Phinney et al. 1967), bismark brown stain (Mundie and Traber 1983) or both (Gaines and Martin 2004, in print). Spray-dye marking equipment consisted of: (1) a 1.5 hp compressor and regulator valve capable of maintaining hose pressure of 0.454 kg/2.54 cm^2; (2) a spray-gun fitted with a 0.9 L canister and a 2.4 mm diameter siphon orifice; and (3) fluorescent, granulated pigment. Fish were stained in bismark brown staining solution prepared at a concentration of 21.0 mg/L of water. Fish were stained in solution for 45-50 minutes and removed.

Marked fish were held for 6-24 h before being released, generally 4 km upstream from RBDD. It was assumed that negligible mark-induced mortality occurred following the holding period (Gaines and Martin 2004, in print).

Horizontal distributions.— The horizontal distribution of winter Chinook juveniles passing RBDD was evaluated by comparing catch per unit volume (CPUV) among traps. Traps were configured behind RBDD such that samples were gathered from three distinct spatial zones: (1) west river-margin, (2) mid-channel and (3) east river-margin (Figure 2). Traps sampling river margin habitats were positioned behind RBDD gates nearest to the river margins that provided sufficient water depth (> 1.2 m) and water velocity (0.6 m/s). Mid-channel positioning was defined as trap(s) positioned between the west and east river-margin. If all three spatial zones could not be sampled simultaneously, then CPUV across traps was not used for analyses of horizontal distributions. Generally, gates 11-10 represented the west river-margin, gates 9-4 the mid-channel and gates 3-1 the east river-margin (Figure 2). Simultaneous sampling of spatial zones was maintained unless river levels, river morphology or RBDD gate positioning inhibited trap grouping in these areas. When this occurred, traps were positioned where water velocities and river depths allowed for proper rotary-screw trap operation. To determine if significant differences in CPUV existed among spatial zones, we used the Kruskal-Wallis test on Log_{10} X + 1.0 transformed values.

Rotary-screw trap modifications.— Traps were structurally modified to sample one-half of the volume of water entering the trap. We used an aluminum plate to completely seal off one of the two pathways, or openings, at the rear portion of the screw-trap cone, thereby, preventing water or fish to pass into the live box from that pathway. We then cut away a portion of the perforated screen covering the cone adjacent to the blocked opening. In doing so, water and fish that entered the cone on one side of the central divider would pass through the cone and out through the opening in the perforated screen, without passing into the live box. Water and fish that entered the cone on the opposite side of the central divider were passed directly into the live box. These modifications were made so we could selectively reduce capture and impact on listed species when abundance was high. We assumed trap modifications would result in a 50% reduction in capture efficiency. We did not test this assumption directly because of very low sample size and also because several factors affect trap efficiency that were unrelated to our modifications. Therefore, we evaluated the relative frequency of capture immediately prior to and immediately following trap modifications. We used a simple two-sample *t*-test to test the hypotheses:

H_0: the difference in CPUV immediately prior to and following trap modifications = zero.

H_1: the difference in CPUV immediately prior to and following trap modifications ≠ zero.

Passage Estimates

Winter Chinook passage was estimated by a model developed to predict daily trap efficiency (T_d). The model was developed by conducting 74 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.

$$P_d = \frac{C_d}{T_d}$$

where,

5.

$$T_d = (0.008011)(\%Q) - 0.000244$$

and, 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.
$$\hat{P} = \sum_{d=1}^{n} \hat{P}_d$$

To estimate $\hat{P}_d$ when samples were *missed* (not conducted or when a sample's integrity was compromised), we assigned a value to $\hat{P}_d$ calculated as the mean of $\hat{P}_d$ from the sample immediately proceeding and following the missing sample. When consecutive samples were missed, we noted the number of samples missed, and assigned a mean value for each missing $\hat{P}_d$ calculated using the same number of samples immediately preceding and following the missed period (i.e., if two consecutive samples were missed, we calculated $\hat{P}_d$ for those samples using the two samples immediately preceding and following the missed samples).

Estimated variance.—

7.
$$Var(\hat{P}) = (1-\frac{n}{N})\frac{N^2}{n} s^2_{\hat{p}_d} + \frac{N}{n}\left[\sum_{d=1}^{n} Var(\hat{P}_d) + 2\sum_{i \neq j}^{n} Cov(\hat{P}_i, \hat{P}_j)\right]$$

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

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

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

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

where,

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

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

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

where,

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

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

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

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

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

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

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.— Sampling effort was greater in 2003 than in 2002 (Table 1). Weekly sampling effort ranged from 0.00 - 1.00 (0 = 0.69, n = 52 weeks). From July 1 through December 31, the period of greatest winter Chinook emigration, sampling effort ranged from 0.32 - 1.00 (0 = 0.90, n = 26 weeks).

Trap efficiency trials.— Eighteen mark-recapture trials were conducted in 2003 to estimate rotary-screw trap efficiency (Table 2). Only naturally produced fish were used in trials, and trap efficiencies ranged from 0.34 - 2.75% (0 = 1.66%). The number of marked fish released per trial ranged from 999 - 5,143 (0 = 1,729) and the number of marked fish recaptured after release ranged from 10 - 33 (0 = 22.6).

The fork lengths of fish marked and released in mark-recapture trials was commensurate with the fork lengths of fish captured by rotary-screw traps. A paired comparison of mean length of marked fish released (44.2 mm FL) was statistically greater than the mean length of marked fish recaptured (42.6 mm FL; $P = 0.011$, df = 17).

We analyzed capture frequencies of marked and unmarked fish among spatial zones to determine if marked fish randomly distributed with unmarked fish after release. Significant differences in capture frequencies of marked and unmarked fish among spatial zones were not detected (chi-square, $P = 0.179$).

Trap efficiency modeling.— Trap efficiency was positively correlated to *%Q*, with higher efficiencies occurring as river discharge volumes decreased and the proportion of discharge volume sampled by rotary-screw traps increased (Figure 3). Regression analysis revealed a significant relationship between trap efficiency and *%Q* ($P < 0.0001$).

The strength of the relationship improved from $r^2 = 0.37$ to $r^2 = 0.40$ (Figure 3) with the addition of 18 trials conducted in 2003 and 3 trials conducted in 2002.

Patterns of Abundance

The information presented below is based on a 2003 calendar year reporting cycle. As such, note the emigration cycle for winter Chinook juveniles begins on July 1 and ends on June 30, for a given brood-year. This 2003 annual report, therefore, contains results for two different brood-years, the last half of BY02 (January 1 through June 30) and the first half of BY03 (July 1 through December 31). Interpretation of the information contained within will be improved by knowing that approximately 97% of any given brood-year will pass RBDD during the period July 1 through December 31 (Martin et al. 2001). Where appropriate, data from 2002 has been included for contrast.

Brood-year 2002.— Passage of BY02 winter Chinook juveniles occurred from January 1 through late April, 2003. Estimated passage during this period was 153,547 and represented approximately two percent of BY02 total passage (fry and pre-smolt/smolts combined), but 16% of pre-smolt/smolt passage. Passage generally declined throughout the period with weekly estimates of ranging from 47,446 in week one to 979 in week 16 (Table 3). Weekly median fork length of BY02 pre-smolt/smolts ranged from 82 to 131 mm from week 3 through week 16, increasing an average of 3.5 mm per week.

Brood-year 2003.— Brood-year 2003 winter Chinook juvenile passage at RBDD was 5,945,585 (Table 3). This represents approximately 23% less juvenile passing RBDD than that observed in 2002, yet is still greater than any other year sampled dating back to 1995.

Brood-year 2003 newly emerged juveniles began to pass RBDD in early July (week 27) and weekly passage increased steadily through late September (Fig. 4b). Weekly fry passage increased from 899 to 11,844 in July, 26,488 to 316,362 in August and peaked at 1,179,960 in late September (week 39). Weekly passage then generally declined through late November. No fry were captured after week 48. Total estimated passage of BY03 winter Chinook fry was 5,100,899. The temporal emigration pattern of BY03 fry was consistent with the pattern observed for BY02 (Figure 5b), with passage of newly emerged fry beginning in early July and peak passage occurring in week 39 (Table 3). Similarly, no BY02 fry were captured after week 48.

Brood-year 2003 pre-smolt/smolt sized (>45 mm FL) juveniles began to emigrate past RBDD in late August (week 34), increased in number weekly and peaked in abundance in late November (week 45) at 248,751 (Table 3). Weekly passage then declined through week 52 (Figure 6b).

Weekly median fork length of BY03 fry increased slowly from 33.0 mm in week 27 to 37.0 mm in week 43. Fork lengths increased rapidly from 37.0 mm to 40.0 mm in week 44 and steadily increased, thereafter, to 45.0 mm in week 47 (Figure 5a). Brood-year 2003 pre-smolt/smolt median fork length ranged from 46.5 to 54.0 mm from week 34 - 44, increasing by 0.5 mm per week on average (Figure 6a). From week 44 - 51, however, weekly median fork length increased by 1.7 mm per week from 54.0 to 64.0 mm. The length frequency distribution of BY03 juveniles was positively skewed and strongly influenced by 34.0-38.0 mm FL individuals (Fig. 7a), similar to the distribution observed for BY02 winter Chinook (Figure 7b). Only 14.2% of BY03 winter Chinook juveniles passing RBDD were pre-smolt/smolt sized individuals (12.0% for BY02). This proportion may minimally increase because BY03 pre-smolt/smolts will undoubtedly pass RBDD after December 31, 2003 and are, therefore, not included in this report. Estimated passage of BY02 pre-smolt/smolts passing after December 31, 2002 was 1.9% of total passage.

Horizontal distribution.— The horizontal distribution of winter Chinook juveniles passing RBDD differed for gates raised versus gates lowered periods. For the gates raised period (Sept. 16-May 14), catch per unit volume (CPUV) was not significantly different among mid-channel (1.51 fish/acre foot), east river-margin (0.87 fish/acre foot) or west river-margin (0.95 fish/acre foot) habitats ($P = 0.067$). However, for the gates lowered period (May 15-Sept. 15), CPUV was significantly greater for the west river-margin habitat (0.94 fish/acre foot) than for the mid-channel (0.57 fish/acre foot) or the east river-margin (0.26 fish/acre foot) habitats ($P = 0.001$).

Trap modifications.— Significant differences in CPUV were not detected among samples gathered immediately prior to and immediately following trap modifications (paired t-test, $P = 0.53$, df = 10). To control for extraneous variables that effect trap efficiency, we only used samples that were gathered when river discharge volume, turbidity, water temperature and weather patterns were stable.

Comparison of JPI and JPE. — The fry-equivalent rotary-trap JPI for BY03 was 6,536,854. The BY03 fry-equivalent carcass survey and fish ladder JPE's were 6,182,038 and 3,327,968, respectively. Only the carcass survey JPE fell within the 90% C.I. about the rotary-trap JPI (Table 4).

We combined data from 1995-2002 with BY03 JPE's and JPI's to evaluate the linear relationship between the estimates. Only a limited number of 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 were significantly correlated *in trend* to carcass survey JPE's ($r^2 = 0.98$, $P < 0.001$, df = 5; Figure 8a) and fish ladder JPE's ($r^2 = 0.85$, $P = 0.003$, df = 6; Figure 8b). However, paired comparisons revealed a significant difference in fry-equivalent production estimates existed among rotary-trap JPI's and fish ladder JPE's ($t = 3.81$, $P = 0.009$, df = 6). Moreover, fish ladder JPE's fell below the lower 90% C.I. about the rotary-trap JPI in five of seven years evaluated (Table 4). On average, fish ladder JPE's were 54% less than rotary-trap JPI's (range = -13 to -86%). Conversely, no significant difference was detected among rotary-trap JPI's and carcass survey JPE's ($t = 1.85$, $P = 0.124$, df = 5), and carcass survey JPE's fell within the 90% C.I. about the rotary-trap JPI in five of six years evaluated. On average, carcass survey JPE's were 7% less than rotary-trap JPI's (range = -37 to +17%).

Discussion

Sampling effort.— Weekly sampling effort was much greater in 2003 than 2002, for two primary reasons (Table 1). First, the project was able to complete hiring actions and attain full staffing levels, allowing for continuous sampling seven days weekly. Secondly, rotary-screw traps were structurally modified to reduce capture and impact on listed species, reducing concerns of exceeding Endangered Species Act Section 10 Permit restrictions on take of juvenile winter Chinook salmon as well as improving the accuracy and precision of abundance estimates. From July through November 2003, the peak winter Chinook emigration period, rotary-screw traps sampled 24 h daily on 141 of 153 days. Seven days were not sampled in mid September due to RBDD operations associated with the annual draw-down of Lake Red Bluff. In contrast, only 112 of 153 days were sampled for the same period in 2002. Also, on many occasions in 2002, a sub-sampling protocol was implemented such that traps sampled less than 24 h daily. During sub-sampling events, daily passage estimates were expanded, sometimes greatly, to account for passage during un-sampled portions of the day. However, Gaines and Martin (2002) determined that juvenile passage was not uniformly distributed within a sampling unit (24 h). Therefore, the precision of our passage estimates was less than desired when sub-sampling protocols were used. Our monitoring program at RBDD has historically used sub-sampling protocols to reduce take and incidental mortality in accordance with ESA restrictions (Martin et al. 2001, Gaines and Martin 2001, Gaines and Poytress, 2003).

Trap modifications.— To reduce our reliance on sub-sampling protocols and improve the accuracy and precision of passage estimates at RBDD, we structurally modified our traps so that we could simultaneously reduce fish capture while maintaining continuous sampling throughout sampling units. We assumed our trap modifications reduced trap efficiency and fish capture by approximately 50%. To determine if traps performed as assumed, we conducted trap efficiency trials with modified traps and compared trap efficiencies to trials conducted with unmodified traps. In 2003, mean trap efficiency for trials using modified traps was 1.08% compared to 2.03% for unmodified traps, well within the range of that expected (Table 2). This comparison was not straightforward and no statistical analysis was performed because trials could not be conducted simultaneously with both modified and unmodified traps. Moreover, many other factors such as fish size, water velocity, water temperature and the spatial distribution of out migrating fish can also greatly affect trap efficiency, and these factors were not consistent among trials. We were, however, able to directly compare CPUV immediately prior to and following trap modifications during times of the year, primarily the fall, when river conditions are stable and we would not expect large differences in capture frequency or trap efficiency among consecutive samples. Using each trap as its own replicate, paired comparisons did not detect a significant difference between CPUV immediately prior to and immediately following trap modifications ($P = 0.53$, df = 10). We concluded that structural modification of rotary-screw traps was a preferable method to sub-sampling protocols to reduce take and impact on listed species while improving the accuracy and precision of passage estimates at RBDD.

Trap efficiency modeling.— On three occasions in 2002 and 18 occasions in 2003, we measured the efficiency of our rotary-screw traps using mark-recapture trials. Data from trials were combined with data from 58 previously conducted trials to model the relationship between trap efficiency and %Q at RBDD (Figure 3). Trap efficiency was moderately correlated with %Q ($r^2 = 0.40$). However, there was substantial variability in trap efficiency that was not explained by %Q. Certainly many factors affect the efficiency of traps such as, fish size, day versus night passage, water turbidity and water velocity. But perhaps the most influential factor affecting trap efficiencies at RBDD was the location, or physical placement, of traps across our sampling transect. In general, traps were located to sample equidistantly from each other while also sampling river-margin and mid-channel habitats (Figure 2). However, river morphology and hydrology ultimately dictated where traps sampled, and given all other factors to be constant, we would expect traps to be differentially efficient under certain placement configurations due to the spatial distribution of juveniles as they pass RBDD. In the future, we propose to integrate other variables into our trap efficiency model. By modeling trap efficiency in a multiple regression setting we may be able to increase the accuracy and precision of passage estimates.

Patterns of abundance.— Brood-year 2003 winter Chinook juvenile passage at RBDD, from July 1 through December 31, 2003, was 5,945,585 fry and pre-smolt/smolts combined, approximately 23% less than that observed for the same period in 2002. While moderately less than BY02, BY03 passage was still greater than any other brood-year dating back to 1995. Among-year comparison of passage estimates from RBDD may be misleading with reference to juvenile year class strength if abundance is the foremost consideration. Primarily because the population of winter Chinook salmon passing RBDD is composed of both fry and pre-smolt/smolts, and the ratio of fry to pre-smolt/smolts is variable among years (Gaines and Martin, 2002). It's likely that differential survival exists between these subpopulations and, therefore, we would expect juvenile year class strength to vary, perhaps even greatly, given equal passage estimates among years. Therefore, we converted passage estimates to fry-equivalent juvenile production indices (JPI's) for among-year comparisons. The NOAA Fisheries JPE model generates a fry-equivalent production value as an intermediate step in the computation, so comparisons among JPI's and JPE's are straightforward.

Comparisons of JPI's and JPE's.— Martin et al. (2002) and Gaines and Poytress (2003) determined that the rotary-screw trap JPI was strongly correlated in trend to carcass survey JPE's, and to a lesser extent, fish ladder JPE's. Martin et al. (2002) reported only a moderate correlation ($r^2 = 0.566$, df = 4) between JPI's and fish ladder JPE's. Remarkably, the correlation was greatly improved ($r^2 = 0.820$, df = 5) with the addition of data from BY02 (Gaines and Poytress 2003). Data from BY03 was also supportive of this stronger relationship, slightly improving r^2 from 0.820 to 0.849 (Figure 8a & b). However, fish ladder JPE's were not supportive of JPI's with respect to the magnitude of fry-equivalent production values ($P = 0.009$, df = 5). Furthermore, it appears that fish ladder JPE's consistently underestimate juvenile production, relative to JPI's and carcass survey JPE's (Table 4). Historically, rotary-screw trap JPI's and carcass survey JPE's have been strongly correlated. Moreover, significant differences in the magnitude of JPI's and carcass survey JPE's were not detected. Data from BY03 strongly support this finding. The reader should be cautioned that our conclusions were based on small sample sizes in both the carcass survey ($N = 6$) and fish ladder ($N = 7$) comparisons between JPI's and JPE's. We conclude that the JPE model produces a more robust estimate of juvenile winter Chinook production using carcass survey data rather than fish ladder data from RBDD.

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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 24 h daily, seven days weekly. Weekly values less than 1.00 represent occasions where less than four traps were sampling, we randomly sub-sampled periods of the day or night, traps were structurally modified to sample only one-half the normal volume of water or when less than seven days were sampled. Trap damage and repair was the primary reason when less than four traps were sampling. Sub-sampling and modifying traps to sample less water volume were implemented to prevent exceeding our authorized take limitations for winter Chinook salmon. A winter Chinook brood-year (BY) is defined as beginning on July 1 and ending on June 30.

	Sampling effort				Sampling effort		
Week	BY01	BY02	BY03	Week	BY01	BY02	BY03
1 (Jan)	-	0.00	-	27	-	0.48	1.00
2	-	0.00	-	28	-	0.50	1.00
3	-	0.27	-	29	-	0.02	1.00
4	-	0.32	-	30	-	0.21	1.00
5 (Feb)	-	0.48	-	31 (Aug)	-	0.36	1.00
6	-	0.50	-	32	-	0.32	0.96
7	-	0.29	-	33	-	0.32	1.00
8	-	0.32	-	34	-	0.23	1.00
9 (Mar)	-	0.84	-	35 (Sep)	-	0.11	1.00
10	-	1.00	-	36	-	0.29	0.86
11	-	0.54	-	37	-	0.21	0.32
12	-	0.68	-	38	-	0.00	0.36
13 (Apr)	-	0.75	-	39	-	0.50	0.89
14	0.04	0.57	-	40 (Oct)	-	0.36	1.00
15	0.21	1.00	-	41	-	0.36	1.00
16	0.25	0.43	-	42	-	0.43	1.00
17	0.29	0.05	-	43	-	0.75	1.00
18 (May)	0.25	0.16	-	44 (Nov)	-	0.88	0.86
19	0.32	0.75	-	45	-	0.88	1.00
20	0.00	0.00	-	46	-	0.98	1.00
21	0.14	0.00	-	47	-	1.00	1.00
22 (Jun)	0.07	0.68	-	48 (Dec)	-	1.00	1.00
23	0.27	1.00	-	49	-	0.96	0.71
24	0.13	1.00	-	50	-	0.57	0.43
25	0.00	0.96	-	51	-	0.07	1.00
26 (Jul)	-	0.43	1.00	52	-	0.11	0.00

Table 2.— Summary results from mark-recapture trials conducted in 2002 (n = 3) and 2003 (n = 18) to determine rotary-screw trap efficiency at Red Bluff Diversion Dam, Sacramento River (RK391), CA. Results include the number of fish released and recaptured, combined trap efficiency (TE %), percent river volume sampled by rotary-screw traps (%*Q*), number of traps sampling during trials and whether or not traps were structurally modified to reduce volume sampled by 50% (Traps modified).

Trial #	Number released	Number recaptured	TE (%)	%*Q*	Number of traps sampling	Traps modified
1	805	8	0.99	1.56	4	Yes
2	743	16	2.15	1.55	4	Yes
3	340	7	2.06	1.45	3	Yes
4	5,143	33	0.64	0.73	4	Yes
5	2,943	10	0.34	1.24	4	Yes
6	3,106	29	0.93	1.53	4	Yes
7	3,256	15	0.46	0.68	3	Yes
8	2,019	22	1.09	1.11	3	Yes
9	1,456	31	2.13	2.98	3	No
10	1,168	28	2.40	3.66	4	No
11	1,053	22	2.09	3.56	4	No
12	1,067	17	1.59	2.59	3	No
13	1,119	14	1.25	2.06	4	No
14	1,283	26	2.03	2.53	3	No
15	1,197	30	2.51	2.56	3	No
16	1,012	18	1.78	2.20	3	No
17	1,017	28	2.75	2.89	4	No
18	1,064	20	1.88	3.08	4	No
19	999	22	2.20	3.02	4	No
20	1,017	16	1.57	3.03	4	No
21	1,209	26	2.15	2.97	4	No

Table 3.— Weekly passage estimates, median fork length and juvenile production indices (JPI's) for winter Chinook salmon passing Red Bluff Diversion Dam (RK391). Sampling was conducted using rotary-screw traps from April 1, 2002 through December 31, 2003. This period represents the last three months of brood-year 2001 (BY01), all of BY02 and the first six months of BY03. Sampling effort was not sufficient to produce robust JPI's for weeks 14 and 15 of BY01, but did provide pertinent fork length data. 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 2001							
14	-	-	-	110	-	110	-
15	-	-	-	127.5	-	127.5	-
16	0	-	325	128	325	128	554
17	0	-	301	141.5	301	141.5	508
18	0	-	0	-	0	-	-
19	0	-	0	-	0	-	-
20	0	-	0	-	0	-	-
21	0	-	0	-	0	-	-
22	0	-	0	-	0	-	-
23	0	-	0	-	0	-	-
24	0	-	0	-	0	-	-
25	0	-	0	-	0	-	-
Brood-year 2002							
26	0	-	0	-	0	-	0
27	9,346	34	0	-	9,346	34	9,346
28	24,760	35	0	-	24,760	35	24,760
29	41,699	35	0	-	41,699	35	41,699
30	40,032	35	0	-	40,032	35	40,032
31	80,576	35	0	-	80,576	35	80,576

Table 3.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
32	152,208	35	0	-	152,208	35	152,208
33	171,844	35	44	-	171,888	35	171,920
34	290,962	35	1,900	46	292,862	35	294,192
35	519,078	36	3,591	47	522,669	36	525,182
36	438,136	36	3,382	48	441,518	36	443,886
37	847,834	36	10,704	50	858,538	36	866,027
38	891,191	-	14,819	-	906,010	-	916,377
39	1,445,079	36	19,232	52.5	1,464,311	36	1,477,769
40	1,298,580	36	35,853	50	1,334,433	36	1,359,528
41	482,887	36	59,317	51	542,204	37	583,725
42	151,660	37	59,854	51	211,514	39	253,410
43	27,477	40	37,030	52	64,507	47	90,428
44	20,607	42	74,223	53	94,830	51	146,786
45	11,141	43	89,522	54	100,663	53	163,327
46	2,768	44	114,163	57	116,931	57	196,846
47	853	45	82,286	60	83,139	59	140,743
48	32	45	46,236	62	46,268	62	78,635
49	0	-	14,455	62.5	14,455	62.5	24,575
50	0	-	22,811	64	22,811	64	39,309
51	0	-	47,446	77	47,446	77	81,900
52	0	-	54,224	72	54,224	72	93,600
1	0	-	47,446	-	47,446	-	81,900
2	0	-	47,446	-	47,446	-	81,900
3	0	-	23,079	95	23,079	95	39,591
4	0	-	3,541	82	3,541	82	6,016
5	0	-	3,953	114	3,953	114	6,722
6	0	-	4,021	109.5	4,021	109.5	6,836
7	0	-	3,716	97	3,716	37	6,316

Table 3.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
8	0	-	1,900	111	1,900	111	3,230
9	0	-	1,024	118	1,024	118	1,740
10	0	-	571	128	571	128	971
11	0	-	1,248	120	1,248	120	2,122
12	0	-	4,943	115	4,943	115	8,400
13	0	-	2,686	116	2,686	116	4,569
14	0	-	2,385	123	2,385	123	4,053
15	0	-	3,076	129	3,076	129	5,230
16	0	-	979	131	979	131	1,666
17	0	-	0	-	0	-	0
18	0	-	0	-	0	-	0
19	0	-	0	-	0	-	0
20	0	-	0	-	0	-	0
21	0	-	0	-	0	-	0
22	0	-	0	-	0	-	0
23	0	-	0	-	0	-	0
24	0	-	0	-	0	-	0
25	0	-	0	-	0	-	0
BY total	6,948,750		943,106		7,891,856	-	8,558,048
Brood-year 2003							
26	0	-	0	-	0	-	0
27	899	33	0	-	899	33	899
28	2,102	34	0	-	2,102	34	2,102
29	7,490	35	0	-	7,490	35	7,490
30	11,844	34	0	-	11,844	34	11,844
31	26,488	35	0	-	26,488	35	26,488
32	58,727	36	0	-	58,727	36	58,727

Table 3.— (continued)

Week	Fry		Pre-smolt/smolts		Total		Fry-equivalents
	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
33	78,037	36	0	-	78,037	36	78,037
34	114,329	37	685	46.5	115,013	37	115,492
35	316,362	37	4,153	47	320,516	37	323,423
36	270,284	37	2,266	48	272,549	37	274,134
37	460,409	37	6,054	49.5	466,464	37	470,699
38	934,891	36	7,814	49	942,704	36	948,171
39	1,179,960	36	12,974	49	1,192,934	36	1,202,015
40	609,919	36	17,796	51	627,716	37	640,174
41	399,485	36	48,689	52	448,175	37	482,258
42	425,418	37	70,237	51	495,653	37	544,819
43	133,600	37	49,410	52	183,007	38	217,592
44	28,902	40	45,389	52	74,291	48	106,062
45	28,569	43	248,751	54	277,324	52	451,450
46	10,028	44	104,444	54	114,474	53	187,584
47	2,754	45	80,105	57	82,858	57	138,933
48	402	45	38,029	59	38,430	59	65,048
49	0	-	61,429	61	61,429	61	104,431
50	0	-	17,913	63	17,913	63	30,453
51	0	-	12,580	64	12,580	64	21,385
52	0	-	15,968	-	15,968	-	27,144
BY03 total[1]	5,100,899		844,686		5,945,585		6,536,854

[1] BY03 totals are for the period July 1 to December 31, 2003.

Table 4.— Comparisons between juvenile production estimates (JPE) and rotary-trapping juvenile production indices (JPI). Fish ladder JPE and carcass survey JPE were derived from the estimated adult female escapement from fish ladder counts at Red Bluff Diversion Dam and the upper Sacramento winter Chinook carcass survey, respectively. From BY95 through BY99, assumptions used in the carcass survey JPE model were as follows: (1) 5% pre-spawning mortality, (2) 3,859 ova per female, (3) 0% loss due to high water temperature, and (4) 25% egg-to-fry survival. From BY00 through BY03, assumptions 1-3 were estimated carcass survey data gathered on the spawning grounds, from Livingston Stone National Fish Hatchery and aerial redd surveys, respectively. The upper Sacramento River carcass survey did not begin until the 1996 brood-year. Rotary-trapping was not conducted in 2000 or 2001.

	Rotary-trapping [a]			Carcass survey [b]		Fish ladder [c]	
		90% C.I.					
Brood-year	Fry-equivalent JPI	Lower	Upper	Fry-equivalent JPE	# female spawners	Fry-equivalent JPE	# female spawners
1995	1,816,984	1,658,967	2,465,169			764,082	4,673
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	8,560,652	4,798,472	11,431,210	6,978,583	5,670	5,270,598	4,673
2003	[d] 6,536,854	4,422,527	8,651,195	6,182,038	8,133	3,327,968	2,752

[a] Fry-equivalent JPI generated by summing fry passage at RBDD with a weighted pre-smolt/smolt passage estimate. Pre-smolt/smolts were weighted by 1.7 (59% fry to pre-smolt/smolt survival; Hallock undated).

[b] Fry JPE based on carcass survey estimates and using estimated effective spawner population from Snider et al. (1997, 1998, and 1999, and Bruce Oppenheim, NOAA Fisheries, pers comm 2000, 2001, 2002).

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

[d] BY03 Fry-equivalent JPI for the period July 1 to December 31, 2003.