BROOD-YEAR 2008 AND 2009 WINTER CHINOOK JUVENILE PRODUCTION INDICES WITH COMPARISONS TO JUVENILE PRODUCTION ESTIMATES DERIVED FROM ADULT ESCAPEMENT

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Brood-year 2008 and 2009 winter Chinook juvenile production indices with comparisons to juvenile production estimates derived from adult escapement

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Abstract.— Brood-year 2008 and 2009 juvenile winter-run Chinook salmon passage at Red Bluff Diversion Dam (RBDD) was 1,265,142 and 4,426,785 fry and pre-smolt/smolts combined, respectively. Fry-equivalent production was estimated to be 1,392,077 for 2008 and 4,993,787 for 2009. We compared rotary-screw trap fry-equivalent juvenile production indices (JPI's) to fry-equivalent juvenile production estimates (JPE's) derived from the National Oceanic and Atmospheric Administration's National Marine Fisheries Service JPE model. The JPE model uses estimates of adult escapement as the primary variate.

Fish ladder counts were conducted in 2008 but not 2009 and unofficial JPE's using adult escapement estimates from the RBDD fish ladders (RBDD JPE) were generated and compared for 2008 only. The 2008 RBDD JPE estimated value of 667,306 was compared to the 2008 JPI value of 1,392,077; indicating an underestimation of juvenile winter-run Chinook juveniles by 52%. Comparisons between rotary trap JPI's to historic RBDD JPE's continued to be moderately strong (r^2 = 0.62, P = 0.002, df = 11). Paired comparisons revealed a significant difference in production estimates between JPI's and RBDD JPE's (t = -3.92, P = 0.002, df = 11). The 2008 RBDD JPE fell below the 90% confidence intervals around the 2008 JPI. The final year of comparison using the 2008 RBDD JPE and rotary trap JPI revealed results similar to previous years' comparisons indicating consistent underestimation of winter-run Chinook juvenile production. The consistent inaccuracy of the RBDD JPE has rendered the estimator of limited utility and its use was discontinued by 2009.

The carcass survey derived JPE's (carcass JPE) were estimated at 1,952,614 and 3,728,444 for 2008 and 2009, respectively. The 2008 carcass JPE exceeded the JPI by 40.3% *and* the 90% confidence interval about the JPI by 1.3%. The 2009 carcass JPE fell within the confidence intervals of the 2009 JPI, yet the estimate was 25.3% less than the JPI. Rotary-screw trap JPI's continued to be correlated strongly in trend when compared to the carcass JPE's (r^2 = 0.83, P < 0.001, df = 11) with the addition of 2008 and 2009 data. Paired comparisons revealed no significant difference in the magnitude of production estimates between JPI's and carcass JPE's (t = -0.72, P = 0.49, df = 11). The relationship between the direct measure of juvenile abundance (JPI) and the indirect or modeled approach using carcass survey data remained strong with the addition of 2008 and 2009 data.

Table of Contents

Abstract iii
List of Tables v
List of Figures vii
Introduction 1
Study Area 3
Methods 3
  Sampling gear 3
  Sampling regimes 3
  Data collection 4
  Sampling effort 4
  Trap efficiency trials 4
  Trap efficiency modeling 4
  Passage estimates 5
    Daily passage 5
    Weekly passage 5
    Estimated variance 6
    Hypotheses testing 7
Results 7
  Sampling effort BY 2008 7
  Sampling effort BY 2009 8
  Trap efficiency trials 8
  Trap efficiency modeling 8
  Fork length evaluations BY 2008 8
  Patterns of abundance BY 2008 9
  Fork length evaluations 2009 9
  Patterns of abundance BY 2009 10
  Comparison of JPI and RBDD JPE 10
  Comparison of JPI and Carcass JPE 11
Discussion 11
  Sampling effort BY 2008 11
  Sampling effort BY 2009 12
  Trap efficiency modeling 13
  Patterns of abundance BY 2008 13
  Patterns of abundance BY 2009 14
  Comparisons of JPI's and JPE's 14
  BY 2008 Rotary trap JPI's and JPE's 15
  2008 and 2009 Rotary trap JPI's and Carcass JPE's 15
Acknowledgments 16
Literature Cited 17
Tables… 20
Figures 31

List of Tables

Table **Page**

1. Annual summary of BY 2008 weekly rotary trapping sampling effort. Full sampling effort was indicated by assigning a value of 1.00 to a week consisting of four, 2.4 m diameter rotary-screw traps sampling 24 hours daily, seven days a week. A winter Chinook brood-year (BY) is identified as beginning on July 1 and ending on June 30..........21

2. Annual summary of BY 2009 weekly rotary trapping sampling effort. Full sampling effort was indicated by assigning a value of 1.00 to a week consisting of four, 2.4 m diameter rotary-screw traps sampling 24 hours daily, seven days a week. A winter Chinook brood-year (BY) is identified as beginning on July 1 and ending on June 30..........22

3. Summary of results from mark-recapture trials conducted in 2009 (N = 2) to evaluate rotary-screw trap efficiency at Red Bluff Diversion Dam (RK391), Sacramento River, California. Results include the number of fish released, the mean fork length at release (Release FL), the number recaptured, the mean fork length at recapture (Recapture FL), combined 4 trap efficiency (TE %), percent river volume sampled by rotary-screw traps (%Q), number of traps sampling during trials, modification status as to whether or not traps were structurally modified to reduce volume sampled by 50% (Traps modified), and RBDD gate configuration at the time of the trial. 23

4. Weekly passage estimates, median fork length and juvenile production indices (JPI's) for winter Chinook salmon passing Red Bluff Diversion Dam (RK391) for the period July 1, 2008 through June 30, 2009 (Brood-year 2008). Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry- equivalents. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry-to-pre-smolt/smolt survival rate (59% or approximately 1.7:1, Hallock undated)................24

5. Weekly passage estimates, median fork length and juvenile production indices (JPI's) for winter Chinook salmon passing Red Bluff Diversion Dam (RK391) for the period July 1, 2009 through June 30, 2010 (Brood-year 2009). Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry- equivalents. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry-to-pre-smolt/smolt survival rate (59% or approximately 1.7:1, Hallock undated)................27

List of Tables Continued

Table **Page**

6. Comparisons between juvenile production estimates (JPE) and rotary trapping juvenile production indices (JPI). Fish ladder JPE's and carcass survey JPE's were derived from the estimated adult female escapement from fish ladder counts at Red Bluff Diversion Dam and the upper Sacramento River winter Chinook carcass survey. From BY95 through BY99, assumptions used in the carcass survey JPE model were as follows: (1) 5% pre-spawning mortality, (2) 3,859 ova per female, (3) 0% loss due to high water temperature, and (4) 25% egg-to-fry survival. From BY00 through BY07, assumptions 1-3 were estimated using carcass survey data gathered on the spawning grounds, from Livingston Stone National Fish Hatchery, and aerial redd surveys, respectively. The upper Sacramento River carcass survey did not begin until the 1996 brood-year. Dashes (-) indicate years surveys not performed. 30

List of Figures

Figure **Page**

1. Location of Red Bluff Diversion Dam on the Sacramento River, California, at river kilometer 391 (RK391) 32

2. Rotary-screw trap sampling transect at Red Bluff Diversion Dam Complex (RK391), Sacramento River, California...33

3. Weekly (bars) and monthly rotary trap sampling effort for the period July 1, 2008 – June 30, 2009 by category. Sampled portions represented by black bars; unsampled portions designated in descending order of frequency: intentional reductions in effort (dark grey), RBDD operations (light grey) and unintentional reductions (dark green)…. 34

4. Weekly (bars) and monthly rotary trap sampling effort for the period July 1, 2009 – June 30, 2010 by category. Sampled portions represented by black bars; unsampled portions designated in descending order of frequency: intentional reductions in effort (dark grey), limited field staff (red), RBDD operations (light grey) and unintentional reductions (dark green)…. 35

5. Trap efficiency model for combined 2.4 m diameter rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, California. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four traps (*N* = 92), three traps (*N* = 11), or with traps modified to sample one-half the normal volume of water (*N* = 22)...36

6. Weekly median fork length (a) and estimated abundance (b) of juvenile winter Chinook salmon fry (dark blue) and pre-smolt/smolts (light blue) passing Red Bluff Diversion Dam (RK391), Sacramento River, California. Winter Chinook salmon were sampled by rotary-screw traps for the period July 1, 2008 through June 30, 2009. Box plots display weekly median fork length, 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles and outliers 37

7. Fork length frequency distribution of brood-year 2008 juvenile winter Chinook salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, California. Fork length data was expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from July 1, 2008 through June 30, 2009...38

8. Weekly median fork length (a) and estimated abundance (b) of juvenile winter Chinook salmon fry (dark blue) and pre-smolt/smolts (light blue) passing Red Bluff Diversion Dam (RK391), Sacramento River, California. Winter Chinook juveniles were sampled by rotary-screw traps for the period July 1, 2009 through June 30, 2010. Box plots display weekly median fork length, 10^{th}, 25^{th}, 75^{th}, and 90^{th} percentiles and outliers 39

List of Figures continued

Figure **Page**

9. Fork length frequency distribution of brood-year 2009 juvenile winter Chinook salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, California. Fork length data was expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from July 1, 2009 through June 30, 2010 40

10. Linear relationship between rotary-screw trap fry-equivalent juvenile production indices (JPI) and (a) 2008 RBDD ladder count derived juvenile production estimates (JPE) and (b) 2008 and 2009 carcass JPE's 41

11. Maximum daily discharge (a) calculated from the California Data Exchange Center's Bend Bridge gauging station and average daily turbidity values (b) from rotary-screw traps at RBDD for the period July 1, 2008 through June 30, 2009..............................42

12. Maximum daily discharge (a) calculated from the California Data Exchange Center's Bend Bridge gauging station and average daily turbidity values (b) from rotary-screw traps at RBDD for the period July 1, 2009 through June 30, 2010..............................43

Introduction

Winter-run Chinook salmon is one of four distinct "runs" of Chinook salmon *(Oncorhynchus tshawytscha)* present in the upper Sacramento River, California. Distinguished by the season of the returning adult spawning migration, the winter-run Chinook salmon begin to return from the ocean to the Sacramento River in December (Vogel and Marine 1991).

Winter-run Chinook salmon have been federally listed as an endangered species since 1994[1]. Numerous measures have been implemented to protect and conserve the endangered winter-run Chinook salmon. One protective measure is adaptively managing water exports from the Central Valley Project's Tracy Pumping Plant and the State Water Project's Harvey Banks Delta Pumping Plant in the Sacramento-San Joaquin Delta (Delta). Exports are managed to limit entrainment of juvenile winter-run Chinook salmon (hereafter referred to as winter Chinook) annually migrating through the Delta seaward. The United States Bureau of Reclamation (USBR) and the California Department of Water Resources are authorized by the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) for incidental take of up to two percent of the annual winter Chinook population estimated to be entering the Delta and recovered at the pumping facilities (CDFG 1996). The NMFS uses a juvenile production model to estimate abundance of the juvenile winter Chinook population entering the Delta. Historically, the model has used adult escapement estimates derived from Red Bluff Diversion Dam (RBDD) fish ladder counts (Diaz-Soltero 1995, 1997; Lecky 1998, 1999, 2000), and more recently, escapement estimates derived from the winter Chinook carcass survey (McInnis 2002, NMFS 2004).

The NMFS juvenile production model uses estimated adult escapement as the primary variate. The two survey methods (carcass surveys and RBDD ladder counts) typically have produced greatly dissimilar adult escapement estimates. Consequently, winter Chinook juvenile production estimates (JPE's) differ greatly as well.

One factor contributing to the incongruence in JPE's, with respect to the annual RBDD adult ladder count estimate, is the annual variability in migration timing. The gates at RBDD are currently only closed during a portion of the winter Chinook spawning migration, and the fish ladders are operational only when the gates are closed. Therefore, the majority of winter Chinook adults pass above RBDD without using the fish ladders. Estimates of annual escapement are derived by assuming the proportion of adults using the fish ladders is 15% on average, and expanding accordingly. However, the proportion of adults passing during the gates closed period has ranged from 3% to 48%, based on data from 1969-1985 when gates at RBDD were closed year-round (Snider et al. 2001).

[1] The Sacramento River winter-run Chinook salmon was listed as endangered May of 1989 under the California Endangered Species Act (California Code of Regulations, Title XIV, section 670.5, filed September 1989), and listed as endangered under the Federal Endangered Species Act (1973, as amended) by the National Marine Fisheries Service in February 1994 (59 FR 440). Their federal endangered status was reaffirmed in June 2005 (70 FR 37160).

Another factor associated with the incongruence between the JPE's is the estimate of female spawners, the second variate of the model. The female escapement estimates derived from the two survey techniques differ, at times, greatly. This may be due to the dissimilar methodologies the two surveys use to produce each estimate. For the carcass survey, the size composition of fish sampled often leads to skewed sex ratios. Adult females are generally larger and may be more easily recognized and recovered than their male counterparts (Boydstun 1994, Zhou 2002). For example, in 1998, 1999, and 2000 the winter Chinook carcass survey male to female ratio was 1:8.9, 1:8.4, and 1:5.0, respectively (Snider et al 2001). For the RBDD ladder counts the sex ratio is determined by an assumed 1:1 sex ratio as gender differentiation is questionable. These disparities in sex ratios between survey techniques can have large net effects on the estimated number of spawning females, which in turn, can have remarkable effects on the JPE.

In light of the technical difficulties in estimating adult escapement described above, the use of the JPE model with either survey technique may be subject to considerable uncertainty. Estimated escapement is just one factor affecting the accuracy of JPE's. Another factor, not addressed directly in the JPE model, is success on the spawning grounds. Many adult salmon may return to spawn, but spawning and rearing habitat conditions vary between years and, at times, may not be favorable for successful reproduction (Heming 1981, Reiser and White 1988, Botsford and Brittnacher 1998). The overall result being the production of fewer juveniles than the JPE model would predict.

The United States Fish and Wildlife Service (USFWS) has conducted direct monitoring of juvenile winter Chinook passage at RBDD since 1994. Martin et al. (2001) developed quantitative methodologies for indexing juvenile passage using rotary-screw traps. The USFWS rotary trap juvenile production indices (JPI's) have been used in support of production estimates generated from escapement data using the JPE model. Martin et al. (2001) stated that RBDD was an ideal location to monitor juvenile winter Chinook production because (1) the spawning grounds occur almost exclusively above RBDD (Vogel and Marine 1991; Snider et al. 1997), (2) multiple traps could be attached to the dam and sample simultaneously across a transect, and (3) operation of the dam could control channel morphology and hydrological characteristics of the sampling area providing for consistent sampling conditions for purposes of measuring juvenile passage.

The objectives of this study were to (1) estimate the abundance of brood year (BY) 2008 and 2009 juvenile winter Chinook passing RBDD, (2) define temporal patterns of abundance, and (3) determine if JPI's from rotary trapping support JPE's generated from the carcass survey and the RBDD ladder counts.

This annual report addresses, in detail, our juvenile winter Chinook monitoring activities at RBDD for the period July 1, 2008 through June 30, 2010. This report includes JPI's for the complete 2008 and 2009 brood-year emigration period and will be submitted to the California Department of Fish and Game and GCAP Services Inc. to comply with contractual reporting requirements for Ecosystem Restoration Program Grant Agreement Number P0685507.

Study Area

The Sacramento River is the largest river system in California, flowing south through 600 kilometers (km) of the state (Figure 1). It originates in Northern California near Mt. Shasta as a mountain stream, widens as it drains adjacent slopes of the Coast, Klamath, Cascade, and Sierra Nevada mountain ranges, and reaches the ocean at the San Francisco Bay. Although agricultural and urban development have impacted the river, the upper river remains mostly unrestricted below Keswick Dam and supports areas of intact riparian vegetation. In contrast, urban and agricultural development has impacted much of the river between Red Bluff and San Francisco Bay. Impacts include, but are not limited to, channelization, water diversion, agricultural and municipal run-off, and loss of associated riparian vegetation.

Red Bluff Diversion Dam is located at river-kilometer 391 (RK391) on the Sacramento River, approximately 3 km southeast of the city of Red Bluff, California. The dam is 226 meters (m) wide and composed of eleven, 18 m wide fixed-wheel gates. Between gates are concrete piers 2.4 m in width. The USBR's dam operators are able to raise the RBDD gates allowing for run-of-the-river conditions or lower them to impound and divert river flows into the Tehama-Colusa Canal. USBR operators generally raise the RBDD gates from September 16 through May 14 and lower them May 15 through September 15 of each year (NOAA 2004). As of the spring of 2009, the RBDD gates can no longer be lowered prior to June 15 and are raised by the end of August or earlier (NMFS 2009) in an effort to reduce the impact to spring Chinook salmon and green sturgeon (*Acipenser medirostris*).

Methods

Sampling gear.—Sampling was conducted along a transect using four 2.4 m diameter rotary-screw traps (E.G. Solutions® Corvallis, Oregon) attached via aircraft cables directly to RBDD. The horizontal placement of rotary traps across the transect varied throughout the study but generally sampled in river-margin (east and west river-margins) and mid-channel habitats simultaneously (Figure 2). Rotary traps were positioned within these *spatial zones* unless sampling equipment failed, river depths were insufficient (< 1.2 m), or river hydrology restricted our ability to sample with all traps (water velocity < 0.6 m/s).

Sampling regimes.—In general, rotary traps sampled continuously throughout 24-hour periods and were sampled once daily. During periods of high winter Chinook abundance, elevated river flows, or heavy debris loads traps were sampled multiple times per day, continuously, or at random periods to reduce incidental mortality. When abundance of winter Chinook was very high, sub-sampling protocols were implemented to reduce take and incidental mortality in accordance with NOAA Fisheries Section 10 Research Permit terms and conditions. The specific sub-sampling protocol implemented was contingent upon the number of winter Chinook captured or the probability of successfully sampling various river conditions. Typically, rotary traps were structurally modified to only sample one-half of the normal volume of water (Gaines and Poytress 2004). If further reductions in capture were needed, we decreased the number of traps sampling from four to three. During storm events and associated elevated river discharge levels, each 24 hour sampling period was divided into four or six non-overlapping strata and one or two strata was randomly selected for sampling (Martin et al 2001). Estimates were extrapolated to un-sampled strata by dividing catch by the strata-selection probability (i.e., $P = 0.25$ or 0.17). If further reductions in impact were needed or river conditions were intolerable sampling was not conducted.

Data collection.—All fish captured were anesthetized, identified to species, and enumerated with fork lengths (FL) measured to the nearest millimeter (mm). When capture of winter Chinook juveniles exceeded approximately 200 fish/trap, a random sub-sample of the catch was taken to include approximately 100 individuals, with all additional fish being enumerated and recorded. Chinook salmon race was assigned using length-at-date criteria developed by Greene[2] (1992). Other data were collected at each trap sampling and included: length of time trap sampled, velocity of water immediately in front of the cone at a depth of 0.6 m, and depth of cone "opening" submerged. Water velocity was measured using a General Oceanic® Model 2030 flowmeter. These data were used to calculate the volume of water sampled by traps (X). The percent river volume sampled by traps (%Q) was estimated by the ratio of river volume sampled to total river volume passing RBDD. River volume (Q) was obtained from the California Data Exchange Center's Bend Bridge gauging station (http://cdec2.water.ca.gov/cgi-progs/queryFx?bnd).

Sampling effort.—We quantified weekly rotary trap sampling effort by assigning a value of 1.00 to a sample consisting of four, 2.4-m diameter rotary-screw traps sampling 24 hours daily, seven days weekly. Weekly values <1.00 represent occasions where less than four traps were sampling, traps were structurally modified to sample only one-half the normal volume of water or when less than seven days were sampled.

Trap efficiency trials.—Fish were marked with bismark brown staining solution (Mundie and Traber 1983) prepared at a concentration of 21.0 mg/L of water. Fish were stained for a period of 45-50 minutes, removed, and allowed to recover in fresh water. Marked fish were held for 6-24 hours before being released 4 km upstream from RBDD after sunset. Recapture of marked fish was recorded for up to five days after release. Trap efficiency was calculated based on the proportion of recaptures to total fish released.

Trap efficiency modeling.—Trap efficiency (i.e., the proportion of the juvenile population passing RBDD captured by traps) was modeled with %Q to develop a simple least-squares regression equation. The equation was then used to calculate daily trap efficiencies based on daily river volume sampled. To model trap efficiency with %Q, we conducted mark-recapture trials and estimated trap efficiency during trials as noted above.

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

Passage estimates.—Winter Chinook passage was estimated by employing the model developed to predict daily trap efficiency ($\hat{T_d}$). The trap efficiency model was developed by conducting 125 mark/recapture trials at RBDD and used *%Q* as the primary variate (Martin et al. 2001, Poytress and Carrillo 2010). Trap efficiency estimates from trials were plotted against *%Q* to develop a least squares regression equation (eq. 5), whereby daily trap efficiencies could be predicted.

Daily passage ($\hat{P_d}$).—The following procedures and formulae were used to derive daily and weekly estimates of total numbers of winter Chinook salmon passing RBDD. We defined C_{di} as catch at trap i (i=1,…,t) on day d (d=1,…,n), and X_{di} as volume sampled at trap i (i=1,…t) on day d (d=1,…n). Daily salmonid catch and water volume sampled were expressed as:

1. $$C_d = \sum_{i=1}^{t} C_{di}$$

and,

2. $$X_d = \sum_{i=1}^{t} X_{di}$$

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

3. $$\%\hat{Q}_d = \frac{X_d}{Q_d}$$

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

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

where,

5. $$\hat{T}_d = (0.00633)(\%\hat{Q}_d) + 0.00329$$

and, $\hat{T_d}$ = predicted trap efficiency on day d.

Weekly passage ($\hat{P}$).—Population totals for numbers of Chinook salmon passing RBDD each week were derived from $\hat{P_d}$ where there are N days within the week:

6. $$\hat{P} = \frac{N}{n}\sum_{d=1}^{n}\hat{P}_d$$

Estimated variance.—

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

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

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

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

9. $$Var(\hat{P}_d) = \frac{\hat{P}_d(1-\hat{T}_d)}{\hat{T}_d} + Var(\hat{T}_d)\frac{\hat{P}_d(1-\hat{T}_d)+\hat{P}_d{}^2\hat{T}_d}{\hat{T}_d^3}$$

where,

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

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

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

where,

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

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

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

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

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

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

Winter Chinook fry (≤ 45 mm FL) and pre-smolt/smolt (≥ 46 mm FL) passage was estimated by size class. However, the ratio of fry to pre-smolt/smolts passing RBDD was variable among years, therefore, we standardized juvenile production by estimating a fry-equivalent JPI for among-year comparisons. Fry-equivalent JPI's were estimated by the summation of fry JPI's and a weighted (1.7:1) pre-smolt/smolt JPI (59% fry-to-presmolt/smolt survival; Hallock undated). Rotary trap JPI's could then be directly compared to JPE's.

Hypotheses testing.— The JPI is a direct measure of juvenile production and has been used to track the JPE, an indirect measure of juvenile production (Martin et al., 2001). Juvenile production estimates derived from effective spawner populations based on the 2008 RBDD adult ladder counts (RBDD JPE) and 2008 and 2009 carcass surveys (Carcass JPE) were used for comparisons with the fry-equivalent JPI. The RBDD ladder count was estimated in 2008 but due to the shortened RBDD gates lowered period starting in 2009 (NMFS 2009), RBDD ladder counts were discontinued in 2008 (Killam 2009). Comparisons of RBDD JPE's and JPI's could not be made in 2009. The hypotheses we tested were:

H_{o1} : Carcass JPE does not differ from in-river estimates of juvenile abundance (JPI)
H_{a1} : Carcass JPE differs from in-river estimates of juvenile abundance (JPI)

H_{o2} : RBDD JPE does not differ from in-river estimates of juvenile abundance (JPI)
H_{a2} : RBDD JPE differs from in-river estimates of juvenile abundance (JPI)

We used a paired *t*-test for testing significant differences using years as replicates. We currently have ten data points to compare with the Carcass JPE. BY 2008 and 2009 data was added to the prior years' data and compared. We currently have eleven data points to compare with the RBDD JPE. Within-year evaluations were made by comparing Carcass JPE's and RBDD JPE's with the JPI and determining whether the JPE's fall within the confidence intervals about the JPI.

Results

Sampling effort BY 2008.—Weekly sampling effort throughout the 2008 brood-year emigration period was highly variable and ranged from 0.11 to 1.00 ($\bar{x}$ = 0.80, N = 52 weeks; Table 1). Weekly sampling effort ranged from 0.32 to 1.00 ($\bar{x}$ = 0.89, N = 26 weeks) between July and December, the period of greatest juvenile winter Chinook emigration, and 0.11 to 1.00 ($\bar{x}$ = 0.71, N = 26 weeks) during the latter half of the emigration period (Table 1).

Variance in sampling effort throughout the year can be attributed to several sources. They included (1) RBDD gate operations, (2) intentional reductions in effort resulting from cone modification(s), sampling < 4 traps, or unsampled days, and (3) unintentional reductions in effort resulting from high flows, elevated debris loads, or inoperable equipment (Figure 3). Nine of 52 weeks sampled had 3 or more different reasons why sampling effort was reduced from the maximum value of 1.00 or 28 possible samples (i.e., 4 traps sampling unmodified for 7 days).

Sampling effort BY 2009.—Weekly sampling effort throughout the 2009 brood-year emigration period was highly variable and ranged from 0.05 to 1.00 ($\bar{x}$ = 0.66, *N* = 52 weeks; Table 2). Weekly sampling effort ranged from 0.21 to 0.86 ($\bar{x}$ = 0.62, *N* = 26 weeks) between July and December, the period of greatest juvenile winter Chinook emigration, and 0.05 to 1.00 ($\bar{x}$ = 0.69, *N* = 26 weeks) during the latter half of the emigration period (Table 2).

Variance in sampling effort throughout the year can be attributed to several sources. They included (1) RBDD gate operations, (2) intentional reductions in effort resulting from cone modification(s), sampling < 4 traps, or unsampled days, (3) limited field staff, and (4) unintentional reductions in effort resulting from high flows, elevated debris loads, or inoperable equipment (Figure 4). Sixteen of 52 weeks sampled had 3 or more different reasons why sampling effort was reduced from the maximum value of 1.00 or 28 possible samples (i.e., 4 traps sampling unmodified for 7 days).

Trap efficiency trials.—Two mark-recapture trials were conducted using naturally produced fall run fry sized Chinook during the winter of 2009 to estimate rotary-screw trap efficiency (Table 3). Sacramento River discharge sampled during the trials ranged from 4,132 to 5,617 cfs. Estimated *%Q* during trap efficiency trials ranged from 4.53% to 4.64% ($\bar{x}$ = 4.59 %; Table 3).

Trials were conducted with RBDD gates raised (*N* = 2), rotary traps unmodified (standard cone; *N* = 2), and while sampling with 4 traps (*N* = 2). All trials were conducted using Chinook sampled from rotary traps, and trap efficiencies ranged from 2.81 to 3.10% ($\bar{x}$ = 2.96%). The number of marked fish released per trial ranged from 1,868 to 1,923 ($\bar{x}$ = 1,896). The number of marked fish recaptured after release ranged from 54 to 58 ($\bar{x}$ = 56). All fish were released after sunset and 93% of recaptures occurred within the first 24 hours, 98% within 48 hours, and 100% within 72 hours. Fork lengths of fish marked and released ranged from 32 to 42 mm ($\bar{x}$ = 36.5 mm). Fork lengths of recaptured marked fish ranged from 34 to 51 mm ($\bar{x}$ = 37.2 mm).

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 5). Regression analysis revealed a significant relationship between trap efficiency and *%Q* ($P < 0.001$). The strength of the relationship was relatively unchanged from that in 2007 (Poytress and Carrillo 2010) with the addition of two trials conducted during brood-year 2008 (r^2 = 0.42; Figure 5).

Fork length evaluations BY 2008.—Weekly median fork length of brood-year 2008 winter Chinook generally remained constant at 35.0 mm from week 29 through week 40

(Table 4). Median fork lengths increased rapidly from 40.0 mm in week 41 to 130.0 mm in week 5 followed by variability in week 6 through week 9. Median fork lengths steadily increased thereafter to 131.0 mm in week 14 (Figure 6a).

The length frequency distribution of brood-year 2008 juveniles captured at RBDD ranged from 28.0 mm to 170.0 mm (Figure 7). Fry sized individuals ranged from 28.0 to 45.0 mm and comprised 82% of all samples collected. Pre-smolt/smolt sized individuals ≥46.0 mm represented the remaining 18% of brood-year 2008 winter Chinook samples.

Patterns of abundance BY 2008.—Brood-year 2008 winter Chinook juvenile passage at RBDD was 1,265,142 fry and pre-smolt/smolts combined (Table 4). Winter Chinook juvenile passage increased steadily from 132 (week 29; July) to 87,220 (week 34; late-August). Peak passage of winter Chinook juveniles occurred during September between weeks 35 and 39 (Figure 6b). Juvenile passage generally declined from week 40 (October) to week 51. Pulses of fish passage associated with winter storms were then detected between weeks 52 and week 11 (March) with fish passage values generally in the hundreds to thousands per week (Table 4). Total passage between weeks 29 through 52 was 1,239,955 and accounted for 98.0% of total annual estimated passage of juvenile winter Chinook for the brood year.

Brood-year 2008 fry sized juveniles (≤45 mm FL) comprised 85.6% of total winter Chinook passage (Table 4). Fry began to pass RBDD during week 29 (mid-July). Weekly fry passage generally increased through week 34 (Table 4). The estimated peak passage of 320,684 fry sized juveniles was observed during the beginning of September in week 35 (Table 4; Figure 6b). Fry passage steeply declined following week 35 and fish fell outside the fry size class by week 46 in November (Table 4).

Brood-year 2008 pre-smolt/smolt sized juveniles (≥46 mm FL) comprised 15.4% of total passage and the first observed emigration past RBDD occurred in week 35 (September; Table 4). Weekly passage increased from 511 with minor fluctuations through week 39 to 4,905. Peak passage was observed between week 40 (October) and week 47 (late November), with the peak estimated passage of 22,099 occurring in early November (Table 4; Figure 6b). Weekly passage trends were sporadic and then declined after week 52 with minor increases in passage through week 11 (March) eventually subsiding in week 20 (May) of 2009 (Table 4).

Fork length evaluations BY 2009.—Weekly median fork length of brood-year 2009 winter Chinook generally increased slowly from 33.0 mm in week 27 to 37.0 mm in week 41 (Table 5). Median fork lengths increased rapidly from 48.0 mm in week 42 to 108.5 mm in week 4 followed by variability and an overall sharp decrease between week 5 through week 7. Weekly median fork lengths generally increased thereafter to 163.5 mm in week 18 (Figure 8a).

The length frequency distribution of brood-year 2009 juveniles captured at RBDD ranged from 27.0 mm to 173.0 mm (Figure 9). Fry sized individuals ranged from 27.0 to

45.0 mm and comprised 82% of all samples collected. Pre-smolt/smolt sized individuals ≥46.0 mm represented the remaining 18% of brood-year 2009 winter Chinook samples.

Patterns of abundance BY 2009.—Brood-year 2009 winter Chinook juvenile passage at RBDD was 4,426,785 fry and pre-smolt/smolts combined (Table 5). Winter Chinook juvenile passage increased from 97 (week 27; July) to 33,466 (week 32; mid-August). Peak passage of winter Chinook juveniles occurred predominantly during weeks 33 through 42; the middle of August through the middle of October (Figure 8b). Juvenile passage generally declined from week 43 (latter half of October) to 32,790, with pulses of fish passage associated with winter storms (weeks 44 through week 11). Total passage between weeks 27 through 52 was 4,396,330 and accounted for 99.3% of total annual passage.

Brood-year 2009 fry sized juveniles (≤45 mm FL) comprised 81% of total winter Chinook passage (Table 5). Fry began to pass RBDD during week 27 (early-July). Weekly fry passage generally increased through week 35 (Table 5). The estimated peak passage of 645,887 fry sized juveniles was observed during the mid to latter half of September in week 38 (Table 5; Figure 8b). Fry passage decreased from week 38 through week 41, but surged in week 42 as 419,569 fry were estimated to have passed (Figure 6b). Fry passage steeply declined following week 42 and fish fell outside the fry size class by week 46 in November (Table 5).

Brood-year 2009 pre-smolt/smolt sized juveniles (≥46 mm FL) comprised 19% of total passage and the first observed emigration past RBDD occurred in week 33 (latter half of August; Table 5). Weekly passage increased from 68 with minor fluctuations through week 41 to 41,386. Peak passage was observed in week 42 (October) at 516,029 (Table 5; Figure 8b). Weekly passage trends were sporadic thereafter and then declined after week 51 with minor increases through week 5 (February); eventually subsiding in week 18 (May) of 2010 (Table 5).

Comparisons of JPI's and RBDD JPE. —The fry-equivalent rotary trap JPI for brood-year 2008 was 1,392,077 (Table 4). The RBDD JPE was estimated at 667,306 (Table 6). Ladder counts of winter Chinook were not conducted in 2009 due to the abbreviated gates lowered period mandated by NMFS (Killam 2009). Therefore, only the 2008 datasets were compared. By direct comparison, the 2008 RBDD JPE was 52% less than the 2008 rotary trap JPI; a difference equating to 724,771 juveniles. The 2008 RBDD JPE was dissimilar to the 2008 fry equivalent rotary trap JPI as it fell below the lower 90% CI about the point estimate (Table 6).

We combined data from 1995 to 2007 with brood-year 2008 JPI's and RBDD JPE's to evaluate the linear relationship between the estimates. Twelve observations were evaluated using both estimates as rotary trapping at RBDD was not conducted in 2000 or 2001. Rotary trap JPI's were significantly correlated in trend to RBDD JPE's ($r^2 = 0.62$, $P = 0.002$, df = 11; Figure 10a). The relationship continued to indicate a moderate correlation and was slightly improved over that found by Poytress and Carrillo (2010) with the addition of the 2008 data.

In terms of the magnitude of the two estimates, a paired t-test detected a significant difference among rotary trap JPI's and RBDD JPE's (t = -3.18, P = 0.002, df =11). For the combined twelve years of data, RBDD JPE's averaged 52% less than rotary trap JPI's (range = -90 to +36%).

Comparisons of JPI and Carcass JPE. —The fry-equivalent rotary trap JPI for brood-years' 2008 and 2009 were 1,392,077 and 4,993,787 (Table 6). The NMFS brood-year 2008 and 2009 fry-equivalent Carcass JPE's were 1,952,614 and 3,728,444, respectively (Table 6; Figure 10b). The Carcass JPE exceeded the 90% CI about the 2008 rotary trap JPI by a mere 1.3% (Table 6). In 2009, the Carcass JPE fell within the 90% CI about the rotary trap JPI (Table 6). By direct comparison of annual point estimates, the Carcass JPE was 40% greater than the 2008 rotary trap JPI and 25% less than the 2009 rotary trap JPI. The difference in numerical values equated to 560,537 for 2008 and (-)1,265,343 for the 2009 comparison (Table 6).

We combined data from 1996 to 2007 with brood-year 2008 and 2009 JPI's and JPE's to evaluate the linear relationship between the estimates. Twelve observations were evaluated using the carcass survey data as the winter Chinook carcass survey did not start until 1996 and rotary trapping at RBDD was not conducted in 2000 and 2001. Rotary trap JPI's were significantly correlated in trend to Carcass JPE's (r^2 = 0.83, P < 0.001, df = 11; Figure 10b).

In terms of the magnitude of the two estimates, a paired t-test detected no significant difference among rotary trap JPI's and Carcass JPE's (t = -0.72, P = 0.49, df =11). For the combined twelve years of data, Carcass JPE's averaged 6% greater than rotary trap JPI's (range = -37 to +62%).

Discussion

Sampling effort BY 2008.—During BY 2008, sampling effort was very strong. Similar to BY 2007, effort was not reduced intentionally to decrease capture of winter Chinook juveniles during the typical peak emigration period (weeks 38 - 42). Compared to BY 2005, the previous generation of winter Chinook outmigrants of this cohort, daily catch was on average only 354 fish per day in BY 2008 as compared to 1,871 per day in BY 2005 and weekly effort averaged over 80% for this period.

Most reductions in effort during the July through December period were attributed to the project's inability to sample a fourth trap during the late summer period (week 32 – 36) when Sacramento River flows were below 11,000 cfs and RBDD diversions were occurring. New RBDD operating criteria put in place in June of 2007 to reduce the potential to impact downstream migrating green sturgeon adults resulted in a reduced number of RBDD gates being open as open gates could not be set at less than 18" off the river bottom in an attempt to allow for safer under gate passage. The result was less area behind the RBDD to sample traps and sampling of the fourth trap was discontinued.

Moreover, sampling was not possible during the majority of week 35 and 36 due to RBDD operations associated with the annual drawdown of Lake Red Bluff (Table 1).

During the secondary migration period between January and June, effort was reduced to minimize catch of wild fall run and fall run production fish released from Coleman National Fish Hatchery (April – May). Intentionally reduced effort occurred by sub-sampling portions of the night and day, modifying traps to sample at 50% effort, or sampling less than 4 traps. Inadequate staffing levels were not a factor in effort reductions during the 2008-2009 emigration period.

Four days were not sampled due to high discharge and debris conditions associated with winter storm events in February (Table 1; Figure 3). Unintended sampling effort reduction occurred during two storm events that resulted in discharges between 15,000 and 26,000 cfs (Figure 11a).

Sampling effort BY 2009.—During BY 2009, sampling effort was fair, but nearly 20% less on average than BY 2008. Similar to BY 2008, effort was not reduced intentionally to decrease capture of winter Chinook juveniles during the typical peak emigration period (weeks 38 - 42). Compared to BY 2006, the previous generation of winter Chinook outmigrants of this cohort, daily catch was on average 1,427 fish per day in BY 2009 as compared to 1,426 per day in BY 2006.

Most reductions in effort during the July through December period were attributed to the project's inability to sample a fourth trap during the entire summer period (week 27 - 36) when Sacramento River flows were below 13,000 cfs and RBDD diversions were occurring. As noted above, RBDD operating criteria put in place in June of 2007 required lowered gates to be open a minimum of 18" for adult sturgeon downstream passage. The result was less area behind the RBDD to sample traps and sampling of the fourth trap was discontinued. Moreover, sampling was not possible during the majority of week 35 due to RBDD operations associated with the annual drawdown of Lake Red Bluff (Table 2; Figure 4).

Following the gates raised period, intentional reductions in sampling effort occurred primarily due to lack of staff (Figure 4). Primary funding of the project was removed in December of 2008, but the effects of staff shortages did not appear until the summer of 2009. Funding was restored by October of 2009, but hiring actions could not be completed to replace lost staff until the latter half of the winter Chinook migration period in 2010. Termination of project funds resulted in a 30% reduction in sample collection as compared to 2008 when staffing of the project was not compromised. Overall, reduction in sampling effort affects the accuracy of passage estimates as more days need to be interpolated as opposed to estimating based on actual daily sample data.

During the secondary migration period between January and June, effort was reduced to minimize catch of wild fall run and fall run production fish released from Coleman National Fish Hatchery (April – May). Intentionally reduced effort occurred by sub-sampling portions of the night and day, modifying traps to sample at 50% effort, or sampling less than 4 traps. Inadequate staffing levels were a minor factor during this period, primarily in January prior to new field staff start dates (Figure 4).

Fourteen days were not sampled due to high discharge and debris conditions associated with winter storm events in January through March (Table 2; Figure 4). Unintended sampling effort reduction occurred during multiple storm events that resulted in discharges in excess of 37,000 cfs (Figure 12a).

Trap efficiency modeling.—On 2 occasions in 2009, we measured the efficiency of our rotary-screw traps by conducting mark-recapture trials using naturally produced fish collected during trap sampling activities. Data from the 2 trials were combined with data from 123 previously conducted trials to model the relationship between trap efficiency and %Q at RBDD (Figure 5). Trap efficiency was moderately correlated with %Q (r^2 = 0.42), yet regression Analysis of Variance continues to indicate a highly significant relationship exists between model variables (P< 0.001, df = 124). Overall, the relationship was minutely changed from that reported in Poytress and Carrillo (2010) indicating consistent conditions for modeling trap efficiency.

Patterns of abundance BY 2008.—Brood-year 2008 winter Chinook juvenile passage at RBDD, from July 1, 2008 through June 30, 2009, was 1,265,142 fry and pre-smolt/smolts combined, representing the lowest value of juvenile passage for this cohort since 1996 (Martin et al. 2001, Poytress 2007). In comparison to brood-year 2005, estimated juvenile passage was 85% less in 2008 representing a juvenile cohort replacement rate of 0.15. The reduction in juvenile production is directly related to the low number of adult winter Chinook spawners estimated in the Upper Sacramento River in 2008 (Killam 2009). The winter Chinook adult return of 2008 was the second consecutive year of poor adult returns indicative of what was a significant system wide decline for multiple runs of adult Chinook returning to the Central Valley as a whole during 2007 and 2008 (See Lindley et al. 2009).

Contributing factors analyzed for the fall Chinook decline are applicable to winter Chinook as both runs enter the ocean in the spring time (USFWS 2007). Lindley et al. (2009) suggested a combination of factors influenced the survival of outmigrating juvenile Chinook in the spring of 2005 and to a lesser extent in 2006. Winter Chinook adults returning to produce the BY 2008 progeny were entering the ocean in the spring of 2006. Juvenile Chinook entering the ocean during the spring of 2006 encountered "anomalous conditions in the coastal ocean" which was believed to have resulted in poor physical fitness of juveniles during an important phase in their life history typically associated with a period of significant growth (Lindley et al. 2009). Although it was suggested conditions in the spring of 2006 were less severe for juvenile Chinook, the BY 2008 adult return and subsequent juvenile production showed a far greater decline in returning adults and production for winter run Chinook in comparison to 2007.

Total passage of BY 2008 winter Chinook juveniles was comprised of 1,083,795 fry sized juveniles and 181,354 pre-smolt/smolt sized individuals (Table 4). The fry component represented 86.4% of juveniles passing. The pre-smolt/smolt component represented a modest 15.6% (Figure 6b).

Peak passage, representing 86% of the annual total estimate, occurred within an eight week period from mid-August early-October (Figure 6b). Between October and the end of December (week 42 – week 52), the first storm events of the fall season produced minor rises in discharge volume and increased turbidity (Figure 11a/b) resulting in a moderate increase of fry and pre-smolt/smolt winter Chinook passage (Table 4).

Patterns of abundance BY 2009.—Brood-year 2009 winter Chinook juvenile passage at RBDD, from July 1, 2009 through June 30, 2010 was 4,426,785 fry and pre-smolt/smolts combined. In comparison to brood-year 2006, estimated juvenile passage was 34% less in 2009 representing a juvenile cohort replacement rate of 0.66. The winter Chinook adult return of 2009 was an improvement over the very low returns seen in 2008 and 2007 (USFWS 2007, Killam 2009).

Total passage of BY 2009 winter Chinook juveniles was comprised of 3,587,227 fry sized juveniles and 839,558 pre-smolt/smolt sized individuals (Table 5). The fry component represented 81.0% of juveniles passing. The pre-smolt/smolt component represented a modest 19.0% (Figure 8b).

Peak passage, representing 92% of the annual total estimate, occurred within a nine week period from mid-August through mid-October (Figure 8b). Between October and the end of December (week 42 – week 52), the first storm events of the fall season produced minor rises in discharge volume and increased turbidity (Figure 12a/b). The first storm event in mid-October resulted in a very high increase in turbidity from 2 NTU to 46 NTU (Figure 12b) resulting in a substantial increase of fry and pre-smolt/smolt winter Chinook passage (Table 5; Figure 8b) translating into a weekly passage value comprising 61% of total pre-smolt/smolt passage for the year. Moreover, total passage for that week accounted for 21% of the annual total passage estimate and appeared driven by the storm and resultant turbidity event.

Comparisons of JPI's and JPE's.—Among-year comparison of passage estimates from RBDD may be misleading with reference to juvenile year class strength if abundance is the foremost consideration. Each brood-year the population of juvenile winter Chinook passing RBDD is composed of both fry and pre-smolt/smolts, and the ratio of fry to pre-smolt/smolts is oftentimes variable among years (Martin et al. 2001). It is possible that differential survival exists between these subpopulations (USFWS 2001) and, therefore, we would expect juvenile year class strength to vary, perhaps even greatly, given equal passage estimates among years. Therefore, we converted passage estimates to fry-equivalent juvenile production indices (JPI's) for among-year comparisons (Table 6). For brood-year 2008 and 2009, fry size class individuals comprised 86% and 81% of annual passage, respectively. The calculation of 1.7 fry:1 pre-smolt/smolt (based on estimated 59% fry to smolt survival; Hallock undated) had a moderate effect of 14% and 19%, respectively, on the overall estimates. The NMFS 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.

BY 2008 Rotary trap JPI and RBDD JPE's.—RBDD JPE's were not supportive of JPI's with respect to the magnitude of fry-equivalent JPI values (t = -3.92, P = 0.002, df = 11). We therefore reject the null hypothesis that RBDD JPE's do not differ from in-river estimates of juvenile abundance (i.e., JPI's). Furthermore, the 2008 RBDD JPE *underestimated* juvenile production relative to JPI's and carcass survey JPE's for the tenth time in eleven years of comparisons (Table 6).

The number of weeks the RBDD fish ladder operates has been decreased over the past several years to the point that the timing of winter-run passage through the ladders has been limited to between 12 and 15% in recent years. Estimates of total escapement into the upper river have been expanded in each year of operation for 85 to 88% of the annual run (Killam 2009). In 2008, many weeks of trapping were missed and so already expanded data was further expanded for the missed periods of sampling. With the recent mandatory reductions of the gates lowered period of the RBDD since 2008 (NMFS 2009), coupled with the inaccuracy of winter run escapement estimates calculated by RBDD fish ladder counts, the California Department of Fish and Game no longer considers the RBDD ladder counts a useful estimator and it's use was discontinued in 2009 (D. Killam, CDFG, pers. comm.). Furthermore, NMFS has been using the carcass survey JPE's as the official estimates for regulatory purposes since 2002 (B. Oppenheim, NMFS, pers. comm.).

2008 and 2009 Rotary trap JPI's and Carcass JPE's.— In contrast to RBDD JPE's, rotary-screw trap JPI's and Carcass JPE's have historically and continue to be strongly correlated. The 2008 and 2009 Carcass JPE's were 40% greater and 25% less than the rotary trap JPI, respectively (Table 6). The 2008 JPE estimate exceeded the upper 90% CI about the rotary trap JPI by a meager 1.3%; whereas the 2009 Carcass JPE fell within the bounds of the rotary trap JPI CI. Significant differences in the magnitude of JPI's and Carcass JPE's were not detected with the addition of 2008 and 2009 data (t = -0.72, P = 0.49, df = 11). We therefore accept the hypothesis for the cumulative 11 years of data that carcass JPE's do not differ from in-river estimates of juvenile abundance (JPI's).

Overall, the relationship between the direct measure of juvenile abundance (JPI) and the indirect or modeled approach using carcass survey data (JPE) remains strong. The addition of the 2008 and 2009 data continues to support this relationship.

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Tables

Table 1.—Annual summary of BY 2008 weekly rotary trapping sampling effort. Full sampling effort was indicated by assigning a value of 1.00 to a week consisting of four, 2.4 m diameter rotary-screw traps sampling 24 hours daily, seven days a week. A winter Chinook brood-year (BY) is identified as beginning on July 1 and ending on June 30.

BY 2008 Sampling effort			
Week	Effort	Week	Effort
27 (Jul)	0.75	1 (Jan)	0.71
28	0.75	2	0.86
29	0.64	3	1.00
30	0.89	4	0.86
31 (Aug)	1.00	5 (Feb)	0.89
32	0.89	6	0.89
33	0.75	7	0.34
34	0.75	8	0.32
35 (Sep)	0.32	9 (Mar)	0.46
36	0.39	10	0.82
37	1.00	11	0.93
38	1.00	12	0.79
39	0.96	13 (Apr)	1.00
40 (Oct)	1.00	14	1.00
41	1.00	15	0.39
42	1.00	16	0.36
43	1.00	17	0.36
44 (Nov)	1.00	18 (May)	0.29
45	1.00	19	1.00
46	1.00	20	1.00
47	1.00	21	0.96
48 (Dec)	1.00	22 (Jun)	1.00
49	1.00	23	1.00
50	1.00	24	0.29
51	1.00	25	0.11
52	0.92	26	0.75

Table 2.—Annual summary of BY 2009 weekly rotary trapping sampling effort. Full sampling effort was indicated by assigning a value of 1.00 to a week consisting of four, 2.4 m diameter rotary-screw traps sampling 24 hours daily, seven days a week. A winter Chinook brood-year (BY) is identified as beginning on July 1 and ending on June 30.

BY 2009 Sampling effort			
Week	Effort	Week	Effort
27 (Jul)	0.54	1 (Jan)	0.29
28	0.54	2	0.36
29	0.75	3	0.13
30	0.75	4	0.05
31 (Aug)	0.75	5 (Feb)	0.66
32	0.75	6	0.55
33	0.75	7	0.79
34	0.64	8	0.98
35 (Sep)	0.21	9 (Mar)	0.75
36	0.54	10	1.00
37	0.75	11	0.86
38	0.86	12	1.00
39	0.71	13 (Apr)	1.00
40 (Oct)	0.71	14	1.00
41	0.43	15	0.25
42	0.68	16	0.36
43	0.71	17	0.89
44 (Nov)	0.57	18 (May)	0.96
45	0.57	19	0.96
46	0.57	20	0.96
47	0.71	21	0.93
48 (Dec)	0.43	22 (Jun)	0.64
49	0.57	23	0.50
50	0.57	24	0.57
51	0.55	25	0.64
52	0.53	26	0.75

Table 3.— Summary of results from mark-recapture trials conducted in 2009 (*N* = 2) to evaluate rotary-screw trap efficiency at Red Bluff Diversion Dam (RK391), Sacramento River, California. Results include the number of fish released, the mean fork length at release (Release FL), the number recaptured, the mean fork length at recapture (Recapture FL), combined 4 trap efficiency (TE %), percent river volume sampled by rotary-screw traps (%Q), number of traps sampling during trials, modification status as to whether or not traps were structurally modified to reduce volume sampled by 50% (Traps modified), and RBDD gate configuration at the time of the trial.

Trial#	Year	Number released	Release FL (mm)	Number recaptured	Recapture FL (mm)	TE (%)	%Q	Number of traps sampling	Traps modified	RBDD Gate Configuration
1	2009	1,923	36.14	54	37.07	2.81	4.53	4	No	Raised
2	2009	1,868	36.80	58	37.38	3.10	4.64	4	No	Raised

Table 4.— Weekly passage estimates, median fork length and juvenile production indices (JPI's) for winter Chinook salmon passing Red Bluff Diversion Dam (RK391) for the period July 1, 2008 through June 30, 2009 (Brood-year 2008). Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry-equivalents. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry-to-pre-smolt/smolt survival rate (59% or approximately 1.7:1, Hallock undated).

Brood-year 2008

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
27 (Jul)	0	-	0	-	0	-	0
28	0	-	0	-	0	-	0
29	132	35	0	-	132	35	132
30	227	34	0	-	227	34	227
31 (Aug)	2,157	35	0	-	2,157	35	2,157
32	7,558	35	0	-	7,558	35	7,558
33	16,459	35	0	-	16,459	35	16,459
34	87,220	35	0	-	87,220	35	87,220
35 (Sep)	320,684	35	511	48	321,195	35	321,552
36	207,921	35	1,378	49	209,299	35	210,259
37	110,221	35	585	48.5	110,807	35	111,217
38	110,021	35	2,004	49	112,024	35	113,427
39	123,153	35	4,905	50	128,058	35	131,491
40 (Oct)	63,829	35	10,548	52	74,373	35	81,757
41	23,982	34	17,549	54	41,531	40	53,815
42	5,090	36	10,022	55	15,111	52	22,127
43	4,183	39	17,709	57	21,890	55	34,285
44 (Nov)	374	43	14,686	60	15,060	60	25,340
45	439	44	22,099	63	22,538	63	38,007
46	78	45	12,365	66	12,443	66	21,098
47	67	43.5	10,985	67	11,052	67	18,742

Table 4.— (continued)

Week	Fry		Pre-smolt/smolts		Total		Fry-equivalents
	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
48 (Dec)	0	-	3,907	69.5	3,907	69.5	6,640
49	0	-	2,640	73	2,640	73	4,486
50	0	-	2,745	74	2,745	74	4,668
51	0	-	3,936	74	3,936	74	6,690
52	0	-	17,593	82	17,593	82	29,906
1 (Jan)	0	-	906	84.5	906	84.5	1,539
2	0	-	558	88	558	88	950
3	0	-	930	104	930	104	1,581
4	0	-	956	114	956	114	1,627
5 (Feb)	0	-	62	130	62	130	105
6	0	-	379	109.5	379	109.5	644
7	0	-	2,911	108	2,911	108	4,948
8	0	-	9,548	101	9,548	101	16,231
9 (Mar)	0	-	4,095	120	4,095	120	6,963
10	0	-	886	113.5	886	113.5	1,505
11	0	-	2,604	121	2,604	121	4,425
12	0	-	36	120	36	120	63
13 (Apr)	0	-	237	126	237	126	404
14	0	-	248	131	248	131	422
15	0	-	0	-	0	-	0
16	0	-	70	140	70	140	119
17	0	-	273	155	273	155	463
18 (May)	0	-	314	154	314	154	531
19	0	-	134	135	134	135	229
20	0	-	40	143	40	143	68
21	0	-	0	-	0	-	0
22 (Jun)	0	-	0	-	0	-	0
23	0	-	0	-	0	-	0

Table 4.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
24	0	-	0	-	0	-	0
25	0	-	0	-	0	-	0
26	0	-	0	-	0	-	0
BY total	1,083,795		181,354		1,265,142		1,392,077

Table 5.— Weekly passage estimates, median fork length and juvenile production indices (JPI's) for winter Chinook salmon passing Red Bluff Diversion Dam (RK391) for the period July 1, 2009 through June 30, 2010 (Brood-year 2009). Results include estimated passage (Est. passage) for fry (< 46 mm FL), pre-smolt/smolts (> 45 mm FL), total (fry and pre-smolt/smolts combined) and fry- equivalents. Fry-equivalent JPI's were generated by weighting pre-smolt/smolt passage by the inverse of the fry-to-pre-smolt/smolt survival rate (59% or approximately 1.7:1, Hallock undated).

Brood-year 2009

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
27 (Jul)	97	33	0	-	97	33	97
28	330	31	0	-	330	31	330
29	363	34.5	0	-	363	34.5	363
30	2,762	34	0	-	2,762	34	2,762
31 (Aug)	5,573	34	0	-	5,573	34	5,573
32	33,466	34	0	-	33,466	34	33,466
33	96,695	35	68	46	96,763	35	96,811
34	339,394	35	1,553	47	340,946	35	342,033
35 (Sep)	611,966	35	866	48	612,832	35	613,438
36	345,807	36	2,165	48	347,972	36	349,488
37	522,992	36	3,516	48.5	526,507	36	528,968
38	645,887	36	11,093	49	656,980	36	664,746
39	327,352	37	16,830	50	344,181	37	355,962
40 (Oct)	118,537	37	26,927	53	145,464	37	164,313
41	109,157	37	41,386	54	150,543	37	179,514
42	419,569	40	516,029	54	935,598	48	1,296,819
43	6,692	42	26,097	55	32,790	53	51,058
44 (Nov)	458	39	14,634	59.5	15,092	59	25,336
45	133	43	7,157	61	7,290	61	12,300
46	0	-	9,887	64	9,887	64	16,809
47	0	-	6,946	66	6,946	66	11,808

Table 5.— (continued)

	Fry		Pre-smolt/smolts		Total		Fry-equivalents
Week	Est. passage	Med FL	Est. passage	Med FL	Est. passage	Med FL	JPI
48 (Dec)	0	-	5,138	69	5,138	69	8,734
49	0	-	6,298	70	6,298	70	10,706
50	0	-	3,095	74	3,095	74	5,261
51	0	-	108,227	77	108,227	77	163,296
52	0	-	1,190	78	1,190	78	2,023
1 (Jan)	0	-	194	78	194	78	329
2	0	-	6,802	98	6,802	98	11,563
3	0	-	11,570	92	11,570	92	19,668
4	0	-	4,007	108.5	4,007	108.5	6,811
5 (Feb)	0	-	659	105	659	105	1,120
6	0	-	238	88	238	88	405
7	0	-	259	95	259	95	441
8	0	-	1,186	107	1,186	107	2,016
9 (Mar)	0	-	861	123	861	123	1,464
10	0	-	565	111.5	565	111.5	960
11	0	-	1,426	125	1,426	125	2,425
12	0	-	190	122.5	190	122.5	324
13 (Apr)	0	-	489	129	489	129	831
14	0	-	816	121	816	121	1,387
15	0	-	0	-	0	-	0
16	0	-	735	116	735	116	1,250
17	0	-	313	146	313	146	533
18 (May)	0	-	147	163.5	147	163.5	249
19	0	-	0	-	0	-	0
20	0	-	0	-	0	-	0
21	0	-	0	-	0	-	0
22 (Jun)	0	-	0	-	0	-	0
23	0	-	0	-	0	-	0

Table 5.— (continued)

Week	Fry Est. passage	Fry Med FL	Pre-smolt/smolts Est. passage	Pre-smolt/smolts Med FL	Total Est. passage	Total Med FL	Fry-equivalents JPI
24	0	-	0	-	0	-	0
25	0	-	0	-	0	-	0
26	0	-	0	-	0	-	0
BY total	3,587,227		839,558		4,426,785		4,993,787

Table 6.—Comparisons between juvenile production estimates (JPE) and rotary trapping juvenile production indices (JPI). Fish ladder JPE's and carcass survey JPE's were derived from the estimated adult female escapement from fish ladder counts at Red Bluff Diversion Dam and the upper Sacramento River winter Chinook carcass survey. From BY95 through BY99, assumptions used in the carcass survey JPE model were as follows: (1) 5% pre-spawning mortality, (2) 3,859 ova per female, (3) 0% loss due to high water temperature, and (4) 25% egg-to-fry survival. From BY00 through BY07, assumptions 1-3 were estimated using carcass survey data gathered on the spawning grounds, from Livingston Stone National Fish Hatchery, and aerial redd surveys, respectively. The upper Sacramento River carcass survey did not begin until the 1996 brood-year. Dashes (-) indicate years surveys not performed.

	Rotary-trapping [a]			Carcass survey [b]		Fish ladder [c]	
		90% C.I.					
Brood-year	Fry-equivalent JPI	Lower	Upper	Fry-equivalent JPE	# female spawners	Fry-equivalent JPE	# female spawners
1995	1,816,984	1,658,967	2,465,169	-	-	573,062	594
1996	469,183	384,124	818,096	550,872	571	279,778	290
1997	2,205,163	1,876,018	3,555,314	1,386,346	1,437	219,963	228
1998	5,000,416	4,617,475	6,571,241	4,676,143	4,847	770,835	799
1999	1,366,161	1,052,620	2,652,305	1,490,249	1,626	491,058	509
2000	-	-	-	4,946,418	5,397	651,635	563
2001	-	-	-	5,643,635	4,827	1,469,637	1,257
2002	8,205,609	4,287,999	12,162,377	6,964,626	5,670	5,766,419	4,685
2003	5,826,672	4,091,200	7,563,240	6,181,925	5,179	3,801,578	3,133
2004	3,758,790	2,673,168	4,846,169	[d]2,786,832	3,185	1,105,900	1,264
2005	8,941,241	6,024,027	12,034,853	12,109,474	8,807	2,766,151	2,012
2006	7,301,362	4,891,041	9,706,610	11,818,006	8,626	3,123,320	2,278
2007	1,642,575	1,058,274	2,226,877	1,864,521	1,517	2,231,474	1,746
2008	1,392,077	856,310	1,927,833	1,952,614	1,443	667,306	493
2009	4,993,787	2,757,558	7,230,016	3,728,444	2,702	-	-

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

[b] Carcass survey JPE using estimated effective spawner population from Snider et al. (1996-2000) and Bruce Oppenheim (2000-2009), NOAA Fisheries pers comm.

[c] Fish ladder JPE obtained from Diaz-Soltero 1995-1996, Lecky 1997-1999, and Bruce Oppenheim (2000-2004), NOAA Fisheries, pers comm. RBDD fish ladder fry-equivalent JPE estimated for 2002-2008; calculated from estimates of winter-run escapement based on counts at RBDD by USFWS as NOAA Fisheries no longer estimates fish ladder JPE's (Bruce Oppenheim 2005, NOAA Fisheries, pers comm.).

[d] The 2004 JPE calculations used a standard value of fecundity of 3,500 eggs/female (Bruce Oppenheim 2006, NOAA Fisheries, pers. comm..).

Figures

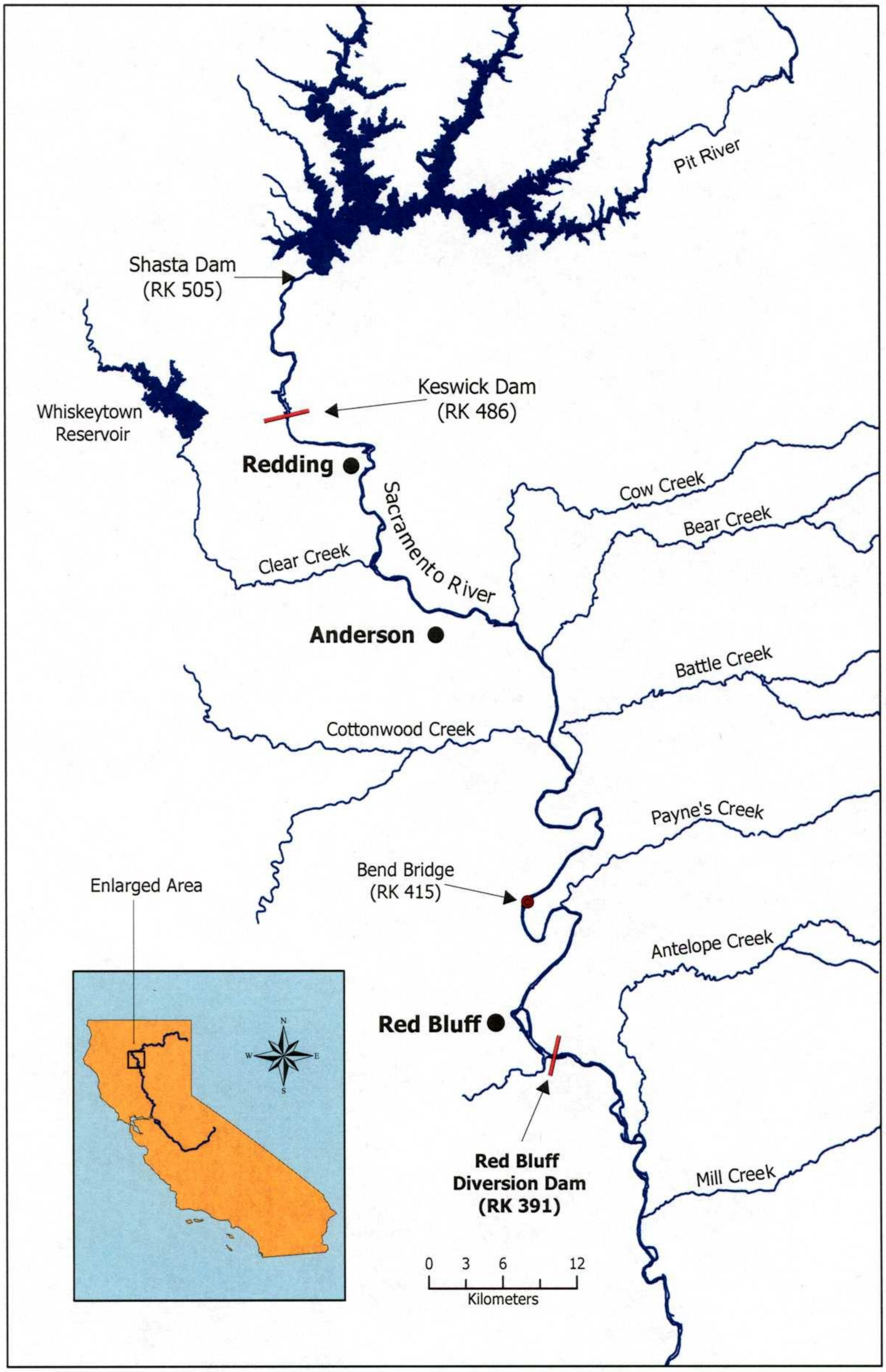

Figure 1. Location of Red Bluff Diversion Dam on the Sacramento River, California at river kilometer 391 (RK 391).

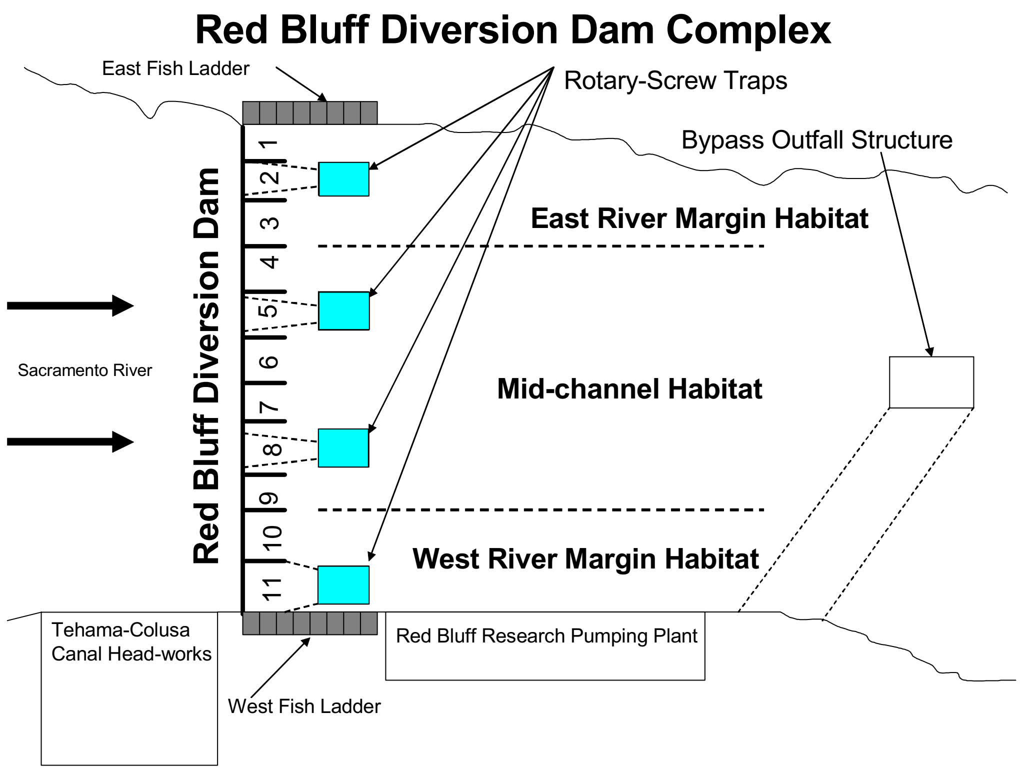

Figure 2. Rotary-screw trap sampling transect at Red Bluff Diversion Dam Complex (RK391) on the Sacramento River, California.

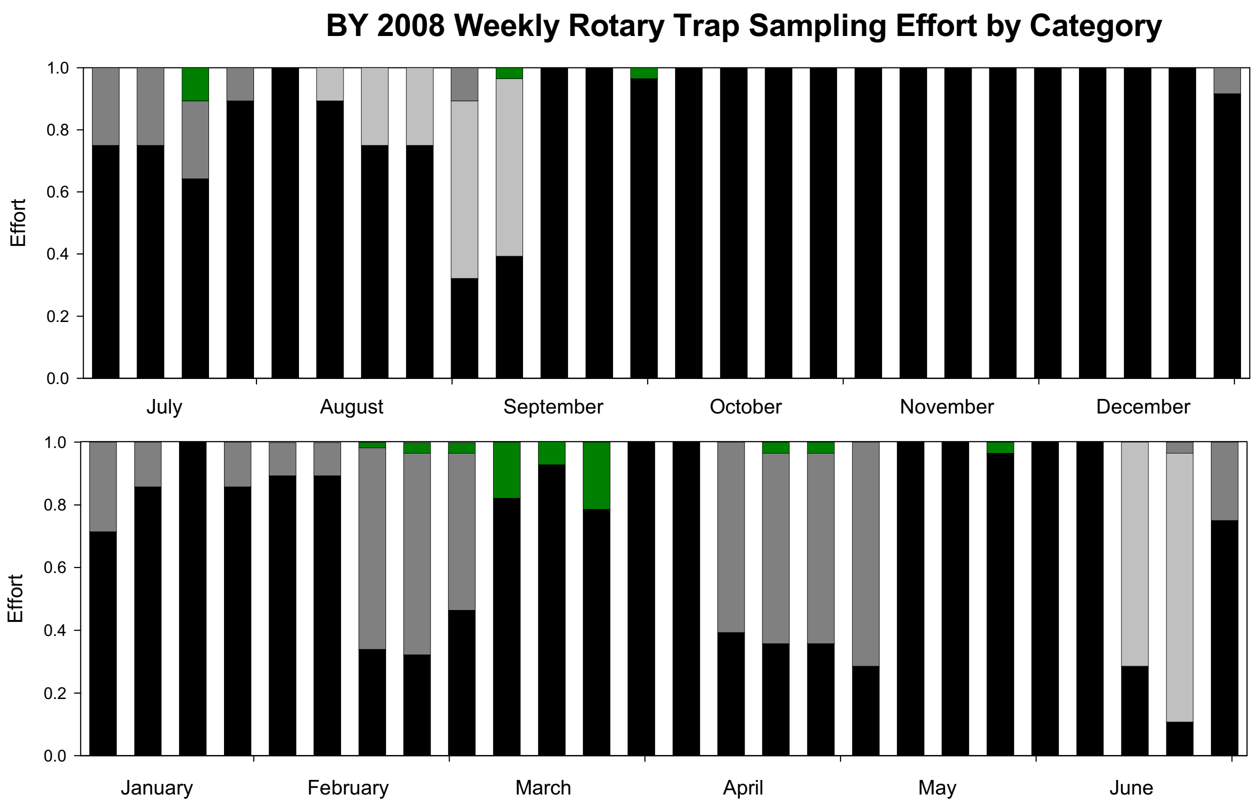

Figure 3. Weekly (bars) and monthly rotary trap sampling effort for the period July 1, 2008 - June 30, 2009 by category. Sampled portions represented by black bars; unsampled portions designated in descending order of frequency: intentional reductions in effort (dark grey), RBDD operations (light grey) and unintentional reductions (darkgreen).

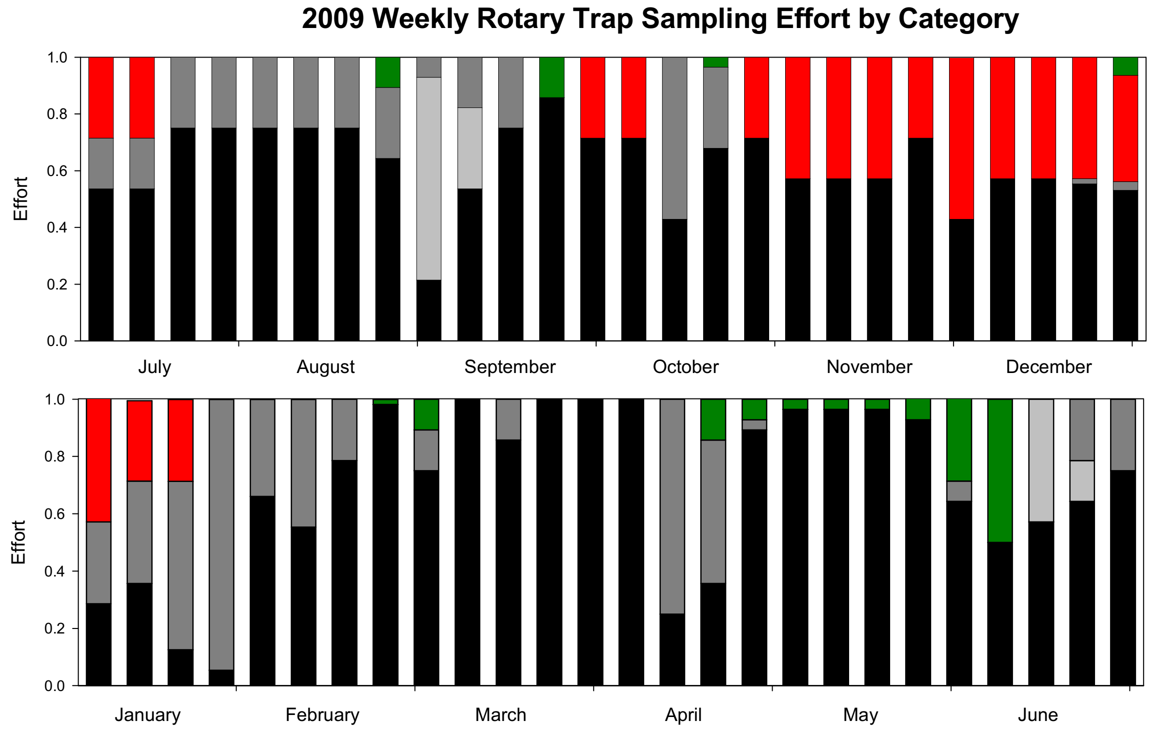

Figure 4. Weekly (bars) and monthly rotary trap sampling effort for the period July 1, 2009 through June 30, 2010 by category. Sampled portions represented by black bars; unsampled portions designated in descending order of frequency: intentional reductions in effort (dark grey), limited field staff (red), RBDD operations (light grey) and unintentional reductions (darkgreen).

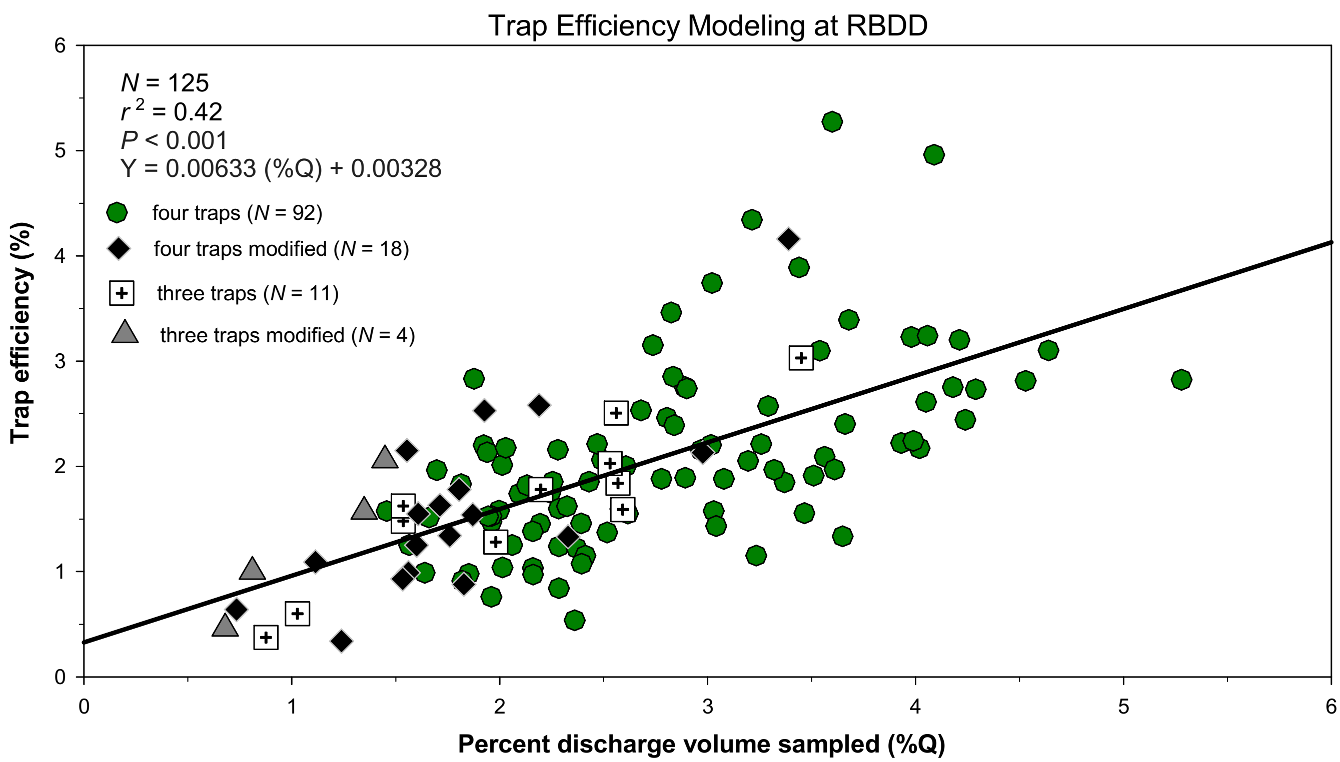

Figure 5. Trap efficiency model for combined 2.4 m diameter rotary-screw traps at Red Bluff Diversion Dam (RK391), Sacramento River, CA. Mark-recapture trials were used to estimate trap efficiencies and trials were conducted using either four traps (*N* = 92), three traps (*N* = 11), or with traps modified to sample one-half the normal volume of water (*N* = 22).

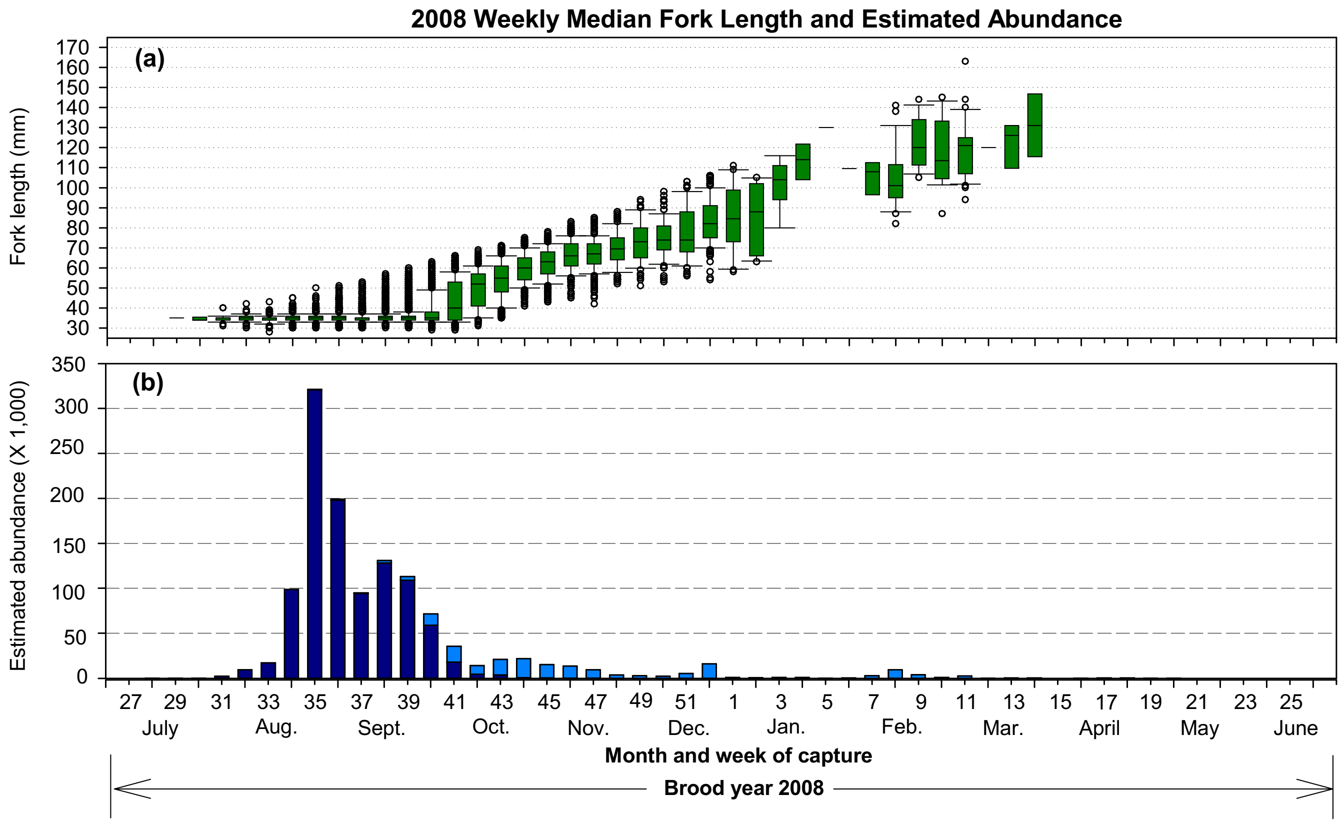

Figure 6. Weekly median fork length (a) and estimated abundance (b) of juvenile winter Chinook salmon fry (dark blue) and pre-smolt/smolts (light blue) passing Red Bluff Diversion Dam (RK391), Sacramento River, California. Winter Chinook salmon were sampled by rotary-screw traps for the period July 1, 2008 through June30, 2009. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

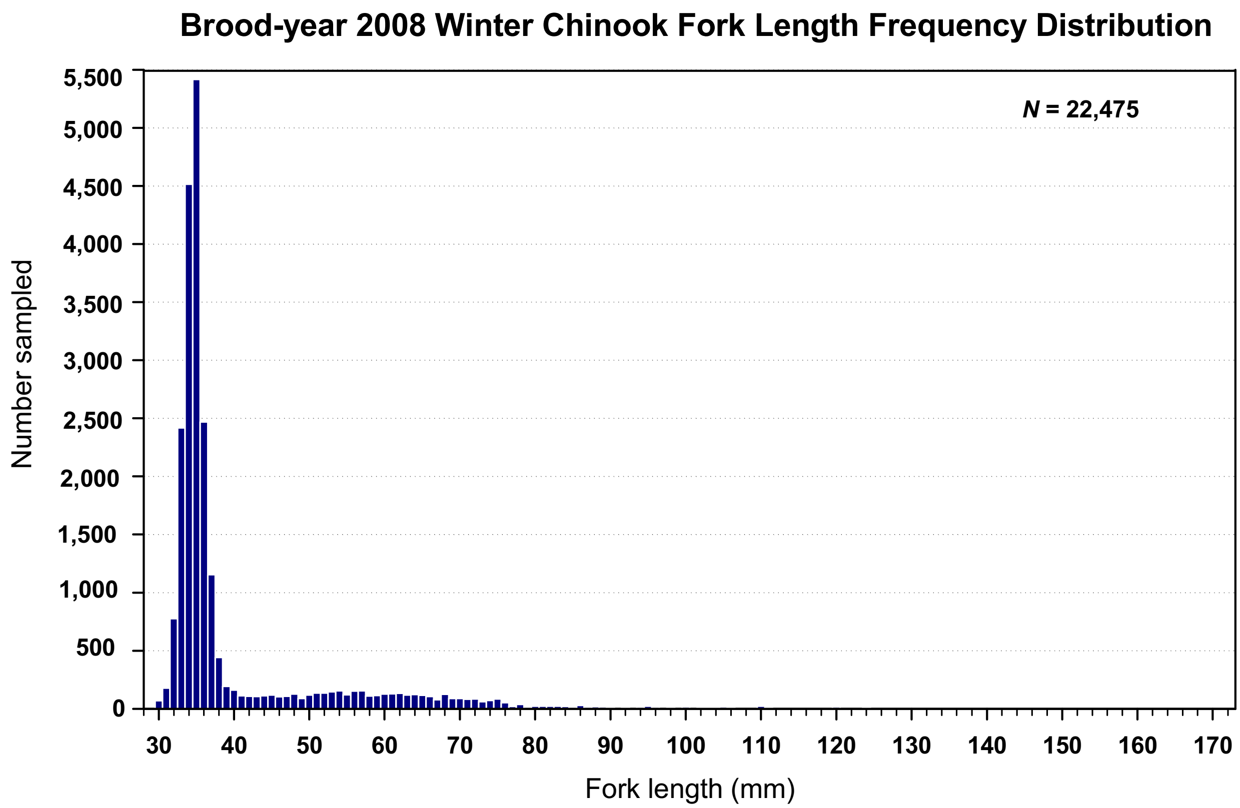

Figure 7. Fork length frequency distribution of brood-year 2008 juvenile winter Chinook salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fork length data was expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from July 1, 2008 through June 30, 2009.

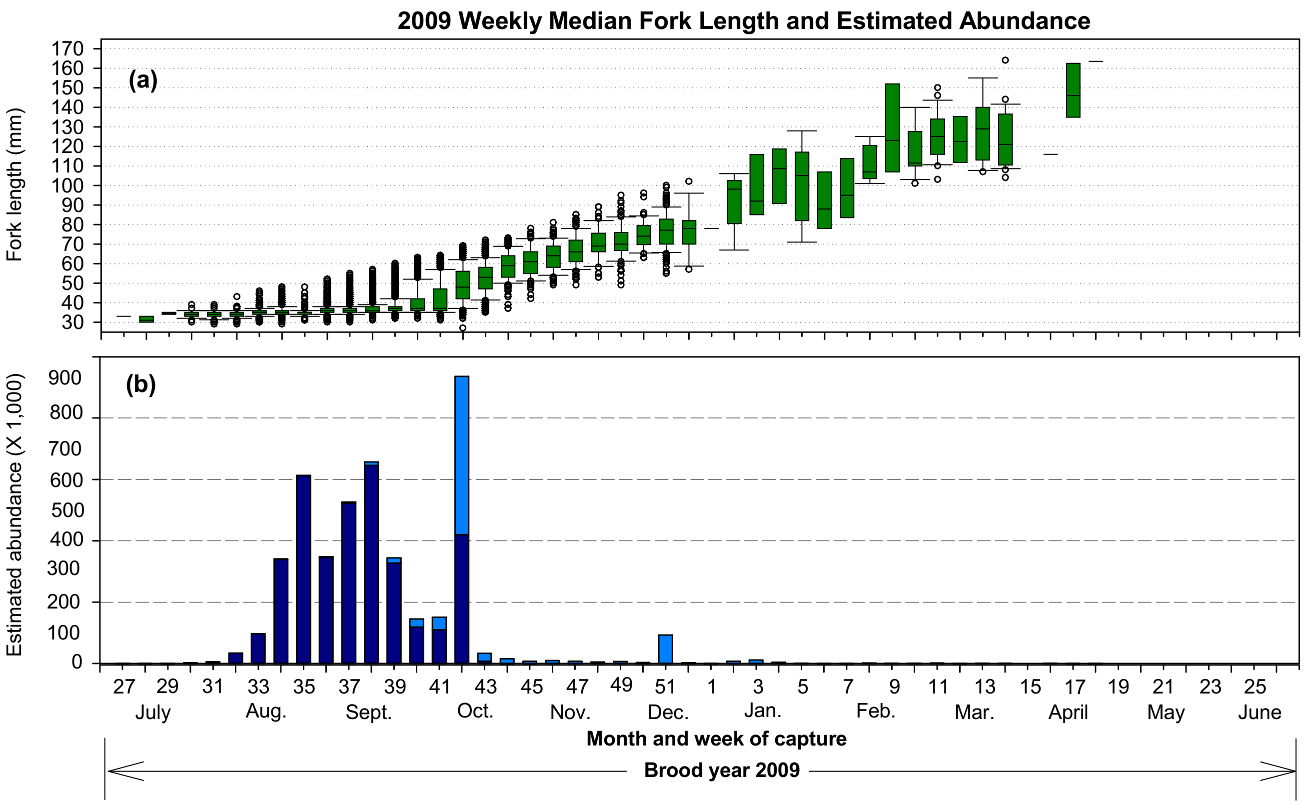

Figure 8. Weekly median fork length (a) and estimated abundance (b) of juvenile winter Chinook salmon fry (dark blue) and pre-smolt.smolts (light blue) passing Red Bluff Diversion Dam (RK391), Sacramento River, California. Winter Chinook salmon were sampled by rotary-screw traps for the period July 1, 2009 through June 30, 2010. Box plots display weekly median fork length, 10th, 25th, 75th, and 90th percentiles and outliers.

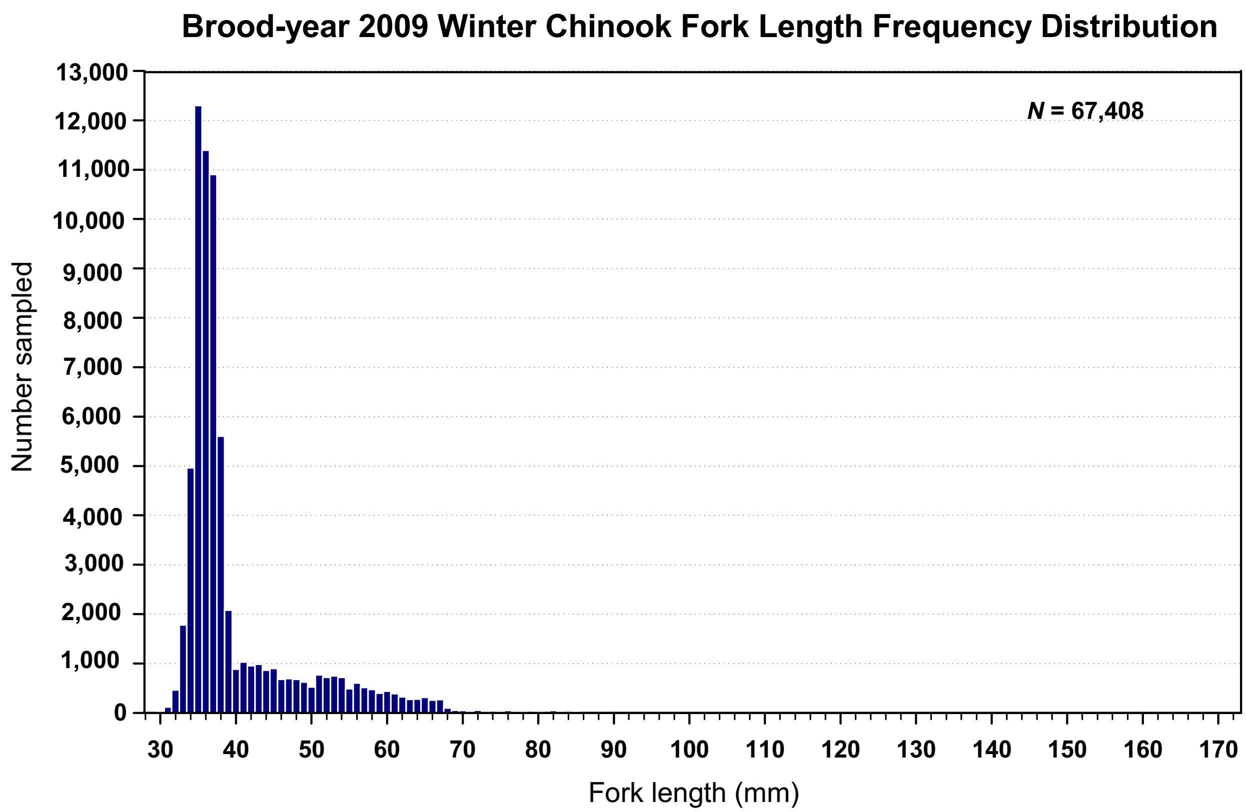

Figure 9. Fork length frequency distribution of brood-year 2009 juvenile winter Chinook salmon sampled by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, California. Fork length data was expanded to unmeasured individuals when sub-sampling protocols were implemented. Sampling was conducted from July 1, 2009 through June 30, 2010.

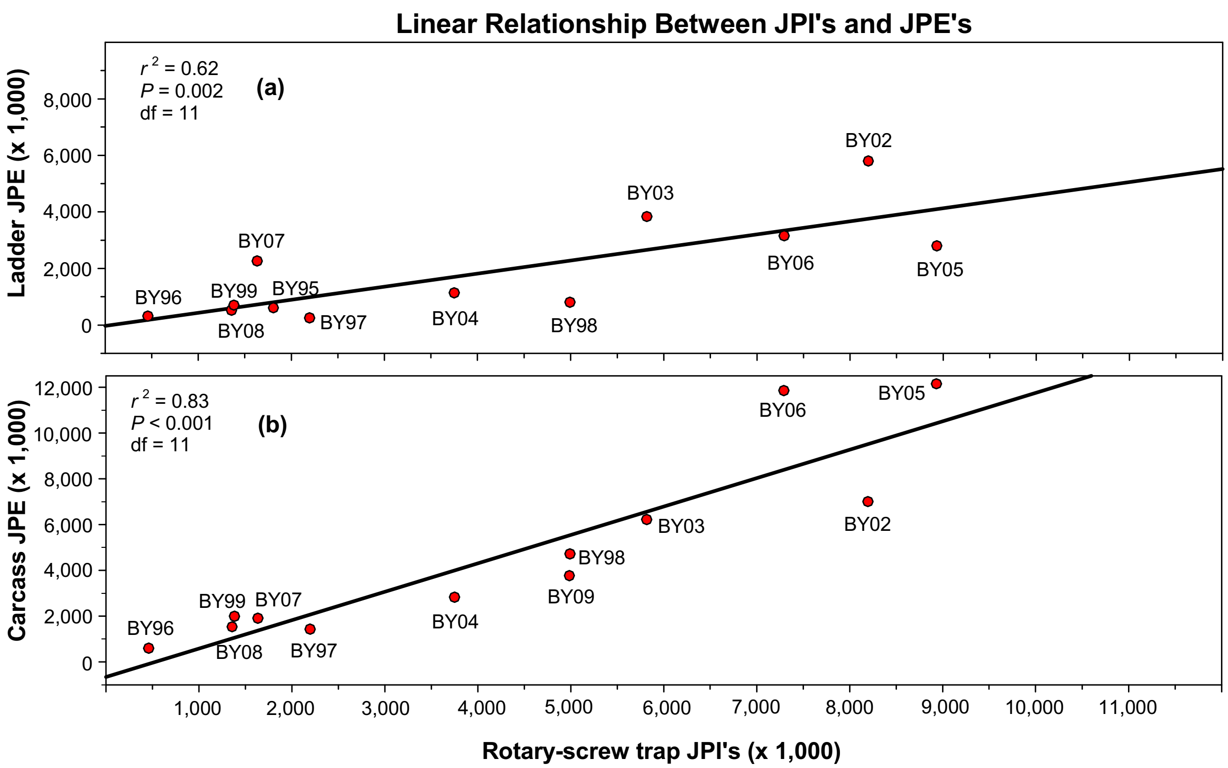

Figure 10. Linear relationship between rotary-screw trap fry-equivalent juvenile production indices (JPI) and (a) 2008 RBDD ladder count derived juvenile production estimates (JPE) and (b) 2008 and 2009 carcass JPE.

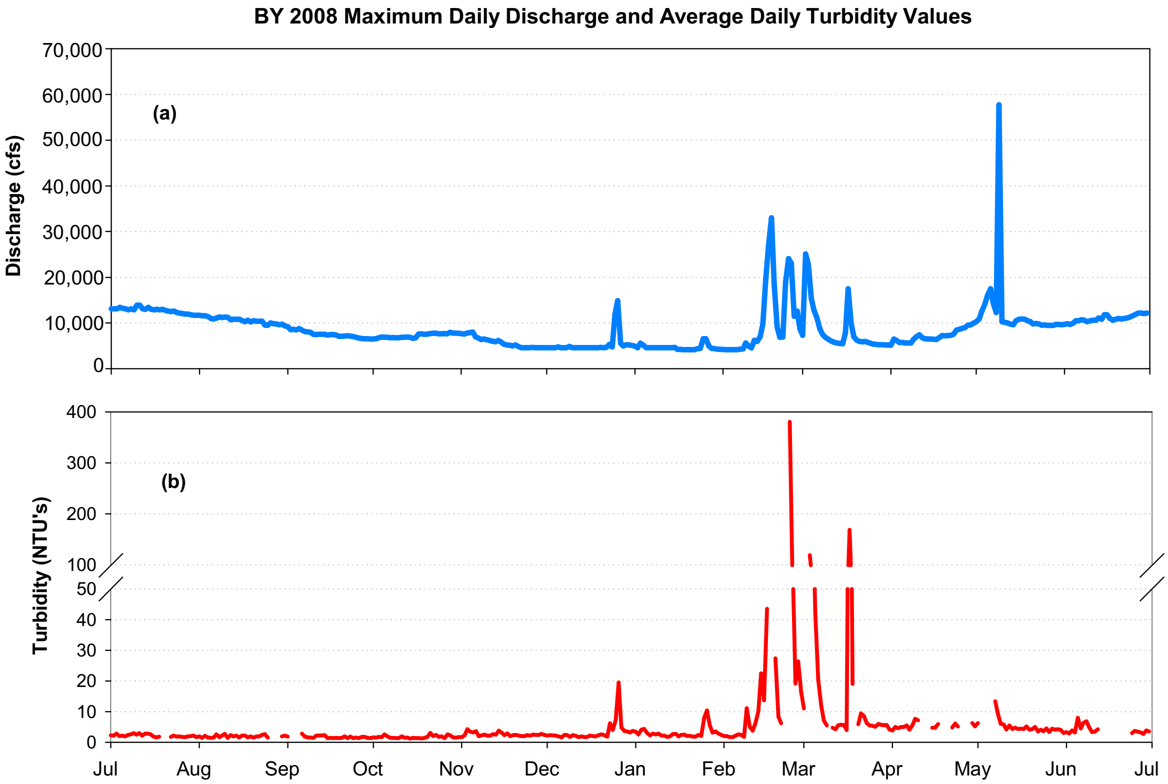

Figure 11. Maximum daily discharge (a) calculated from the California Data Exchange Center's Bend Bridge gauging station and average daily turbidity values (b) from rotary-screw traps at RBDD for the period July 1, 2008 through June 30, 2009.

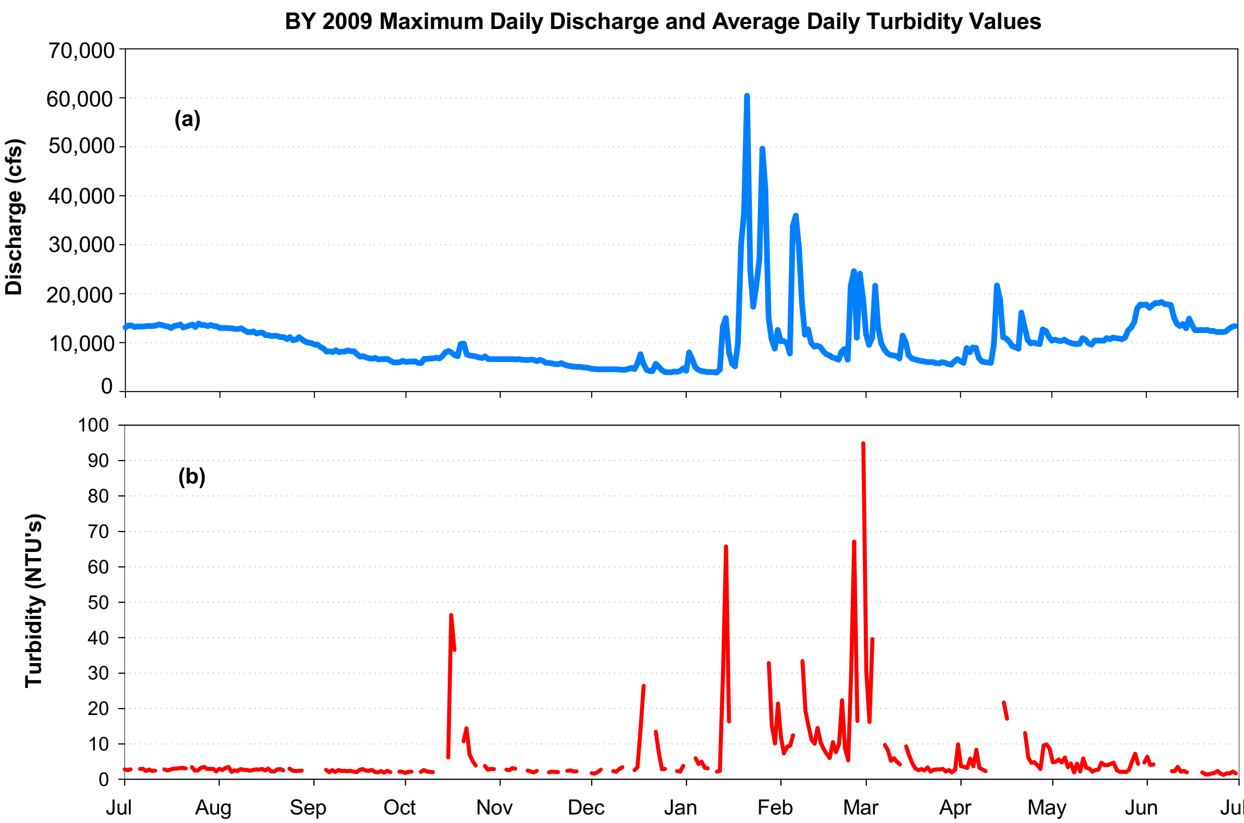

Figure 12. Maximum daily discharge (a) calculated from the California Data Exchange Center's Bend Bridge gauging station and average daily turbidity values (b) from rotary-screw traps at RBDD for the period July 1, 2009 through June 30, 2010.