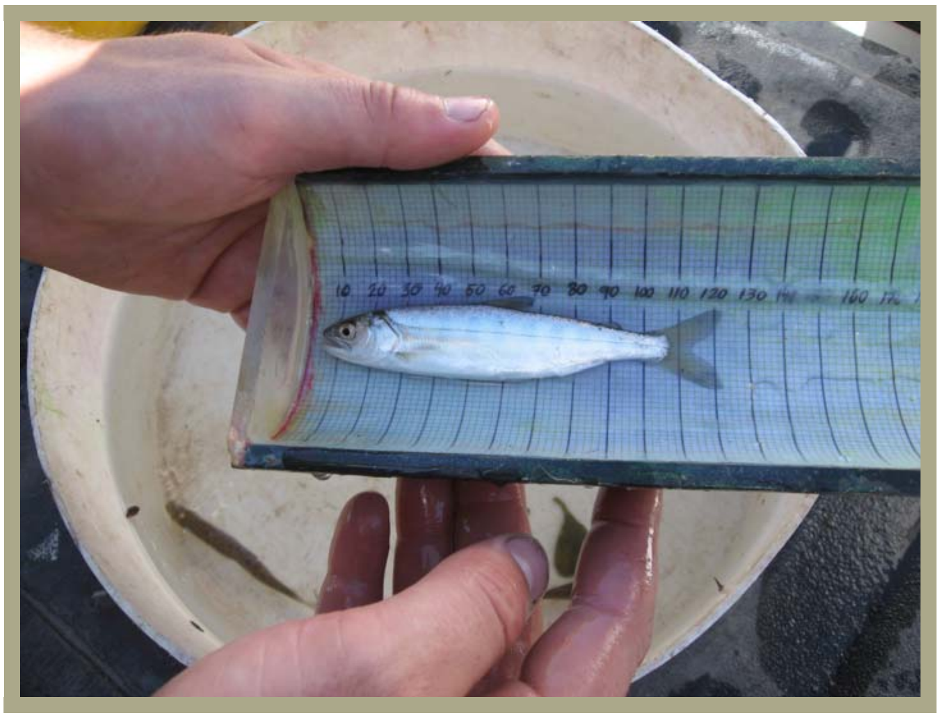
Juvenile Salmonid Out-migration Monitoring at Caswell Memorial State Park in the Lower Stanislaus River, California

2008 Annual Data Report



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SUMMARY

In 2008, Cramer Fish Sciences (CFS) continued to monitor juvenile salmonid out-migration in the lower Stanislaus River at Caswell Memorial State Park (Caswell; N 37°42'7.533", W 121°10'44.882"), at river kilometer (rkm) 13.8 near the town of Ripon, California. Since 1996, CFS has conducted annual operations at this site to estimate abundance of out-migrating fall-run juvenile Chinook salmon *Oncorhynchus tshawytscha* and Central Valley steelhead/rainbow trout *O. mykiss* to the San Joaquin River as part of the U.S. Fish and Wildlife Service's Anadromous Fish Restoration Program (AFRP). As in previous years, we used two rotary screw traps (RST) configured side-by-side to capture out-migrants from 22 January to 26 June 2008. The overall catch of out-migrating juvenile salmonids declined substantially this year compared with previous years, with catch falling from 2,909 juvenile Chinook salmon and 23 *O. mykiss* (i.e., 22 yearling-smolts and one fry) in 2007 (Watry et al. 2007) to only 229 juvenile Chinook salmon and one *O. mykiss* yearling-smolt in 2008. The dramatic decline in juvenile salmon abundance was expected given severely depressed salmon spawning escapement numbers observed fall 2007 following the West Coast Chinook salmon fishery collapse (National Oceanic and Atmospheric Administration (NOAA) 2008). As in previous years, we developed abundance estimates for Chinook salmon by measuring trap efficiency and developing estimates of daily trap efficiency and cumulative passage. We determined trap efficiency with a series of mark-recapture tests. A predictive logistic regression model was then developed with efficiency data from previous years, and the results of six efficiency tests conducted in 2008. The abundance estimate of juvenile Chinook salmon passing Caswell between 22 January and 26 June 2008 was 14,016 (±3,015 SE) compared to 94,448 (±15,357 SE) in 2007. In 2008, the estimated abundance by life stage was 984 (± 440 SE) fry; 80 (± 170 SE) parr; 12,951 (± 2,917 SE) sub-yearling smolts; and, zero yearling smolts. Natural Chinook salmon catch was 92% sub-yearling smolts. In the Stanislaus River, the proportion of fry migrants typically dominates the out-migrant population (as in many other Central Valley rivers). Sampling from previous years on the Stanislaus River indicates that fry migrant abundance is often strongly correlated with outflow conditions. Depressed outflow conditions may decrease water quality, increase predation risk, limit available habitat, and exert other stresses on out-migrants, leading to poor in-river survival. Early life history diversity is important and essential to the plasticity and adaptability characteristic of Chinook salmon populations in the Stanislaus River and elsewhere. Documentation of population status with annual monitoring provides valuable information to restoration and fisheries management efforts. Continued monitoring at the Caswell will provide critical data on Stanislaus River salmonid life history diversity and population abundance to help AFRP meet their objectives for salmon recovery in California's Central Valley.

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INTRODUCTION

California's Central Valley produced scores of Chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* throughout the Sacramento and San Joaquin river drainages before a variety of anthropogenic impacts in the last 150 years led to a precipitous overall decline (Williams 2006). Central Valley Chinook salmon stocks have experienced unprecedented abundance declines, largely due to the onset of gold mining in the mid-19th century. Extensive operations for gold recovery drastically altered critical habitats for salmonids (Yoshiyama et al. 2001). Other factors affecting these runs included gravel mining, over-harvest, logging, hydropower development, agriculture, and corresponding urban development (Nehlsen et al. 1991; Yoshiyama et al. 2001; Williams 2006). Dam construction has prevented passage to important staging areas and spawning grounds with greater impacts to spring-run Chinook salmon (and *O. mykiss*) populations who make extensive use of higher elevation habitats (Moyle 2002; May and Brown 2002). Hatchery supplementation has only compounded the problem by compressing run timing and stock complexity (Lichatowich 1999; Augerot et al. 2005; Bottom et al. 2005).

In late 2007, an Emergency Action under Magnusson-Stevens Act authority declared a commercial fishery failure for the West Coast Chinook salmon fishery due to historically low returns (National Oceanic and Atmospheric Administration (NOAA) 2008). On 1 May 2008, the U.S. Department of Commerce stated in a news release that the commercial fishery failure was due to an "unprecedented collapse of the salmon population" and that 2008 returns are estimated to be fewer than 60,000 adult Chinook salmon (NOAA 2008). While these levels are far below sustainable numbers, the reasons for decline are not yet fully understood. Changing ocean conditions (i.e., shifting ocean temperatures and food sources) may be a causal factor contributing to poor juvenile salmon survival (NOAA 2008). Additional, reports state cumulative impacts to freshwater habitats have "made salmon populations more susceptible to the occasional poor ocean conditions" (NOAA 2008).

The 1992 Central Valley Project Improvement Act (CVPIA) granted authority to the U.S. Fish and Wildlife Service (USFWS) to develop and implement a series of restoration programs, with the goal of doubling the natural production of anadromous fish in Central Valley streams. The U.S. Bureau of Reclamation (BOR) and USFWS are responsible for implementing provisions outlined in the CVPIA (Available: http://www.usbr.gov/mp/cvpia/title_34/index.html). To support this goal, USFWS established the Anadromous Fish Restoration Program (AFRP) and the Comprehensive Assessment and Monitoring Program (CAMP). These programs set anadromous fish production targets, recommended fishery restoration actions for Central Valley streams, and formed a juvenile Chinook salmon and *O. mykiss* monitoring program to assess the relative effectiveness of fishery restoration actions. The two programs support informed feedback on population dynamics of target species that allow adjustments or improvements to adaptive management plans and approaches.

The Stanislaus River, a major tributary to the San Joaquin River, still provides valuable spawning and rearing habitat for Central Valley Chinook salmon and *O. mykiss*, considered a species of concern under the federal Endangered Species Act (NOAA 2004). Additionally, multiple habitat improvement projects are currently in development. Juvenile out-migration monitoring is an important component of fisheries habitat restoration and management in the Stanislaus River. Moreover, BOR is currently developing a Revised Plan of Operations (RPO) for New Melones Reservoir, located in the upper Stanislaus River drainage, to "…reduce the reliance on New Melones Reservoir for meeting water quality and fishery flow objectives, and to ensure that actions to enhance fisheries in the Stanislaus River are based on the best available science (P.L. 108-361)." One component of the RPO is to develop an instream fishery flow schedule for the lower Stanislaus River; however, insufficient information exists relating to juvenile salmonid survival, growth, migration timing, and the relative contribution of different life stages to provide a basis for determining the optimum flow timing and magnitude needed for out-migrating juvenile salmonids.

Since 1996, the USFWS has supported CFS to monitor juvenile salmonid out-migration in the Stanislaus River. The current monitoring program determines annual juvenile Chinook salmon and *O. mykiss* production using RSTs at Caswell Memorial State Park (Caswell; N 37°42'7.533", W 121°10'44.882") (rkm 13.8), and quantifies emigrants to the San Joaquin River. This long-term data set provides a valuable source of information for evaluating fish responses to in-river management actions. The primary objectives of this project were to:

1. Estimate abundance of juvenile salmonid out-migrants in the lower Stanislaus River using RSTs operated near Caswell; and,
2. Determine and evaluate patterns of timing, size, and abundance of juveniles relative to flow and other environmental conditions.

This juvenile salmon monitoring program helps AFRP and CAMP address their goals to track population dynamics, evaluate the results of past and future habitat restoration efforts, and to understand the impacts of instream flow schedules and management on the fall-run Chinook salmon population. This annual report details results from 2008 RST operations at Caswell in the lower Stanislaus River and addresses these objectives.

STUDY AREA

The Stanislaus River, a major tributary to the San Joaquin River, flows southwest from the western slopes of the Sierra Nevada Mountains with a drainage area of approximately 240,000 ha and approximately 40% of its basin above snowline (Kondolf et al. 2001) (Figure 1). The confluence of the Stanislaus and San Joaquin rivers is located near the southern end of the Sacramento-San

Joaquin Delta (Figure 2). The basin has a Mediterranean climate with dry summers and about 90% of the annual precipitation occurs between November and April (Schneider et al. 2003). More than 40 dams exist on the Stanislaus River. Collectively, these dams have the capacity to store 240% of the average annual runoff in the basin. Approximately 85% of this total storage capacity is in New Melones Reservoir (Schneider et al. 2003). Dams control the Stanislaus River for flood protection, power generation, irrigation and municipal water. The river is also used for whitewater recreation and off-channel gravel mining. Goodwin Dam (GDW), located at river kilometer (rkm) 94 of the Stanislaus River, is the upstream migration barrier to adult Chinook salmon (see Figure 1; Appendix 1). Most spawning in the Stanislaus River is by fall-run Chinook salmon and occurs in the 29 km reach below GDW; however, spawning has been observed as far downstream as rkm 53.1. Additionally, rare observations of spring-run Chinook salmon in the Stanislaus River do exist (Anderson et al. 2007).

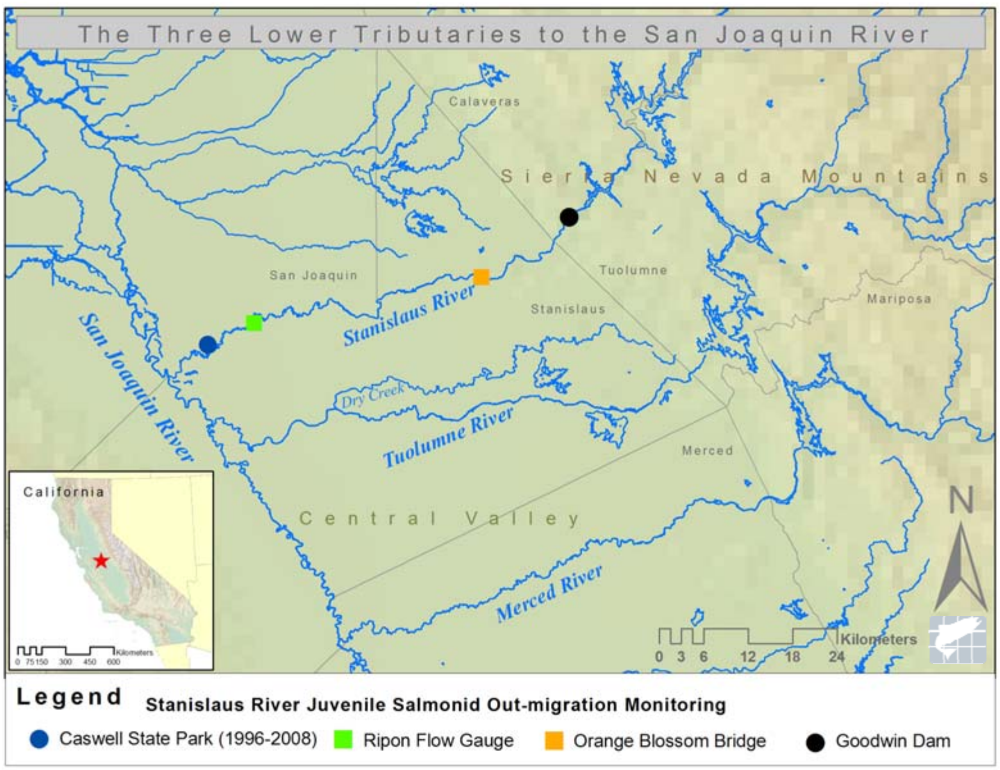

Figure 1. Map of the Stanislaus River below Goodwin Dam with landmarks.

Figure 2. The river landscape: aerial image of the lower Stanislaus River between the Caswell trapping site and the confluence with the San Joaquin River.

METHODS

Trap Operations

In 2008, we continued operations in the Stanislaus River at the Caswell site used since 1996. We monitored two 2.5 m diameter side-by-side RSTs, manufactured by EG Solutions, Inc. (Corvallis, OR), to track juvenile salmonid out-migration (Figure 3). Traps were secured with 6.35 mm galvanized steel cable leaders fastened to large trees, and state park permits allowed CFS access to the trap by land or boat as necessary. This site was selected as the furthest downstream location with suitable channel characteristics and access to install and monitor traps. The river is approximately 24 – 30 m wide and 1.5 – 4.6 m deep at this location, depending on flow. Traps were oriented adjacent to a sandbag wall, similar to previous years, which acts to divert flow into the trap cone for increased rotations. Traps were positioned to operate in the thalweg of the river channel where water velocities were greatest. We monitored trap operation following guidelines standard guidelines (CAMP 1997). Trap rotations were enumerated by a mechanical counter (Redington Counters, Inc.; Model 29) secured to the pontoon adjacent to the leading edge of the cone. Trap rotations were recorded when a bolt attached to the front of the cone activated the counter once per revolution. The total number of rotations for a sampling period provides a tool for assessing trap operation. The volume and type of debris accumulation on or in the cone affected rotation rate. We recorded total stoppages that resulted from debris accumulations. Similar to our primary objectives, several authors have used this methodology to monitor population dynamics and abundance for salmonid out-migrations (e.g., Thedinga et al. 1994; Fleming 1997; Roper and Scarnecchia 1998; Sparkman 2001; Workman 2002 – 2006; Seesholtz et al. 2004; Bottom et al. 2005; Rayton 2006; Johnson and Rayton 2007; Workman et al. 2007). Traps were raised and non-operational on days when sampling did not occur.

Figure 3. The north and south rotary screw traps positioned side-by-side (left), and upstream view of RSTs at Caswell (right) showing safety buoys and exposed gravel bar.

Safety Measures

Staff members were trained in RST operational safety, and safety precaution signage was posted to warn river users and park visitors of the inherent dangers of the RSTs (see Figure 3). We placed signs in conspicuous places at the trap site and on each side of the trap, to warn people of drowning danger as well as “Keep Out” and “Private Property” signs. A warning sign strategically placed upstream of the trap stated “Danger Ahead – Stay Left” with a large arrow pointing in the direction of the best side of the river channel for boaters to pass the traps. Flashing lights and flagging were placed on the traps and along the rigging. All signs were in English and Spanish.

Fish Capture and Handling

We generally checked traps once a day, and twice a day (or more) as conditions required (i.e., debris loads due to freshets or during scheduled releases from New Melones Dam). We followed the RST protocol (Gray et al. 2008) and used established fish handling procedures. We used tricaine methanesulfonate (Tricaine-S; Western Chemical, Inc.) to anesthetize fish for safe handling. To limit injury and stress from handling, all captured fish were anesthetized in groups of 5 – 10 fish immediately prior to handling using a solution of river water and Tricaine-S at a 26.4 mg/L concentration. River water used for holding is cooled with frozen water bottles to reduce thermal stress. Litmus strips were used to check pH and baking soda was added to buffer the acidity of the solution. The effectiveness of Tricaine-S varies with changes in temperature and fish density;

therefore, all solutions were tested with a few fish to determine potency and adjusted if necessary. StressCoat (Aquarium Pharmaceuticals, Inc.), which helps fish replace their slime coat and scales, was added to the Tricaine-S solution and recovery buckets at a rate of 2.5 ml per 9.5 L. Processed fish were returned to a bucket with fresh river water to recover prior to release. Water temperature and dissolved oxygen (DO) levels were monitored and maintained above critical levels (Gray et al. 2008). For Chinook salmon and *O. mykiss,* we recorded fork length (mm FL), weight (g), and life stage for 25 randomly-selected fish each day, any additional fish were counted. Life stage was determined by assigning a smolt index value based on morphological characteristics (Table 1). We only used the silvery parr designation to describe *O. mykiss*; it was not applied to juvenile Chinook salmon. All captured fish were released approximately 150 m downstream of the traps below a large, deep pool to decrease risk of predation and prevent recapture. Night check procedures were identical to daytime checks, with the exception of only measuring the first 20 fish of any species and counting the remainder.

Table 1. Smolt index rating adapted from CDFG.

Smolt Index	Life Stage	Criteria
1	Yolk-sac Fry	-Newly emerged with visible yolk sac
2	Fry	-Recently emerged with sac absorbed; Pigment undeveloped
3	Parr	-Darkly pigmented with distinct parr marks; No silvery coloration; Scales firmly set
4*	Silvery Parr	-Parr marks visible but faded, or completely absent; Intermediate degree of silvering
5	Sub-yearling smolt	-Parr marks highly faded or absent; Bright silver or nearly white coloration; Scales easily shed; Black trailing edge of caudal fin; More slender body
	Yearling smolt	-All the same characteristics as a smolt; Generally larger than 110 mm FL

**Silvery parr life stage was only used for O. mykiss.*

Catch

We compared daily catch with flow, and summarized our weekly catch by life stage (as determined by the smolt index). We developed a length histogram from our data to evaluate size classes, and compared with catch date to assess emigration timing and life history patterns.

Environmental Variables

We measured physical variables daily. We used HOBO® Pendant temperature logger (Onset Computer Corporation; Part #-UA-001-08) to measure hourly water temperature both in river and inside trap live-boxes. Loggers were downloaded once a week. All temperatures reported are from the in-river logger. We recorded instantaneous water temperature and dissolved oxygen using an YSI Handheld Dissolved Oxygen Instrument (YSI; Model 550A). Daily instantaneous temperature measured with the YSI provided in-river conditions for technicians monitoring water temperatures in holding buckets. We measured instantaneous water velocity using a Global Flow

Probe (Global Water Instrumentation, Inc.; Model FP101) in front of the trap cone. Instantaneous turbidity was measured in Nephelometric Turbidity Units (NTU) using a turbidity meter (LaMott Company; Model 2020). We obtained average daily flow data from three U.S. Geological Survey (USGS) gauging stations from the California Data Exchange Center (CDEC), including Goodwin Dam (GDW; rkm 94), Orange Blossom Bridge (OBB; rkm 75.5), and Ripon (RIP; rkm 25.4). We determined trap effort by measuring the rate of cone revolution during each trap check and recording revolutions between checks from counters. Our results were summarized in tables and included in our further analysis of passage abundance.

Analysis

Comparison of Sub-yearling Smolt Fork Length

To address our hypothesis about sub-yearling smolt size, we created box plots and used analysis of variance (ANOVA) to compare mean FL for 2007 and 2008 sub-yearling smolts (as determined by smolt index). We used ANOVA to test the following null hypothesis:

$H1_0$: There is no difference in mean sub-yearling smolt FL among years.

Comparison of Environmental Parameters

To address our hypotheses about environmental conditions, we used ANOVA to compare mean daily flow (RIP) and temperature (OBB), by month, from 1 January through 30 June 2007 and 2008. We used ANOVA to test the following null hypotheses:

$H2_0$: There is no difference in mean daily flow, by month, among years.

$H3_0$: There is no difference in mean daily temperature, by month, among years.

Trap Efficiency

We determined trap efficiency to estimate the number of natural migrants passing our traps (passage). We conducted seven efficiency tests with juvenile Chinook salmon from Merced River Hatchery (MRH). Due to low catch, sufficient natural smolts were unavailable; therefore, hatchery smolts were used as surrogates during the time period when natural smolts were passing the trap. Releases consisted of approximately 500 fish each for the first six tests (14 April – 19 May 2008) and 1,333 fish for the seventh and final test conducted on 27 May 2008. Fish were dye-marked using a photonic marking gun (Meda-E-Jet; A1000) with pink dye on the caudal or anal fin (Figure 4), or immersed in a Bismarck Brown Y (Sigma-Aldrich) solution (Baker and Modde 1977; Gaines and Martin 2004; Rayton 2006; Gray et al. 2008) resulting in a full body mark (Figure 5). Efficiency releases are summarized in Table 2. Releases occurred approximately 430 m upstream of the traps from the north bank at a narrow (~ 20 m) and deep area of the river.

Figure 4. Technician marking fish (left) and sub-yearling smolt marked with pink photonic dye (right).

Figure 5. Sub-yearling smolt marked by immersion in Bismarck Brown Y solution. Note: mark is most prominent and visible around the mouth, operculum and on the ventral fins (i.e., pectoral, pelvic and anal), especially when compared with unmarked fish (see Figure 4).

Table 2. Summary of efficiency releases at Caswell, 2008. Note, AFP = anal fin pink; CFP = caudal fin pink; LCP = lower caudal pink; UCP = upper caudal pink; and, BB = Bismarck Brown.

Release Code	Release Date	Number Released	Mark
C01	4/15/2008	499	AFP
C02	4/23/2008	523	CFP
C03	4/30/2008	518	LCP
C04	5/7/2008	517	UCP
C05	5/15/2008	496	UCP
C06	5/20/2008	497	CFP
C07	5/28/2008	1333	BB

To encourage mixing with wild fish, prevent schooling, and mimic natural periods of nighttime migration, fish releases occurred approximately one hour after dark in groups of five to ten. Water depth and flow often prevented wading into channel, so fish were released using a long-handled (3 m) dip net. We processed traps one hour after completing release activities to check for immediate recaptures, and again at one-hour intervals until we recaptured < 1% of marked fish during a check. Additional recaptures were recorded with the subsequent days' catch.

Passage Estimates

Following methods from previous years, we conducted mark-recapture of juvenile Chinook salmon to estimate catch rate (trap efficiency) (Watry et al. 2007), and to develop a predictive logistic regression model to determine daily trap efficiency and estimate total juvenile salmonid passage. We used logistic regression to develop models for predicting daily trap efficiencies as a function of environmental conditions. A total of 144 experimental mark-recapture release groups across years (1996 – 2008) were used to estimate trap efficiencies at Caswell (Table 3).

Table 3. Summary by year of mark-recapture release groups at the Caswell.

Year	Release Groups	Average Number Released / Group	Total Released	Total Recaptures
1996	8	2,720	21,757	1,000
1997	2	3,391	6,781	187
1998	7	2,714	18,996	463
1999	8	1,964	15,713	407
2000	15	1,011	15,166	456
2001	12	1,085	13,014	1,330
2002	11	800	8,804	973
2003	35	109	3,823	495
2004	8	255	2,039	263
2005	16	238	3,802	489
2006	6	1,017	6,102	58
2007	9	77	697	28
2008	7	626	4,383	59
Total	144	1,231	121,077	6,208

Briefly, logistic regression is a form of generalized linear model that is applicable to binomial data (McCullach and Nelder 1989; Dobson 2002). (In this case, binomial data would refer to the potential outcomes of fish collection, i.e., either the fish is caught or not.) Here, the binomial probability of interest is the observed trap efficiency (q):

(3) $$q = \frac{m}{R},$$

where m is number of observed recaptures (a binomial variable) of a given release group of size R. The logistic model with n explanatory variables (x) can be expressed in linear form as:

(4) $$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_n x_n \ ,$$

where *y* is the "logit" transform of the observed trap efficiency (*q*):

(5) $$y = \text{logit}(q) = \log\left(\frac{q}{1-q}\right) \ .$$

The coefficients (*β*), which are estimated via maximum likelihood, provide predicted values of trap efficiency via the following back-transformation of the logit function:

(6) $$\hat{q} = \frac{\exp(y)}{1+\exp(y)} \ .$$

We examined the following explanatory variables (x) for trap efficiency: flow, temperature, turbidity, and length (average fish length at release). We used the natural logarithm of flow, denoted log(flow), which had a roughly linear relationship with y (=logit(*q*)). We also examined the categorical variable year to explore year-to-year differences in mean trap efficiency that might arise due to annual changes, e.g., channel morphology, bank vegetation, predator abundance, trap placement, etc. Our approach was to fit logistic models using all years of available data. This approach assumes the relationship between trap efficiency and an explanatory variable such as flow will have a similar form across years. An alternative would be to fit models separately to each year of data, but this potentially allows relationships to differ appreciably among years (e.g., a positive effect of flow in one year, but a negative effect in a different year). Such differences would likely have little biological support and would be considered spurious. In contrast, modeling all years simultaneously provides fewer models and more data, which reduces the chance of finding spurious relationships and increases the statistical power to detect relationships that have a consistent basis across years.

We used a forward stepwise regression procedure to determine the "best fitting" logistic regression model. In the first step, a model was fit with an intercept (β_0), and then each explanatory variable was entered one at a time. The variable with the greatest explanatory power was then included in the model, and the remaining variables were again entered one at a time. The procedure was terminated when none of the remaining variables had a statistically significant effect on survival at the $\alpha = 0.05$ significance level. An alternative approach to model selection was also examined, in which the "best fitting" model was determined using the Akaike Information Criterion (AIC), adjusted for over-dispersion (Burnham and Anderson 2002). However, the stepwise regression and AIC procedures provided the same "best" model in all analyses.

The statistical significance of explanatory variables in the "best fitting" model was tested using analysis of deviance (McCullach and Nelder 1989; Venables and Ripley 1999). Under the binomial assumption, a logistic model that adequately explains variability in trap efficiencies will have a deviance roughly equal to the residual degrees of freedom. However, in our analyses, model deviances were much greater than that expected due to binomial sampling error alone. Such extra-binomial variation, which may arise from either over-dispersion or inadequate model structure (i.e., when key processes affecting trap efficiencies are missing from the model), must be accounted for when testing variables and estimating confidence intervals. Extra-binomial variation is represented by a dispersion parameter, Φ, which is a scalar of the assumed binomial variance. To conduct statistical tests and compute confidence intervals, we multiplied the variance-covariance matrix for the logistic coefficients by the dispersion parameter, which is easily estimated from the fit of a logistic regression (Venables and Ripley 1999).

The daily passage abundance (*n*) of migrating juvenile Chinook salmon was estimated as follows:

(7) $$\hat{n} = \frac{c}{\hat{q}} ,$$

where *c* was observed daily count and *q* was the estimated trap efficiency for that day based on the "best" logistic model. Annual passage was estimated by summing the daily abundance estimates. Standard errors (SE) and confidence intervals for measures of total annual passage were computed using the methods described in the Appendix 2.

During some years, there were periods when traps were not fished. To estimate a missing value of daily count (c) within a sampling period, we used the weighted average of all observed counts for the five days before and five days after the missing value. The weights were equal to one through five, where values that were directly adjacent to the missing day were weighted as five, values that were two days before and after the missing day were weighted as four, and so on. This weighted average was reasonably effective at capturing the temporal trends in daily counts observed across years.

RESULTS

Trap Operations

We began our sampling effort immediately following trap installation on 22 January 2008, and terminated operations on 26 June 2008, due to low catch and increased temperatures. During periods when catch was consistently low (< 2 – 5 juvenile Chinook salmon), we sampled four days a week, which resulted in 135, out of a possible 158, trapping days.

Catch

We captured a total of 229 natural, unmarked juvenile Chinook salmon and one rainbow trout during the 2008 trapping season (Table 4). The first catch of natural Chinook salmon occurred on 25 January 2008, and the season's only rainbow trout (220 mm; 91.7 g) was captured on 3 May 2008. Peak daily catches (n = 15, 13 and 12) occurred on 30 April, 5 May, and 27 May 2008, respectively; and, coincided with sharp decreases in controlled flow releases for the Vernalis Adaptive Management Plan (VAMP, 22 April to 19 May 2008) and Vernalis water quality releases (Figure 6). Median catch date was 30 April 2008, and immediately preceded increased water temperatures in early May which persisted even under flow increases. The overall mortality rate was 3.1% (n = 7) of the total juvenile Chinook salmon catch; no more than one salmon mortality was found when encountered. Most mortalities occurred under conditions of increased flow or high debris load when trap was stopped or partially blocked upon arrival.

Table 4. Catch by life stages (determined by smolt index) of juvenile Chinook salmon by week at Caswell, 2008.

Week	Number of Days Trapped	Weekly Catch				
		Total	Fry	Parr	Sub-yearling Smolt	Yearling-smolt
1/21 – 1/27	5	11	11	0	0	0
1/28 – 2/3	7	8	8	0	0	0
2/4 – 2/10	5	4	4	0	0	0
2/11 – 2/17	4	2	2	0	0	0
2/18 – 2/24	6	0	0	0	0	0
2/25 – 3/2	5	3	2	1	0	0
3/3 – 3/9	6	0	0	0	0	0
3/10 – 3/16	7	0	0	0	0	0
3/17 – 3/23	7	4	1	0	3	0
3/24 – 3/30	5	4	2	1	1	0
3/31 – 4/6	4	1	0	0	1	0
4/7 – 4/13	6	14	0	0	14	0
4/14 – 4/20	7	14	0	0	14	0
4/21 – 4/27	7	19	0	0	19	0
4/28 – 5/4	7	46	0	0	46	0
5/5 – 5/11	7	44	0	0	44	0
5/12 – 5/18	7	22	0	0	22	0
5/19 – 5/25	5	8	0	0	8	0
5/26 – 6/1	6	21	0	0	21	0
6/2 – 6/8	7	2	0	0	2	0
6/9 – 6/15	5	2	0	0	2	0
6/16 – 6/22	6	0	0	0	0	0
6/23 – 6/29	4	0	0	0	0	0
1/21 – 6/29/2008	135	229	30	2	197	0

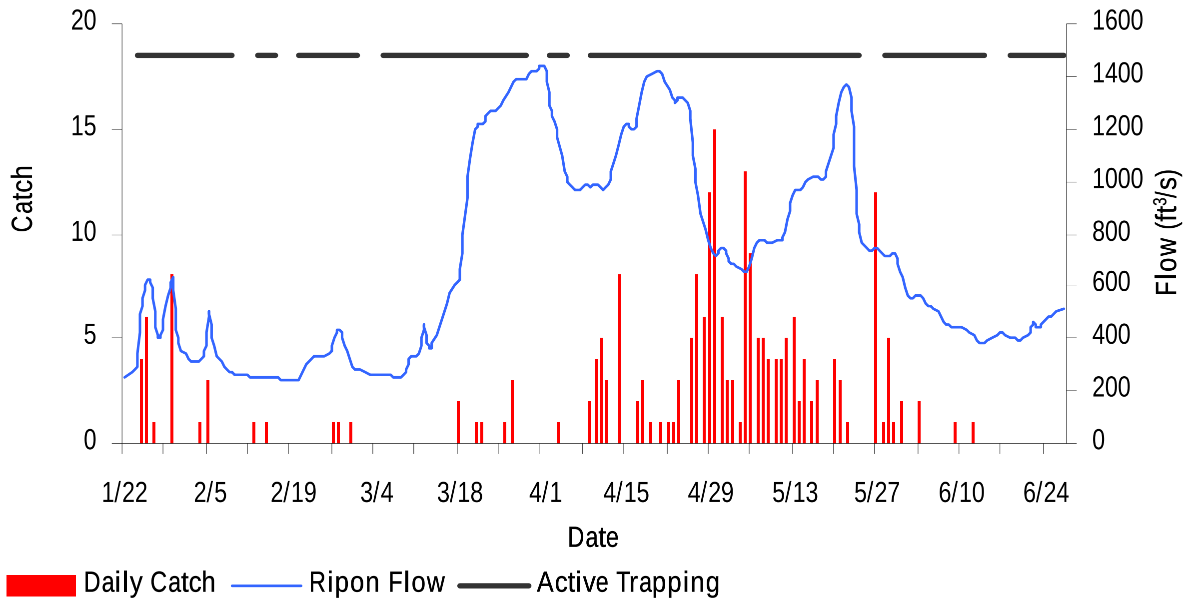

Figure 6. Daily Chinook salmon catch and flow at Ripon (RIP), 2008.

We captured three of the four known juvenile Chinook salmon life stages occurring in the Stanislaus River. Our catch included fry, parr, and sub-yearling smolt emigrants, but yearling-smolt life stages were absent and only two individuals from the parr life stage were collected between 22 January and 26 June 2008 (Table 5). The majority of the out-migration catch was composed of sub-yearling smolts (86%). Each life stage has different timing patterns and size distributions (Figure 7 and 8).

Table 5. Percent of run by life stage (according to smolt index) of Chinook salmon from Caswell, 2008.

Life Stage	Number	Percent of Run	Date Range	Average FL (mm)
Fry	30	13	1/25 – 3/27	37.4 ± 1.3
Parr	2	1	2/29 – 3/26	54 ± 3.9
Sub-yearling smolt	197	86	3/18 – 6/21	92.7 ± 1.1
Yearling-smolt	0	0	n/a	n/a
Cumulative Total	229	100	1/25 – 6/21/2008	

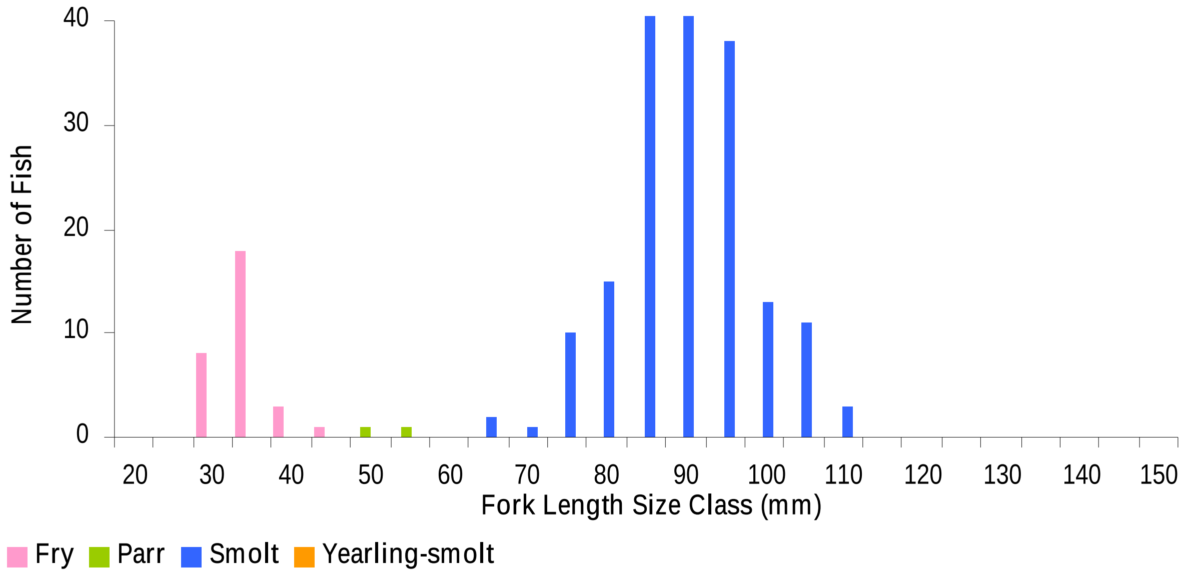

Figure 7. Fork length (mm) distributions for juvenile Chinook salmon caught at Caswell, 2008.

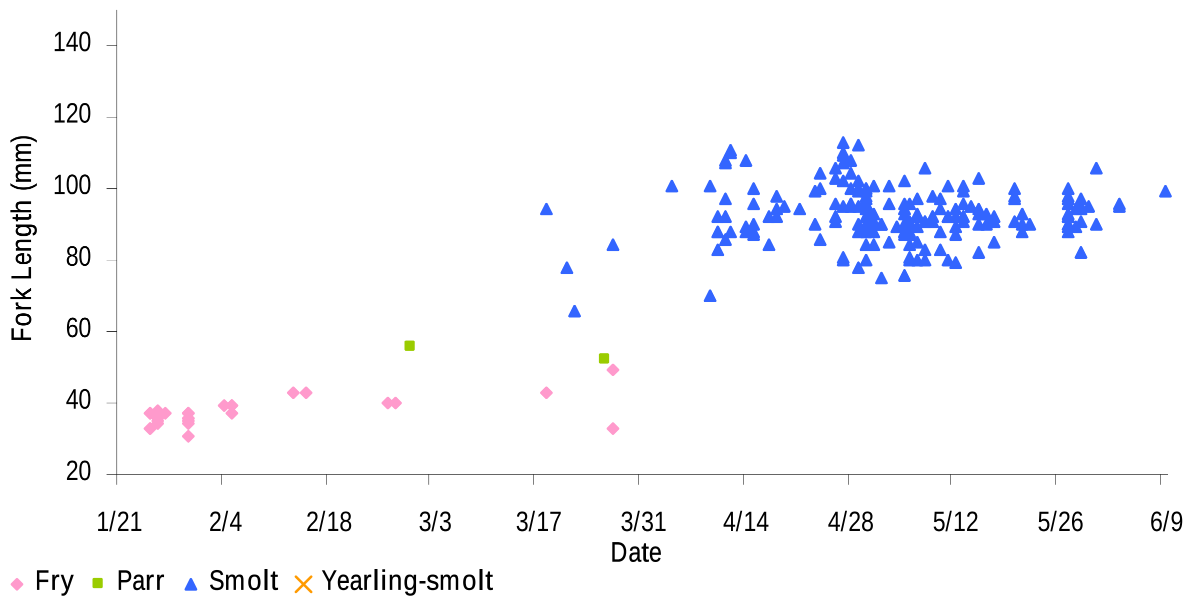

Figure 8. Fork length (mm) distributions for juvenile Chinook salmon caught at Caswell, 2008.

Environmental Variables

Flow at RIP during the season ranged from 250 to 1,375 ft^3/s, and were controlled by releases from New Melones Dam (Table 6). Daily temperature ranged from 7.9 – 24.1°C during the sample period. Turbidity (NTU) was greatest in the early part of the out-migration season, but decreased as rain events ceased with the onset of spring and summer. Instantaneous DO was never measured below 5 mg/l (critically low level); 7.81 mg/l was found to be the lowest measurement. The majority of Chinook salmon catch occurred during controlled flow releases for the Vernalis Adaptive Management Plan (VAMP) effective from 22 April to 19 May 2008.

Table 6. Summary of environmental variables (i.e., mean daily flow reported at Ripon, mean daily temperature recorded on-site, instantaneous DO and instantaneous turbidity) in the Stanislaus River, 2008.

Date	Daily Flow (ft^3/s)		Daily Temperature (°C)			DO (mg/l)		Turbidity (NTU)	
	Min	Max	Min	Max	Average	Min	Average	Max	Average
1/21 – 1/27	250	407	7.9	10.2	8.8	9.71	10.44	37.60	21.56
1/28 – 2/3	311	411	8.1	10.3	9.1	10.14	10.33	39.40	19.63
2/4 – 2/10	261	325	7.8	11.7	9.6	10.49	10.64	26.40	14.87
2/11 – 2/17	245	250	9.2	12.6	10.9	9.98	10.32	4.12	3.54
2/18 – 2/24	245	300	9.9	12.7	11.1	10.48	10.68	5.24	3.86
2/25 – 3/2	262	328	10.1	15.0	12.6	9.37	10.04	11.70	7.57
3/3 – 3/9	252	270	11.8	15.1	13.5	9.59	10.36	4.12	2.67
3/10 – 3/16	340	454	10.9	15.8	13.7	10.04	10.41	4.67	3.92
3/17 – 3/23	624	1087	10.9	13.7	12.4	10.88	11.10	5.13	4.00
3/24 – 3/30	1284	1375	11.9	14.1	13.0	10.69	10.81	4.54	3.81
3/31 – 4/6	968	1145	12.0	14.1	13.1	10.39	10.58	3.90	2.81
4/7 – 4/13	968	1025	12.2	15.9	13.8	10.27	10.58	4.86	2.72
4/14 – 4/20	1199	1332	12.7	15.4	13.9	10.25	10.60	3.29	2.37
4/21 – 4/27	818	1167	12.1	17.1	13.7	9.85	10.59	2.88	2.09
4/28 – 5/4	658	700	14.3	17.7	15.9	9.35	9.73	5.65	3.26
5/5 – 5/11	700	772	15.5	17.4	16.6	9.31	9.53	3.99	2.34
5/12 – 5/18	964	1010	15.1	19.2	17.2	9.49	9.59	4.23	3.10
5/19 – 5/25	739	1054	14.8	17.7	16.2	9.10	9.62	3.77	2.88
5/26 – 6/1	551	663	14.5	19.7	17.0	8.85	9.37	4.12	2.87
6/2 – 6/8	439	497	17.6	21.6	19.3	8.50	8.76	3.18	2.65
6/9 – 6/15	383	411	19.5	23.5	21.5	8.10	8.28	3.63	2.86
6/16 – 6/22	397	420	20.5	24.1	22.3	7.81	7.88	4.13	2.60
6/23 – 6/29	471	494	19.5	22.2	20.8	8.15	8.29	4.50	3.08

Analysis

Comparison of Sub-yearling Smolt Fork Length

To test the hypothesis that there was no difference in the length of fish between 2007 and 2008 (Hypothesis 1), we used ANOVA to test for differences in mean FL and determined mean FL was significantly larger ($P < 0.00001$) in 2008, by a mean difference of 12.4 mm, compared to 2007

(Figure 9). Mean FL was 80.6 ± 0.5 mm (95% CI; n = 816) in 2007 and 93.0 ± 1.2 mm (95% CI; n = 172) in 2008 (Table 7).

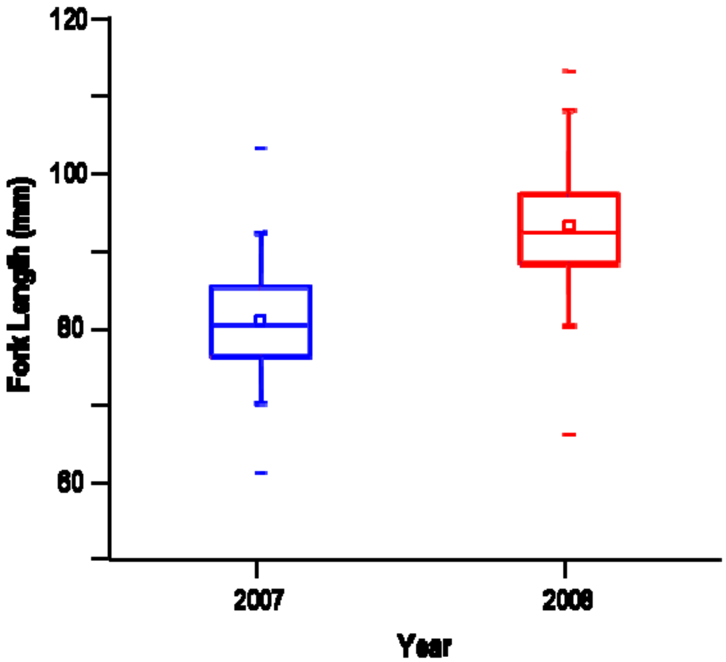

Figure 9. Boxplot displaying differences in mean smolt fork length among years at Caswell for 2007 and 2008. Displayed are minimum and maximum values; 5% and 95% values; 25%, median and 75% values (large, outer boxes); and, mean with 95% confidence (small, inner box).

Table 7. ANOVA results testing $H1_0$: mean smolt fork length is equal between years for the Stanislaus River (2007 and 2008). Bolded P-value indicates significance at α = 0.05.

	2007	2008
Mean FL (mm)	80.6	93.0
SD	6.70	7.91
F-value	452.74	
df	986	
P-value	< 0.00001	

Comparison of Environmental Parameters

To test the hypothesis that there was no difference in mean daily flow, by month, between 2007 and 2008 (Hypothesis 2), we paired months for each year, created a composite box plot (Figure 10) to display comparisons. We used ANOVA to test differences in mean daily flow by month and determined significant differences between 2007 and 2008 (Table 8).

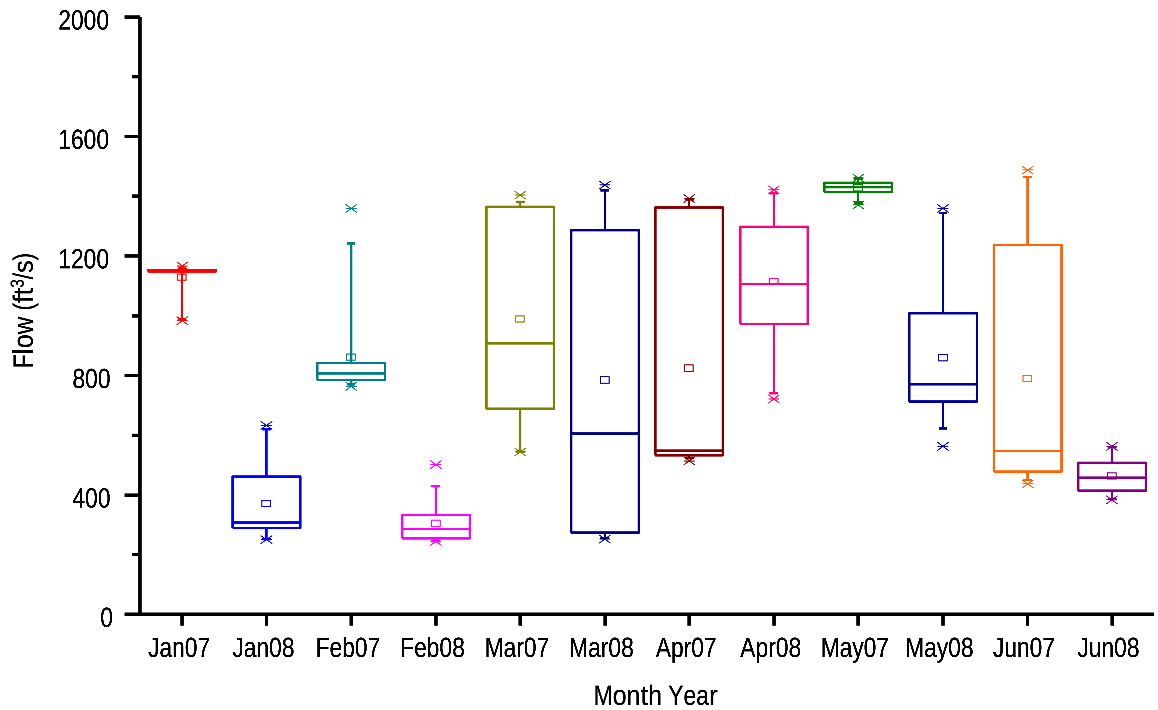

Figure 10. Box plot displaying differences in mean daily flow, by month, among years at Caswell for 2007 and 2008. Displayed are minimum and maximum values; 5% and 95% quantile values; 25%, median and 75% quartile values (large, outer boxes); and, mean with 95% confidence (small, inner box).

Table 8. ANOVA results testing $H2_0$: mean daily flow, by month, is equal between years for the Stanislaus River (2007 and 2008). Bolded P-values indicate significance at α = 0.05.

	January		Febuary		March		April		May		June	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
Mean Daily Flow (ft^3/s)	1128	371	860	305	989	784	824	1114	1428	859	789	460
SD	55.3	125.5	146.3	62.9	341.7	486.9	391.9	211.7	22.3	210.8	372.3	51.1
F-value	944.9		350.4		3.5		12.7		223.1		23.0	
df	60		55		58		58		60		58	
P-value	< 0.00001		< 0.00001		= 0.066		= 0.00075		< 0.00001		< 0.00001	

To test the hypothesis that there was no difference in mean daily temperatures, by month, between 2007 and 2008 (Hypothesis 3), we paired months for each year, created a composite box plot (Figure 11) to display comparisons and used ANOVA to test differences in mean daily flow by month; we determined there were only significant differences for April and May mean temperatures between 2007 and 2008 (Table 9).

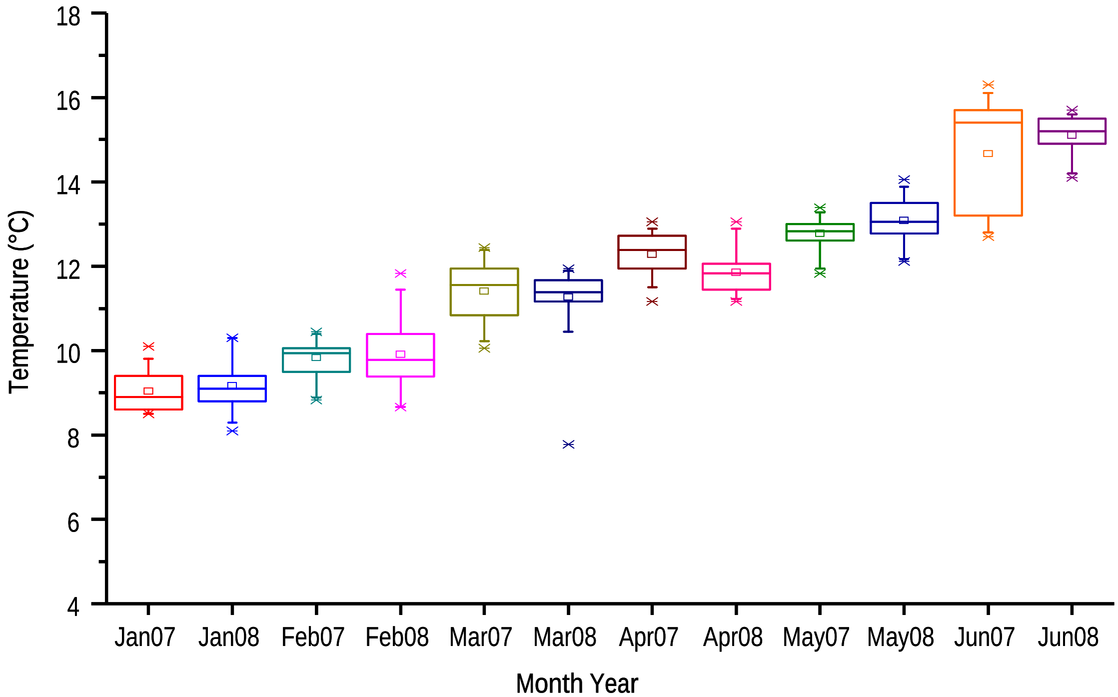

Figure 11. Box plot displaying differences in mean daily temperatures, by month, among years at Caswell for 2007 and 2008. Displayed are minimum and maximum values; 5% and 95% quantile values; 25%, median and 75% quartile values (large, outer boxes); and, mean with 95% confidence (small, inner box).

Table 9. ANOVA results testing $H3_0$: mean daily temperatures, by month, are equal between years for the Stanislaus River (2007 and 2008). Bolded P-values indicate significance at α = 0.05.

	January		February		March		April		May		June	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
Mean Daily Temp (°C)	9.0	9.2	9.8	9.9	11.4	11.3	12.3	11.9	12.8	13.1	14.7	15.1
SD	0.44	0.52	0.43	0.78	0.66	0.76	0.49	0.51	0.36	0.49	1.27	0.47
F-value	1.10		0.22		0.62		10.88		7.53		3.14	
df	60		55		60		58		60		58	
P-value	= 0.30		= 0.64		= 0.44		= 0.0017		= 0.008		= 0.082	

Trap Efficiency

We observed a strong negative trend between trap efficiencies and flow at the Caswell site across all years of trapping (1996 – 2008) (Figure 12; Table 10). A negative trend was also apparent between trap efficiencies and average fish length (at release). However, there was no obvious trend between trap efficiencies and turbidity (see Figure 12).

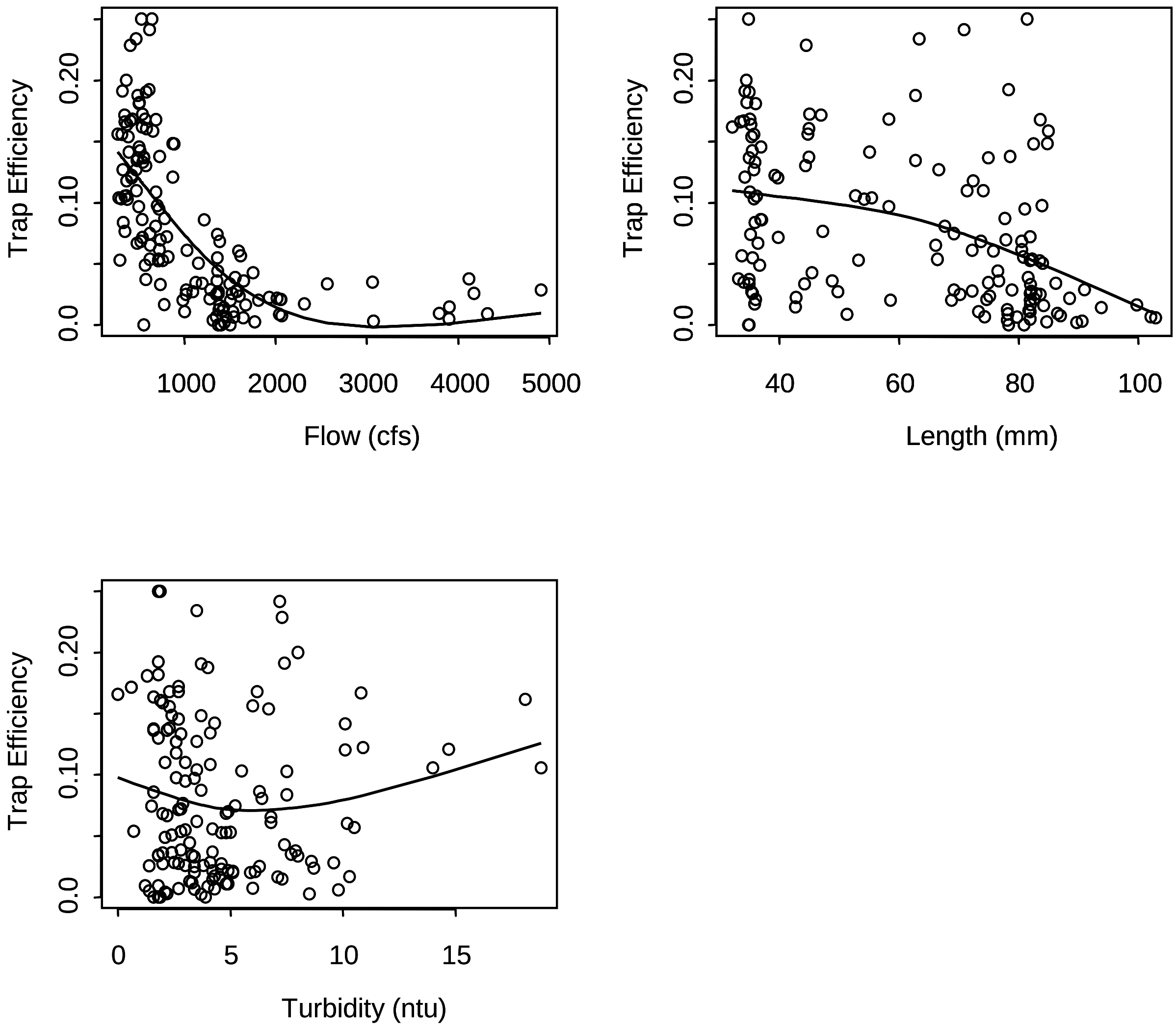

Figure 12. Trap efficiencies as a function of flow, fish length, and turbidity for the 144 mark-recapture releases at Caswell (1996–2008). Note, solid lines are exploratory fits of smoothing splines.

Table 10. Analysis of deviance for the logistic model fit to trap efficiencies of 144 mark-recapture releases at the Caswell trap site. Note, Df = degrees of freedom.

Variable	Df	Deviance	Residual Df	Residual Deviance	F Value	Pr (F)
Intercept			143	4944.5		
log(flow)	1	3297.5	142	1647.0	409.8	< 0.001
Length	1	299.5	141	1347.6	37.2	< 0.001
Year	12	360.8	129	986.8	3.7	< 0.001
Total	14	3957.7	412	986.8		

Passage Estimates

The logistic regression analysis indicated that trap efficiencies were significantly related to the variables log(flow), length, and year (Table 10 and 11; Figure 13). The dominant explanatory variable was log(flow), accounting for 67% of the total deviance. Fish length at release, which accounted for 6.1% of the deviance, had a moderate negative effect on trap efficiencies. The categorical variable 'year' accounted for 7.3% of the deviance, and indicated that trap efficiencies from 2006 to 2008 were lower on average than during the previous five years 2001 – 2005. Adding the variable turbidity to the model did not improve the model fit (deviance explained = 0.7; P = 0.78).

Table 11. Regression coefficients and standard errors (SE) for the best fitting logistic model fit to trap efficiencies of 144 mark-recapture releases at the Caswell trap site. Note, the coefficient for 1996 is taken to be zero, whereas coefficients for 1997-2008 represent differences in logit(catch rate) relative to 1996.

Variable	Coefficient	Standard Error (SE)
Intercept	2.36	0.81
log(flow)	-0.66	0.12
Length	-0.01	0.00
1997	-0.21	0.12
1998	-0.07	0.06
1999	-0.04	0.04
2000	-0.06	0.03
2001	0.07	0.03
2002	0.03	0.02
2003	0.09	0.02
2004	0.02	0.03
2005	0.01	0.02
2006	-0.07	0.04
2007	-0.02	0.05
2008	-0.06	0.03

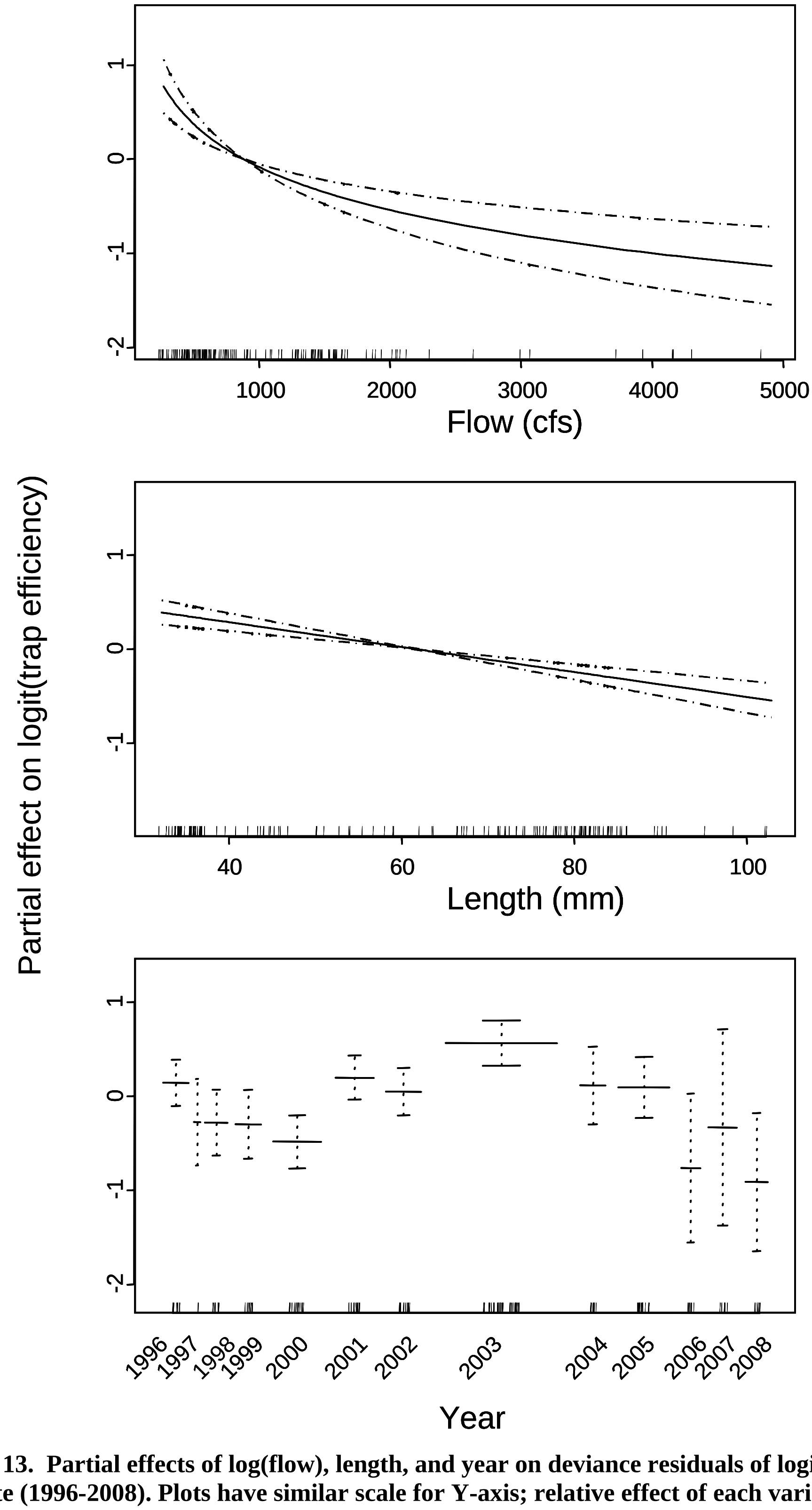

Figure 13. Partial effects of log(flow), length, and year on deviance residuals of logit(efficiency) for the Caswell trap site (1996-2008). Plots have similar scale for Y-axis; relative effect of each variable can be compared. Dashed lines indicate approximate 95% confidence intervals. Tick marks show locations of trap efficiency estimates for a given variable.

Estimates of the total abundance of juvenile Chinook salmon passing the Caswell trap site from 1996 to 2008 are presented in Table 12. Total annual passage estimates for all sample years ranged from 14,016 to 2,141,260 (mean = 502,851) with the highest abundance occurring in 2000, and the lowest in 2008. The estimated precision (an indicator of reliability) and confidence interval for the total passage estimate for 2008 suggests that the estimate is reasonably precise (95% CI: 9,159 to 21,446; CV = 21.5%), although the coefficient of variation for 2008 was the highest among all available years (Table 12), likely the results of a small sample size. In 2008, passage estimates by life stage totaled 984 fry, 80 parr, and 12,951 sub-yearling smolts (Table 13). Total juvenile passage was dominated by sub-yearling smolts (reflective of catch), which accounted for approximately 92% of the total passage estimate. This year fry and parr out-migrants accounted for 7% and 1% of the total passage estimate, respectively. The majority of fish migrated past the Caswell trap site between 17 March and 27 May 2008, with peak (median) passage occurring on 30 April 2008 (Figure 14).

*Table 12. Estimated total number of juvenile Chinook salmon passing the Caswell trap site, 1996-2008. SE = standard error of the estimate. CV = coefficient of variation of the estimate, where % CV = (SE / Total Passage) * 100. 95% confidence intervals are reported for both normal and lognormal error distributions.*

Year	Passage Estimate	SE	CV	Lower 95% CI	Upper 95% CI
1996*	70,824	7,848	11.1%	56,785	88,334
1997*	95,997	11,175	11.6%	76,117	121,068
1998	1,244,438	193,712	15.6%	913,219	1,695,788
1999	1,556,576	243,144	15.6%	1,141,064	2,123,394
2000	2,141,260	244,269	11.4%	1,705,703	2,688,039
2001	164,474	17,150	10.4%	133,589	202,499
2002	104,088	12,239	11.8%	82,343	131,577
2003	170,470	22,457	13.2%	131,133	221,606
2004	418,831	70,297	16.8%	300,099	584,539
2005	262,082	37,837	14.4%	196,646	349,293
2006	199,561	30,923	15.5%	146,651	271,562
2007	94,448	15,357	16.3%	68,373	130,467
2008	14,016	3,015	21.5%	9,159	21,446

**Trap only operated during part of the out-migration due to high water conditions, estimates are not comparable.*

Table 13. Passage estimates for juvenile Chinook salmon by life stage at the Caswell, 2008.

Life Stage	Passage Estimate	SE	CV	Lower 95% CI	Upper 95% CI
Fry	984	440	44.7%	419	2,312
Parr	80	170	212.4%	6	1,093
Smolt	12,951	2,917	22.5%	8,300	20,208
Total	14,016	3,015	21.5%	9,159	21,446

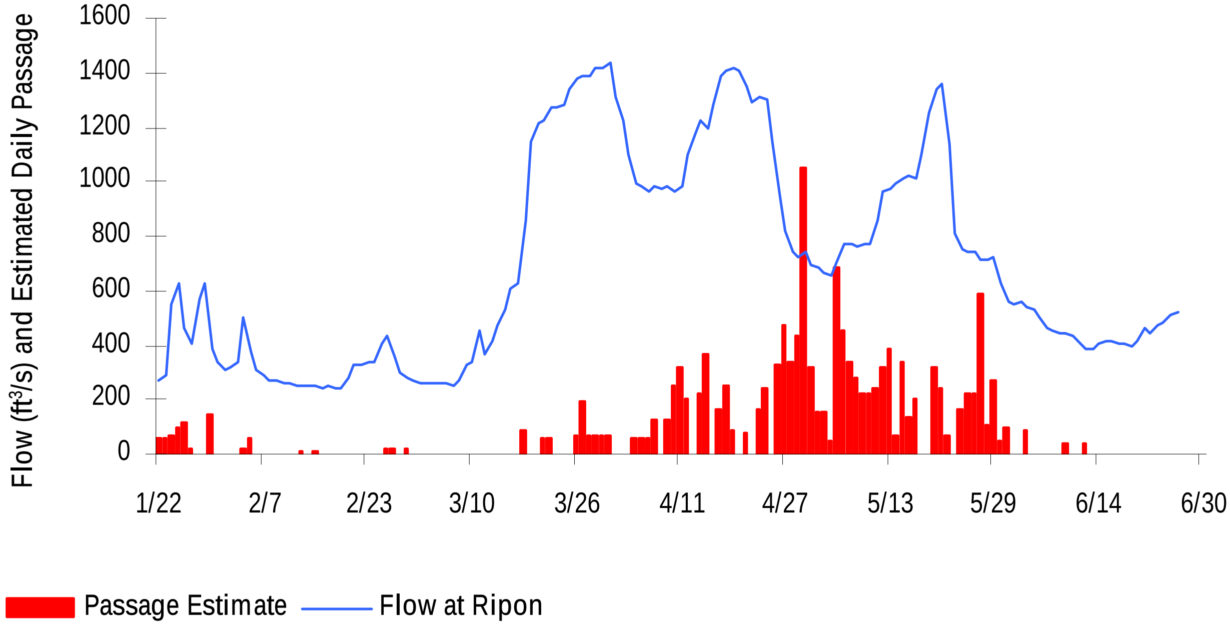

Figure 14. Daily passage of juvenile Chinook salmon and flow at Ripon in the Stanislaus River at Caswell, 2008.

DISCUSSION

Catch for the 2008 out-migration season was very low. We caught 229 juvenile Chinook salmon and one *O. mykiss*, and estimated juvenile Chinook salmon migrant passage as 14,016 (SE 3,015), the lowest abundance level recorded in the Stanislaus River since 1996. Sub-yearling out-migrants dominated in 2008, with 92% of fish emigrating as sub-yearling smolts and with few fish collected from the fry, parr, or yearling-smolt life history types. Fry migrants typically compose a larger proportion of the population based on previous out-migration data. Diversity in salmon early life history is an important factor affecting the adaptability (Thorpe 1989; Mangel 1994a, b) and fitness (Healey and Prince 1995) of salmonid populations.

We compared mean FL between the last two sampling years (i.e., 2007 and 2008) and also assessed environmental conditions, in addition to determining passage abundance, assessing timing and life stage diversity. Fish were found to be significantly shorter in 2007. We found significant differences in 2007 and 2008 mean daily flow, by month, for all months except March. However, neither year could be classified as clearly drier than the other; 2007 was classified as a 'Critical' water year (Available: http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST), and 2008 conditions were comparable. Mean daily temperature differences were only significant in April and May. Further exploration of these differences in outflow conditions among many years may help explain some of the size differences. Overall, passage abundance was exceptionally low, in 2008, and was dominated by a single life stage; however, migration timing occurred over a similar period as previous years.

In 2007, the Sacramento-San Joaquin River system fall-run Chinook salmon escapement fell far below conservation objective targets of 122,000 – 180,000 natural and hatchery adult spawners; resulting in the declaration of a West Coast commercial salmon fishery failure under the Magnusson-Stevens Act (NOAA 2008). The 2007 Stanislaus River fall-run Chinook salmon adult escapement was just 315 individuals, the 4th lowest number in the past 25 years (Available September 2008: http://www.delta.dfg.ca.gov/afrp/documents/Chinookprod_33108.xls). While the overall cause of this decline is not completely understood, NOAA (2008) indicates broad-scale effects across the Central Valley and the ocean as possible causes. During the 2008 sampling season, our low catch and passage estimate reflect this situation.

Understanding the effects of flow, temperature and life history diversity on the success and condition of salmonid populations in the Stanislaus River is important. Flow, turbidity, and water temperature are all key factors affecting migration patterns of juvenile Chinook salmon (Holtby et al. 1989; Gregory and Levings 1998; Giannico and Healey 1998; Sommer et al. 2001). Differing magnitude flow pulses have been found to stimulate juvenile Chinook salmon migration rates. Kjelson et al. (1981) found that peak catches in the Sacramento-San Joaquin Delta were often correlated with flow peaks caused by storm runoff. They suggested flow pulses stimulated fry to emigrate from spawning grounds; a finding supported by USFWS (2003). Turbidity and flow are related terms when evaluating migration triggers, as higher turbidity is usually caused by a freshet or increased flow. Several authors have found increased turbidity to reduce predation on resident and migrating young salmonids by providing a form of protective cover, enabling them to evade detection or capture (Gradall and Swenson 1982; Cezilly 1992; Gregory 1993; Gregory and Levings 1998). This phenomenon could contribute to higher in-river survival resulting in increased catch rates during periods of higher flows and increased turbidity. Other authors have demonstrated the influence of flow and temperature on juvenile Chinook salmon size (Marine 1997; Myrick and Cech 2001) and determined rearing conditions (e.g., water temperature, prey production) to have strong affects on growth and development (Holtby et al. 1989; Sommer et al. 2001).

Results from the 2008 season provide critical information to AFRP and CAMP which may be used to better understand and improve conditions for Chinook salmon and *O. mykiss* within the lower Stanislaus River.

RECOMMENDED FUTURE WORK

We recommend the following improvements to the ongoing out-migration monitoring for the Stanislaus River. In 2008, we worked with AFRP, CAMP, and the USFWS Juvenile Migration Project Work Team to streamline and refine sampling protocols. This work will continue so we may help AFRP and CAMP meet their programmatic objectives. Specifically, we suggest the following for future years:

1. Develop comprehensive analyses to investigate the influence of flow, temperature, and other environmental variables on the juvenile salmonid out-migrant population abundance, relative size, timing, and life history structure;
2. Continue to monitoring at trap and live-box water temperature with recording data loggers;
3. Coordinate with other agencies (e.g., U.S. Geological Survey or USBR) to measure flow and develop a rating curve to match local staff gauge;
4. Conduct further evaluations on fish size and condition, and the potential relationship with environmental variables and habitat quality and availability;
5. Continue to evaluate fish health and water quality standards at Caswell; and,
6. Continue marking with coded wire tags when/if adequate abundances are available.

Continued monitoring is essential to better understand salmonid population dynamics in the Stanislaus River, better inform fisheries managers and stakeholders, and determine any population-level improvements due to management actions. The CFS team has improved reporting efforts in an effort to further improve communication between scientists and managers to improve efficiency in salmon fisheries management and support, and promote informed approaches to address critical problems associated with continuing declines of Chinook salmon and *O. mykiss* runs in the San Joaquin basin.

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APPENDIX 1: STANISLAUS RIVER POINTS OF INTEREST

Point	Purpose/Significance	Operator	rkm (RM)
New Melones Dam	Constructed in 1978; Flood control, water supply, power generation, recreation	BOR	96.6 (60)
Tulloch Dam	Constructed in 1957; Flood control, water supply, recreation	TriDam	88.5 (55)
Goodwin Dam	Constructed in 1913; Irrigation water diversion canals	BOR	93.9 (58.4)
Knights Ferry Covered Bridge	Historic feature	ACOE	87.4 (54.3)
Knights Ferry Gravel Augmentation	Habitat improvement	CDFG	87.4 – 86.6 (54.3 – 53.8)
Orange Blossom Bridge	Temperature gauging station	DWR	75.5 (46.9)
Oakdale Rotary Screw Traps	Juvenile salmonid abundance and out-migration timing	Oakdale Irrigation District (OID)	64.5 (40.1)
Stanislaus River Weir	Adult passage and timing	AFRP/TriDam	49.9 (31)
Hwy 99 Bridge (Ripon)	Temperature, discharge and DO	USGS	25.4 (15.8)
Caswell Memorial State Park	Juvenile salmonid abundance and out-migration timing	AFRP	13.8 (8.6)
Two Rivers Trailer Park	San Joaquin-Stanislaus confluence	—	0 (0)

APPENDIX 2: PASSAGE ESTIMATE VARIANCES AND CONFIDENCE INTERVALS

The following describes the methods we used to estimate the variance and confidence intervals for total annual juvenile passage. We begin by describing the variance of a given daily passage estimate ($\hat{n}$), and then extend the formulas to the total annual passage. As noted in the methods, daily passage was estimated by:

(A1) $$\hat{n} = \frac{c}{\hat{q}} \quad ,$$

where *c* was the observed daily count of trapped juveniles and $\hat{q}$ was the estimated trap efficiency for that day. To simplify notation, we express the $\hat{q}$ in terms of the daily "expansion factor" denoted *e*, where:

(A2) $$\hat{e} = \frac{1}{\hat{q}} \quad .$$

Thus, the daily passage estimate ($\hat{n}$) can be expressed as the following product:

(A3) $$\hat{n} = \hat{e}c \quad .$$

There are two sources of variability in $\hat{n}$. First, there is error associated with the estimation of trap efficiency via logistic regression, which will be expressed as error in $\hat{e}$. Second, there is sampling error associated with the daily count (*c*), which is assumed to be a binomial variable. An estimate of the variance of $\hat{n}$ is given by (Goodman 1960):

(A4) $$\hat{\sigma}^2\{\hat{n}\} = \hat{e}^2 \cdot \hat{\sigma}^2\{c\} + c^2 \cdot \hat{\sigma}^2\{\hat{e}\} - \hat{\sigma}^2\{\hat{e}\} \cdot \hat{\sigma}^2\{c\} \quad .$$

To obtain a variance estimate for $\hat{e}$, we first express $\hat{e}$ in terms of the back-transformation of the logit function (see equation (4)). Substituting equation (A2) into equation (4) and rearranging yields:

(A5) $$\hat{e} = 1 + \exp[-(\hat{\beta}_0 + \hat{\beta}_1 x)] = 1 + \exp(-\hat{y}) \quad ,$$

where $\hat{y}$ is the logit transform of the estimated trap efficiency $\hat{q}$ (see equation (3)). Given that the distribution of $\hat{y}$ is approximately normal, $\hat{e}$ is assumed to be log-normally distributed with an estimator of variance given by Gelman et al. (1995), p. 478:

(A6) $$\hat{\sigma}^2\{\hat{e}\} = \exp(-2\hat{y}) * \exp(\hat{\sigma}^2\{\hat{y}\}) * [\exp(\hat{\sigma}^2\{\hat{y}\}) - 1] \ .$$

The variance of $\hat{y}$, which is a prediction from a linear regression, can be expressed in matrix notation as (Neter et al. 1990, p. 215):

(A7) $$\hat{\sigma}^2\{\hat{y}\} = \mathbf{X}'\mathbf{s}^2\{\mathbf{b}\}\mathbf{X} \ ,$$

where **X** is a vector containing the daily values of the explanatory variables, **X'** denotes the transpose of **X**, and $\mathbf{s}^2\{\mathbf{b}\}$ denotes the scaled estimate of the variance-covariance matrix for the logistic regression coefficients ($\hat{\beta}$). Specifically,

(A8) $$\mathbf{X} = \begin{bmatrix} 1 \\ x \end{bmatrix}, \quad \mathbf{X}' = \begin{bmatrix} 1 & x \end{bmatrix}, \quad \mathbf{s}^2\{\mathbf{b}\} = \hat{\phi}\begin{bmatrix} \hat{\sigma}^2\{\hat{\beta}_0\} & \hat{\sigma}\{\hat{\beta}_0, \hat{\beta}_1\} \\ \hat{\sigma}\{\hat{\beta}_0, \hat{\beta}_1\} & \hat{\sigma}^2\{\hat{\beta}_1\} \end{bmatrix} .$$

Here, x is the daily value of log(flow). Note that the variance-covariance matrix for the logistic regression coefficients is multiplied (i.e., scaled) by the estimated dispersion parameter (ϕ) to account for extra-binomial variation. Equations (A6) – (A8) define the variance estimate for $\hat{e}$ required in equation (A4). Also required in equation (A4) is the variance of c, the observed daily count of trapped juveniles. Assuming that c follows a binomial distribution conditional on daily passage (n) and trap efficiency (q) (i.e., $c \sim \text{Bin}(n, q)$), the theoretical variance for c would equal $nq(1\text{-}q)$. However, a more reasonable and conservative approach is to assume that c is subject to the same extra-binomial variation estimated for the trap-efficiency tests. Extra-binomial variation would be expected due to unaccounted for factors affecting trap-efficiency or characteristics of fish behavior such as schooling. Thus, the variance of c is estimated as:

(A9) $$\hat{\sigma}^2\{c\} = \hat{\phi}\hat{n}\hat{q}(1-\hat{q}) \ .$$

Equations (A4) – (A9) define the variance estimate for a given daily passage estimate ($\hat{n}$) given the estimated trap efficiency ($\hat{q}$) and trap count (c) for that day. The estimated total passage (N) of juveniles across days (i = 1, 2, 3, …, k) of the sampling season is the sum:

(A10) $$\hat{N} = \sum_{i=1}^{k} \hat{n}_i \ ,$$

with associated variance (Mood et al. 1974, p. 179)

(A11) $$\hat{\sigma}^2\{\hat{N}\} = \sum_{i=1}^{k}\hat{\sigma}^2\{\hat{n}_i\} + 2\sum_{i=1}^{k-1}\sum_{j>i}^{k}\hat{\sigma}\{\hat{n}_i,\hat{n}_j\} \ .$$

The left side of equation (A11) is sum of the variances of the daily passage estimates as defined by equation (A4). The right side denotes the sum of the covariances among all pairs of daily passage estimates. These covariances arise from the fact that all daily passage estimates are based on predictions of q derived from the same logistic regression. Following from equations (A3) and (A5), the covariance of any two passage estimates can be approximated as follows:

(A11) $$\hat{\sigma}\{\hat{n}_i,\hat{n}_j\} = (c_i\hat{e}_i)*(c_j\hat{e}_j)*(\mathbf{X}'\mathbf{s}^2\{\mathbf{b}\}\mathbf{X}) \ ,$$

where

(A12) $$\mathbf{X} = \begin{bmatrix} 1 & x_i \\ 1 & x_j \end{bmatrix}, \quad \mathbf{X}' = \begin{bmatrix} 1 & 1 \\ x_i & x_j \end{bmatrix} \ .$$

Again, $\mathbf{s}^2\{\mathbf{b}\}$ denotes the scaled variance-covariance matrix for the logistic coefficients as in equation (A8).

We computed approximate 95% confidence intervals for the total passage estimate ($\hat{N}$) assuming lognormally distributed error given by:

(A13) $$95\%LCI\{\hat{N}\} = \frac{\hat{N}}{c}, \text{ and } \ 95\%UCI\{\hat{N}\} = \hat{N}*c,$$

where

(A14) $$c = \exp(Z_{\alpha/2} * \sqrt{\log_e(1+(\hat{\sigma}\{\hat{N}\}/\hat{N})^2)}$$

Preliminary simulation analyses examining the sampling distribution of the total passage estimates and their standard errors indicated standard errors of the passage estimates were proportional to the passage estimates themselves, and the lognormal assumption provided slightly better confidence interval coverage than the normal distribution. In addition, lognormally distributed variables are constrained to be greater than zero, which is consistent with our biological expectations regarding catch data.