

Juvenile Salmonid Out-migration Monitoring at Hatfield State Park in the Lower Merced River, California

2008 Annual Data Report



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SUMMARY

The Merced River is currently the southernmost extent for populations of Chinook salmon *Oncorhynchus tshawytscha* and Central Valley steelhead/rainbow trout *O. mykiss*, which are considered species of concern under the federal Endangered Species Act (ESA). In 2007, Cramer Fish Sciences (CFS) began a collaborative effort with the U.S. Fish and Wildlife Service (USFWS) Anadromous Fish Restoration Program (AFRP) to implement salmonid out-migration monitoring in the lower Merced River (N 37°21'25.963", W 120°57'51.469") near the town of Stevinson, California (Montgomery et al. 2007). California Department of Fish and Game (CDFG) previously monitored salmonid out-migration in the lower Merced River; however operations ceased in 2002. In 2008, CFS and USFWS continued monitoring downstream salmonid migration from 3 March to 6 June 2008, and collected information on various environmental parameters. We developed abundance estimates using a logistic regression model that predicted daily trap efficiency based on results from six mark-recapture efficiency tests and associated flow levels. We captured a total of 60 natural juvenile Chinook salmon and estimated a seasonal passage of 4,273 (SE = 2,243) for the 2008 season. No *O. mykiss* were captured, as in 2007. For Chinook salmon, our results include very low catch abundance, compressed migration timing, and one dominant early life history pattern characteristic of a depressed population. Life history patterns, or life stage, in juvenile salmon are defined by the size and timing of out-migration. The smolt index, adapted from CDFG, is a numerical system of evaluating these factors and assigning a life stage category to the fish. We used this system to determine life stage of fish in our catch. Our natural Chinook salmon catch in the Merced River was 98% sub-yearling smolts and one fry. No parr or yearling emigrants were captured. We also compared size (fork length) at out-migration between 2007 and 2008 sub-yearling smolts and assessed differences in monthly environmental conditions (i.e., flow and temperature) between years. Out-migration timing strongly coincided with the Vernalis Adaptive Management Program (VAMP) flow releases in late April and May. The dramatic abundance decline in juvenile salmon abundance was expected given severely depressed salmon spawning escapement numbers observed during fall 2007 following the West Coast Chinook salmon fishery collapse (National Oceanic and Atmospheric Administration (NOAA) 2008). Our seasonal passage estimates from the Merced River indicate very poor natural production of salmon; however, subsequent monitoring over several more seasons will provide a better understanding of population dynamics and trends. Documentation of population status and recovery trajectory provides valuable information to restoration and fisheries management efforts. Monitoring in the lower Merced River continues to provide valuable data on the salmonid populations to help AFRP and the Comprehensive Assessment and Monitoring Program (CAMP) meet their goals and objectives.

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INTRODUCTION

Since the 1850s Pacific salmonid stocks have experienced dramatic declines (Nehlsen et al. 1991; Yoshiyama et al. 1998; Lichatowich 1999; Williams 2006). Historically, Chinook salmon *Oncorhynchus tshawytscha* and steelhead/rainbow trout *O. mykiss* distributions ranged throughout California's Central Valley with spawning reaches extending into streams and rivers of the Coastal Range and Sierra Nevada mountains to elevations above 1,000 m (Yoshiyama et al. 2001; Moyle 2002). The San Joaquin River and its tributaries represent the southernmost extent of Chinook salmon and Central Valley *O. mykiss* distributions in North America, and provide important spawning and rearing habitats for runs considered as species of concern under the federal Endangered Species Act (ESA). Four different Chinook salmon races (i.e., fall-run, late fall-run, spring-run and winter-run) were common throughout the Central Valley; the spring-run are reasoned to have been the most abundant race in the San Joaquin and its tributaries (Yoshiyama et al. 1998). Heavy snow pack characterizes the Sierra Nevada Mountains, which gain elevation as they move south reaching a height of 4,419 m at Mount Whitney. The resulting high spring runoff allowed fish to ascend rivers to elevations where favorable thermal conditions promoted large spring-run populations (Yoshiyama et al. 1998; Williams 2006).

Since the mid-19th century a succession of dams, diversions, and habitat alterations have drastically reduced or degraded spawning and rearing habitat for Chinook salmon populations (Williams 2006). As a result, the spring-run no longer exist in the San Joaquin or its tributaries (Campbell and Moyle 1991; Yoshiyama et al. 2001); however, limited data have documented these fish in small numbers (Anderson et al. 2007). Whether these are hatchery strays, natural production or a combination of both is uncertain. Today, fall-run Chinook salmon populations persist in San Joaquin River tributaries, and extensive work is underway on recovering spring-run populations in the mainstem San Joaquin River. However, in 2008 an Emergency Action under the Magnusson-Stevens Act authority was implemented that declared a commercial fishery failure for West Coast salmon after unprecedented low returns. Various causal factors contributed to poor juvenile salmon ocean survival including shifting ocean conditions and habitat degradation (National Oceanic and Atmospheric Administration (NOAA) 2008). Fall-run Chinook salmon escapement estimates were extremely low for all San Joaquin River tributaries, including the Merced River, increasing the importance of understanding current population dynamics, targeting restoration efforts to improve conditions, and monitoring the effectiveness of all efforts.

The 1992 Central Valley Project Improvement Act (CVPIA) granted authority to U.S. Fish and Wildlife Service (USFWS) to develop and implement a series of restoration programs for the benefit of fish and wildlife resources, with the goal of doubling the natural production of



anadromous fish in Central Valley rivers. To support this goal, the 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 monitoring program to assess the relative effectiveness of fishery restoration actions. The two programs support informed feedback on population dynamics of target species which allow adjustments or improvements to adaptive management plans and approaches.

Numerous projects to restore and protect channel and riparian habitat have been initiated or completed on the Merced River as a result of CVPIA initiatives; however, consistent monitoring of juvenile Chinook salmon and steelhead *O. mykiss* emigration has been lacking. Monitoring often pales in priority when compared with on-the-ground restoration actions; however, effective monitoring provides a valuable tool for determining optimal [fisheries] management by understanding population dynamics (Adaptive Management Forum Scientific and Technical Panel 2002). By documenting trends, setting baseline conditions, and determining the influences of changing environmental variables (i.e., flow, temperature, turbidity, etc.) management efforts are informed and can be refined.

In 2007, Cramer Fish Sciences (CFS) began a partnership with USFWS to monitor juvenile salmonid population in the Merced River at George Hatfield State Park (Hatfield; rkm 3.2) under contract with AFRP. The monitoring effort continued previous work by California Department of Fish and Game (CDFG) at Hagan State Park (Hagan; rkm 19.3) from 1998 through 2002, and compliments concurrent upstream juvenile out-migration monitoring efforts (Natural Resources Scientists, Inc. (NRS); rkm 61.2). No sampling out-migration monitoring occurred in the lower Merced River from 2002 to 2007, leaving a 5-yr gap in available data. We used rotary screw traps (RST), an established method for measuring juvenile out-migration abundance to capture juvenile salmonid species while monitoring environmental variables. The three main objectives of this study were to:

1. Establish abundance estimates of juvenile Chinook salmon and *O. mykiss* from the Merced River;
2. Determine and evaluate patterns of migration timing and size distribution as they relate to flow and other environmental variables; and,
3. Compare production estimates to upper river estimates, if available, to develop indices of in-river survival.

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 Hatfield in the lower Merced River and addresses the first two objectives. The third objective relies on currently unavailable data (at this time) from NRS. In 2007, this sampling near Hopeton, CA did not occur, but was continued in 2008. At the time of this reporting effort, data were unavailable; however, when available, determinations of in-river survival will be evaluated and reported.

STUDY AREA

The Merced River, a major tributary to the San Joaquin River, originates in Yosemite National Park, and drains approximately 3,305 km² of the western Sierra Nevada Mountain range (Figure 1). Watershed elevations range from 4,000 m at headwater to 15 m at the San Joaquin River confluence, located 140 km south of Sacramento at rkm 190 near the town of Stevinson (N 37°21'25.963", W 120°57'51.469") (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). The Merced River is regulated by several dams, including New Exchequer, McSwain, Merced Falls, and Crocker-Huffman, which are used for flood protection, power generation, irrigation and municipal water. Details and additional points of interest are listed in Appendix 1. California Department of Fish and Game operates the Merced River Hatchery (MRH), which is located immediately downstream of Crocker-Huffman Dam (the upstream terminus of anadromous salmonid migration on the Merced River, see Figure 1). The primary spawning reach, located from Crocker-Huffman (rkm 83.7) to rkm 52.2 (based CDFG spawning surveys), has experienced significant impacts from gold and gravel mining that extensively altered channel and floodplain morphology, negatively affecting salmonid spawning and rearing habitats (Yoshiyama et al. 1998). Since mid-1997 typical regulated flow on the Merced River averages ~ 250 ft³/s. The Army Corps of Engineers permits maximum discharges of 6,000 ft³/s into the Merced River; however, flow exceeded 8,000 ft³/s under emergency circumstances created during the 1997 flood (Stillwater Sciences 2001). Other than seasonal rain events, scheduled water releases for the Vernalis Adaptive Management Program (VAMP) normally result in increased flow during April and May. During rain events, Dry Creek (rkm 50.7), a tributary of the Merced River, is subject to flow increases exceeding 2,200 ft³/s which contributes large amounts of water to the river. Several agricultural diversion pumps of varying capacity operate between Crocker-Huffman and the confluence, and collectively, can significantly reduce total flow reaching the San Joaquin River. Substrate downstream of Crocker-Huffman dam is dominated by gravel and cobble. Downstream fining results in sand and silt below the lowest spawning area (Stillwater Sciences 2001).



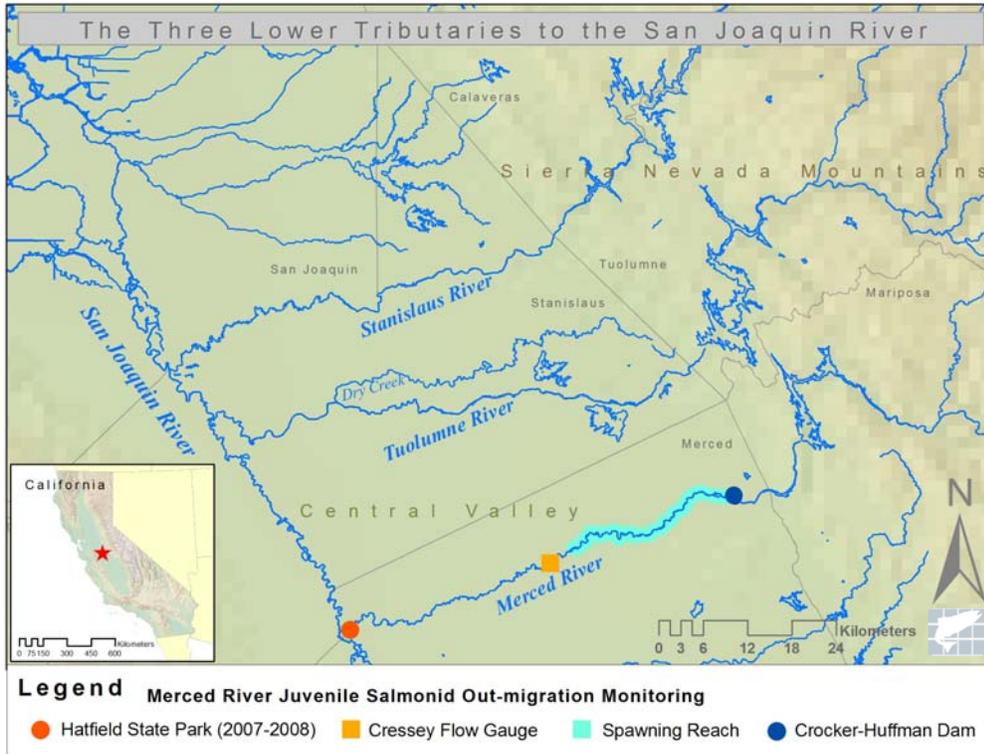


Figure 1. Map of tributaries to the San Joaquin River, including details on the Merced River.



Figure 2. Aerial imagery of lower Merced River and confluence with San Joaquin River with Hatfield and RST location.



METHODS

Trap Operations

The 2008 Hatfield trapping site was relocated slightly (~ 40 m upstream) compared with 2007 due to dramatic change in channel bathymetry following late summer flows in the Merced River which made RST operation impossible. As in 2007, the new site was located at the upstream end of the park day use area, and approximately 100 m downstream of an agricultural diversion pump (Figure 3). State park permits allowed CFS access to the site by land or boat if necessary. Previous sampling efforts were located further upstream, and Hatfield was chosen in 2007 as the more representative estimate of the Merced River juvenile salmonid contribution to the San Joaquin River. The site had excellent accessibility and appropriate river morphology to operate RSTs. In 2008, we configured two (i.e., one 2.5 m and one 1.5 m diameter) RSTs, manufactured by EG Solutions, Inc. (Corvallis, OR), to operate side-by-side. The traps were secured using 6.35 mm galvanized steel cable leaders fastened to large trees. 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. We recorded stoppages 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. Trap operation at Hatfield with warning signs and upstream buoy (left), and field technicians with biologist during training activities (right).

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 followed the CFS rotary screw trapping operational protocols (Gray et al. 2008) and established fish handling procedures. Trapped fish were collected and processed by CFS and USFWS staff at least once per day. During high flows ($> 500 \text{ ft}^3/\text{s}$) and peak migration times (i.e., after flow changes, generally April to May) traps were processed twice per day, in the morning and evening. Additionally, traps were processed prior to, and an hour following, night efficiency releases. To limit injury and stress from handling, all captured fish were anesthetized in groups of 5 to 10 immediately prior to handling using a solution of river water and tricaine methanesulfonate (Western Chemical, Inc.; Tricaine-S), at a 26.4 mg/L concentration. River water used for holding was cooled with frozen water bottles to reduce water temperature and the potential for thermal stress. Litmus strips were used to check pH and baking soda was added to buffer the acidity of the Tricaine-S solution. The effectiveness of Tricaine-S varies with changes in temperature and fish density; therefore, all Tricaine-S 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). Note, the silvery parr designation is only used to describe *O. mykiss* and not applied to juvenile Chinook salmon. All captured fish were released approximately 150 m downstream of the traps 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. HOBO® Pendant temperature logger (Onset Computer Corporation; Part #-UA-001-08) were used 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. Thermograph data was also provided by CDFG from various sites along the river. When available, dissolved oxygen and water temperature were recorded using a digital handheld meter (YSI; Model 550A). Daily instantaneous temperature measured with the YSI provided in-river conditions for technicians monitoring water temperatures in holding buckets. River stage was recorded daily using an established on-site staff gauge. 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 California Data Exchange Center (CDEC), Cressey gauge (CRS; rkm 43.5). 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:

H1₀: 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 and temperature (CRS), by month, from 1 January through 30 June 2007 and 2008. We used ANOVA to test the following null hypotheses:

H2₀: There is no difference in mean daily flow, by month, among years.

H3₀: 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 a surrogate during the time period when natural smolts were passing the trap. Releases consisted of approximately 1,000 fish each and were conducted between 17 March and 15 May 2008 (Table 2). Fish were dye-marked using a photonic marking gun (Meda-E-Jet; A1000) with either green or 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. We alternated between dye color and fin marked for the first three releases to distinguish fish from different release groups (see Table 2).



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 Hatfield, 2008. Note, CFP = caudal fin pink; CFG = caudal fin green; AFG = anal fin green; and, BB = Bismarck Brown Y.

Release Code	Release Date	Number Released	Mark
H01	3/17/2008	1007	CFP
H02	4/1/2008	1017	CFG
H03	4/14/2008	982	AFG
H04	4/29/2008	1012	BB
H05	5/7/2008	1004	BB
H06	5/12/2008	1002	BB
H07*	5/20/2008	998	BB

*Test not used; results may not be representative of trap function.

To encourage mixing with wild salmon, prevent schooling, and mimic natural periods of nighttime migration, fish were released approximately one hour after dark in groups of five to ten individuals. Released occurred approximately 180 m upstream of the traps, either across the channel (when permitted by flow conditions), or from the north bank. During periods of high flow ($> 500 \text{ ft}^3/\text{s}$), we used a long-handled (3 m) net from the north bank in an attempt to increase our ability distribute fish into the channel. We processed the traps one hour after completing release activities to check for immediate recaptures so catch of any marked fish could be determined and they could be immediately released (as possible), and again at one-hour intervals until we recaptured $< 1\%$ of marked fish during a check. Additional recaptures were recorded with subsequent catches.

Passage Estimates

In 2008, results from the first six efficiency tests were used to develop a logistic regression model to predict daily trap efficiencies and estimate daily smolt passage. The seventh efficiency test (H07; see Table 3) results from 20 May 2008 were not included in the model, as trap



conditions substantially changed and conditions were not representative of trap function under those specific flow conditions. The limited number of mark-recapture trap efficiency estimates precluded our ability to rigorously examine the potential effects of physical and biological factors on trap efficiency. Instead, we assumed trap efficiency was a function of flow. The form of the relationship between trap efficiency and flow was consistent with relationships estimated for screw traps at two sites on the Stanislaus River (Caswell and Oakdale; CFS, unpublished data).

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):

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

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

$$(4) \quad y = \beta_0 + \beta_1 x,$$

where y is the “logit” transform of the observed trap efficiency (q):

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

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

$$(6) \quad \hat{q} = \frac{\exp(\hat{\beta}_0 + \hat{\beta}_1 x)}{1 + \exp(\hat{\beta}_0 + \hat{\beta}_1 x)}.$$

In the model, we used values of $\log(\text{flow})$ as the explanatory variable (x). Consistent with results for screw traps on the Stanislaus River (CFS, unpublished data), we found greater deviance in this model than that expected due to binomial sampling error alone (McCullach and Nelder 1989; Venables and Ripley 1999). Such extra-binomial variation is represented by a dispersion parameter, ϕ , which is a scalar of the assumed binomial variance. The dispersion parameter is estimated from the fit of a logistic regression and does not affect coefficient point estimates (Venables and Ripley 1999). When estimating standard errors and computing confidence intervals, the coefficient variance-covariance matrix must be multiplied by the ϕ estimate. The daily passage abundance (n) of migrating juvenile Chinook salmon was estimated as follows:



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

where c was observed daily count and q was the estimated trap efficiency for that day based on flow. Standard errors (SE) and confidence intervals for measures of total annual passage were computed using the methods described in Appendix 2.

RESULTS

Trap Operations

We began sampling immediately following trap installation on 3 March 2008 and terminated operations on 5 June 2008, due to low catch and increased temperatures. During periods when daily catch was consistently low (< 2 – 5 juvenile Chinook salmon), we sampled four days a week, which resulted in 70, out of a possible 95, trapping days.

Catch

We captured a total of 60 natural, unmarked juvenile Chinook salmon and no *O. mykiss* during the 2008 trapping season (Figure 6; Table 3). The first catch of natural Chinook salmon occurred on 21 March 2008. Peak daily catches ($n = 13$ and 18) occurred on 25 April and 26 April 2008, respectively; and, coincided with sharp increases in controlled flow releases for the Vernalis Adaptive Management Plan (VAMP, 22 April – 19 May 2008) and Vernalis water quality releases. Our overall mortality rate was 11.9% ($n = 7$) of the total Chinook salmon catch.

Table 3. Catch by life stages (determined by smolt index) of juvenile Chinook salmon by week at Hatfield, 2008.

Date	Number of Days Sampled	Weekly Catch Total and By Smolt Index				
		Total	Fry	Parr	Sub-yearling Smolt	Yearling-smolt
3/3 - 3/9	4	0	0	0	0	0
3/10 - 3/16	4	0	0	0	0	0
3/17 - 3/23	6	3	1	0	2	0
3/24 - 3/30	4	1	0	0	1	0
3/31 - 4/6	5	0	0	0	0	0
4/7 - 4/13	4	0	0	0	0	0
4/14 - 4/20	4	0	0	0	0	0
4/21 - 4/27	6	37	0	0	37	0
4/28 - 5/4	7	15	0	0	15	0
5/5 - 5/11	7	1	0	0	1	0
5/12 - 5/18	7	3	0	0	3	0
5/19 - 5/25	5	0	0	0	0	0
5/26 - 6/1	4	0	0	0	0	0
6/2 - 6/5	3	0	0	0	0	0
3/3 - 6/5/2008	70	60	1	0	59	0



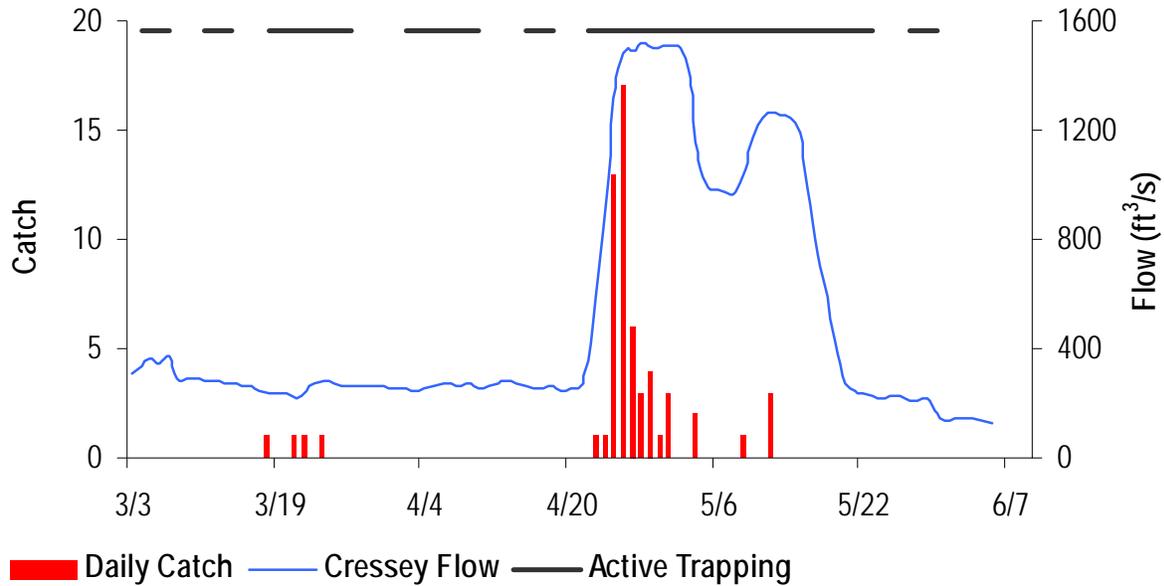


Figure 6. Daily catch of juvenile Chinook salmon, Merced River flow at Cressey, and days of operation at Hatfield, 2008.

Each juvenile salmonid life stage has different timing patterns and size distributions. In both years of sampling, the majority of the catch has consisted of the sub-yearling smolt life stage (Table 4). In 2008, catch was dominated by sub-yearling smolts (98%); however, one fry was captured on 17 March 2008 (Figure 7 and 8).

Table 4. Percent of run and range of catch dates for each life stage (according to smolt index) of Chinook salmon from Hatfield, 2008

Life Stage	Number	Percent of Run	Date Range	Average FL (mm)
Fry	1	2	3/17 – 3/23	42
Parr	0	0	n/a	n/a
Sub-yearling smolt	59	98	3/17 – 5/18	92.7 ± 2.1
Yearling-smolt	0	0	n/a	n/a
Cumulative Total	60	100	3/17 – 5/18/2008	



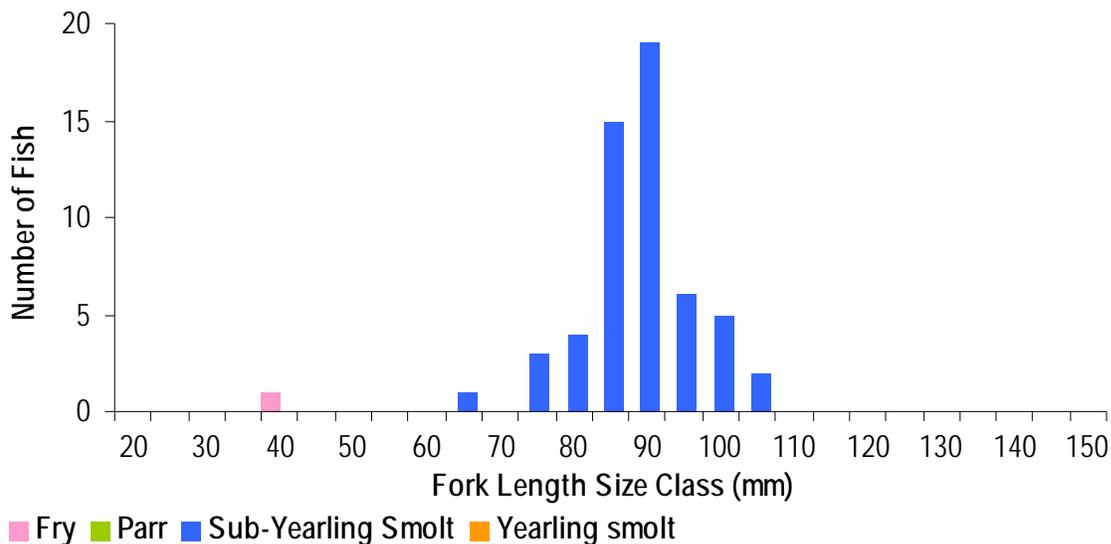


Figure 7. Fork length (mm) frequency distributions for fry, parr (none caught), sub-yearling smolts, and yearling smolts (none caught) at Hatfield, 2008.

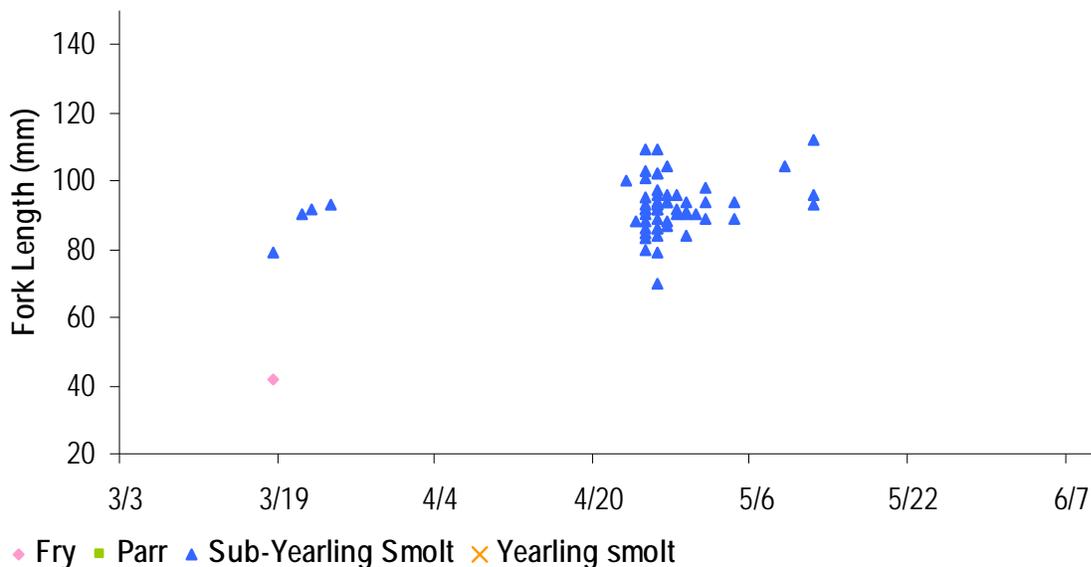


Figure 8. Daily fork length (mm) distributions for fry, parr (none caught), sub-yearling smolts, and yearling smolts (none caught) at Hatfield, 2008.

Environmental Variables

Flow at CRS during the season ranged from 123 to 1,514 ft³/s, and were controlled by releases from New Exchequer Dam (Table 5). Daily temperature ranged from 12.1 – 25.0°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); 7.1 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), and the last Chinook salmon were captured on 13 May (n = 3).

Table 5. Summary of environmental variables (i.e., mean daily flow reported at Cressey, mean daily temperature recorded on-site, instantaneous DO and instantaneous turbidity) in the Merced River, 2008.

Date	Daily Flow (ft ³ /s)		Daily Temp (°C)			DO (mg/L)		Turbidity (NTU)	
	Min	Max	Min	Max	Average	Min	Average	Max	Average
3/3 – 3/9	292	369	13.4	16.9	15.0	9.5	9.7	22.4	16.0
3/10 – 3/16	265	287	12.1	18.8	15.8	8.7	9.1	8.5	6.8
3/17 – 3/23	217	273	12.1	19.3	15.9	8.7	9.6	6.4	4.6
3/24 – 3/30	260	281	14.1	19.6	16.8	8.5	9.2	7.7	6.0
3/31 – 4/6	249	272	14.0	20.0	17.2	8.5	8.9	4.8	3.6
4/7 – 4/13	256	278	14.2	23.2	18.0	8.6	8.9	4.3	3.1
4/14 – 4/20	249	274	15.7	22.2	19.0	8.3	8.5	5.1	3.5
4/21 – 4/27	265	1495	14.1	19.9	16.2	9.1	9.7	11.1	5.9
4/28 – 5/4	1094	1514	13.4	16.8	15.3	9.5	10.0	8.5	5.3
5/5 – 5/11	973	1250	15.6	18.7	17.3	9.2	9.5	4.0	3.4
5/12 – 5/18	589	1267	15.8	22.2	18.3	8.6	9.3	7.7	4.4
5/19 – 5/25	215	423	16.5	23.0	19.7	7.6	7.9	5.5	4.1
5/26 – 6/1	134	226	17.3	24.5	20.6	8.1	8.2	2.7	2.3
6/2 – 6/5	123	147	19.8	25.0	22.3	7.1	7.5	3.5	2.7

Analysis

Comparison of Sub-yearling Smolt Fork Length

To test the hypothesis that there was no difference in the length of smolts 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 10.4 mm, compared to 2007. Mean FL was 82.3 ± 1.2 mm (95% CI; n = 187) in 2007 and 92.7 ± 2.1 mm (95% CI; n = 59) in 2008 (Figure 9; Table 6).



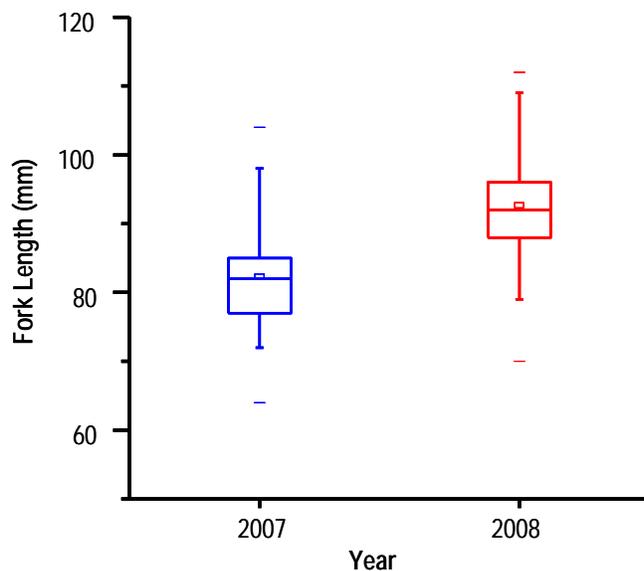


Figure 9. Boxplot displaying differences in sub-yearling smolt FL between years at Hatfield. Note, displayed are minimum and maximum values; 5% and 95% quantile values; 25% median; and, 75% quartile values (large, outer boxes) and mean with 95% confidence (small, inner box).

Table 6. ANOVA results testing H_{10} : mean smolt fork length is equal between years for the Stanislaus River (2007 and 2008). Bolded P-value indicates significance at $\alpha = 0.05$.

	2007	2008
Mean FL (mm)	82.3	92.7
SD	7.64	7.73
F-value		82.4
df		179
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 7).



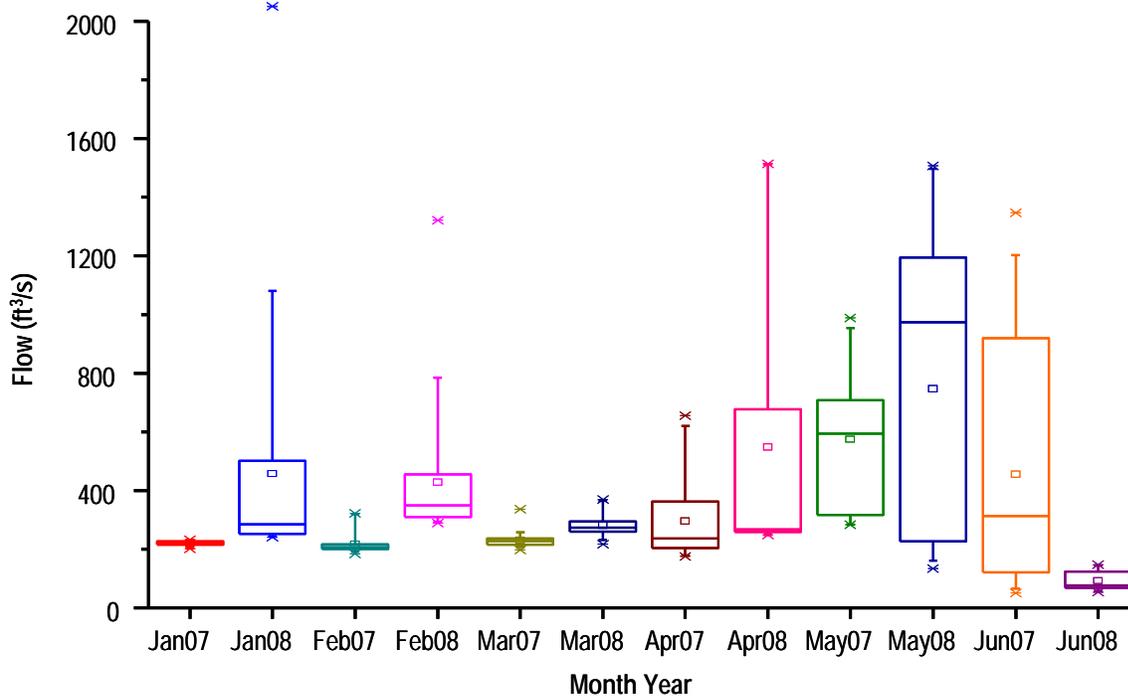


Figure 10. Box plot displaying differences in mean daily flow, by month, among years at Cressey for 2007 and 2008. Displayed are minimum and maximum values; 5% and 95% quantile values; 25%, median and 75% quartile values (large, outer boxes); and, mean with 95% confidence (small, inner box).

Table 7. ANOVA results testing H₂₀: mean daily flow, by month, is equal between years for the Merced 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 Flow (ft ³ /s)	220	457	217	428	229	282	296	549	574	748	455	93
SD	7.9	370.1	32.5	218.1	24.6	37.3	131.5	499.9	234.6	482.9	410.9	30.8
F-value	12.8		25.6		39.1		7.2		3.2		23.2	
df	60		55		60		58		60		58	
P-value	= 0.0007		< 0.00001		< 0.00001		= 0.01		= 0.077		= 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 significant mean daily temperature differences between 2007 and 2008 for all months except June (Table 8).



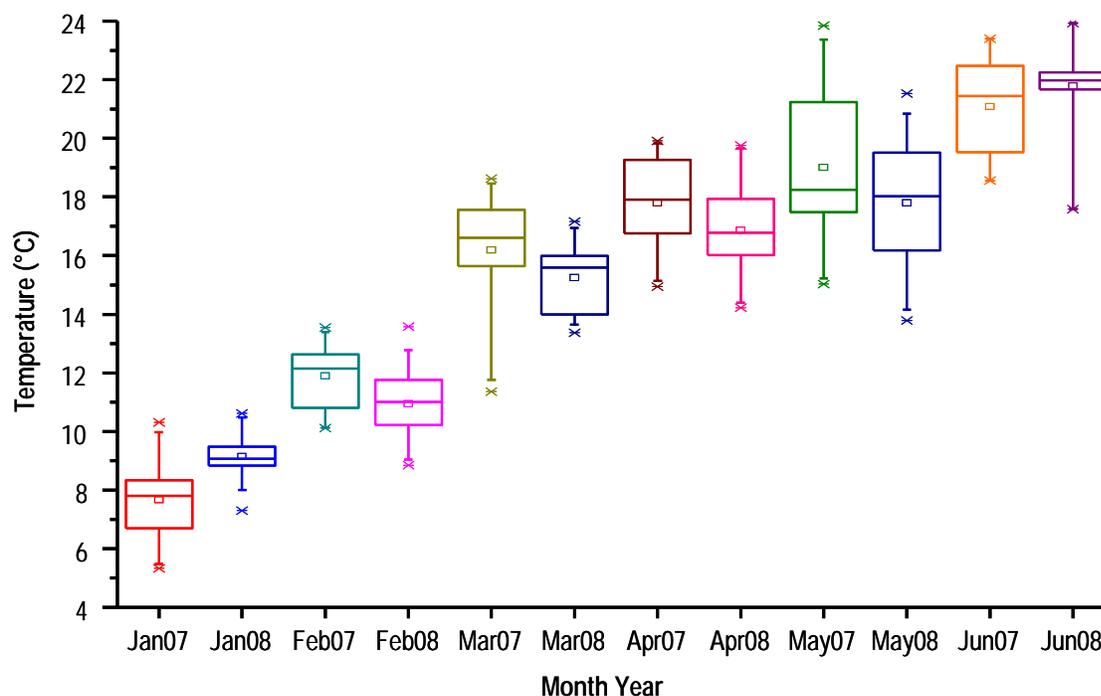


Figure 11. Box plot displaying differences in mean daily temperatures, by month, among years at Hagaman for 2007 and 2008. Displayed are minimum and maximum values; 5% and 95% quantile values; 25%, median and 75% quartile values (large, outer boxes); and, mean with 95% confidence (small, inner box).

Table 8. ANOVA results testing H_{30} : mean daily temperatures, by month, are equal between years for the Stanislaus River (2007 and 2008). Bolded P-values indicate significance at $\alpha = 0.05$.

	January		February		March		April		May		June*	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
Mean Daily Temp (°C)	7.7	9.1	11.9	11.0	16.2	15.3	17.8	16.9	19.0	17.8	21.1	21.8
SD	1.34	0.69	1.08	1.23	1.90	1.11	1.47	1.48	2.60	2.13	1.67	1.53
F-value	31.16		9.60		5.63		5.95		4.08		1.27	
df	60		55		60		58		60		58	
P-value	< 0.00001		= 0.003		= 0.02		= 0.018		= 0.048		= 0.27	

*Dataset for June was incomplete for both years

Trap Efficiency

In 2008, we conducted seven efficiency tests during the out-migration period (March to May) in the Merced River. Flow remained low between the first three tests, increased between the fourth and sixth tests due to VAMP flow releases and was similar to tests one through three for the last test. In general, trap efficiency decreased as flow increased (Figure 12) with the exception of the last test conducted on 20 May 2008. Results from the final efficiency test were not used to develop abundance estimates; altered river conditions necessitated relocating the trap before the



final efficiency test, and catch conditions were not representative of conditions existing when the majority of fish were collected. Trap efficiencies ranged from 7.28% to 0.90%, and were 3.53% on average for the first six tests.

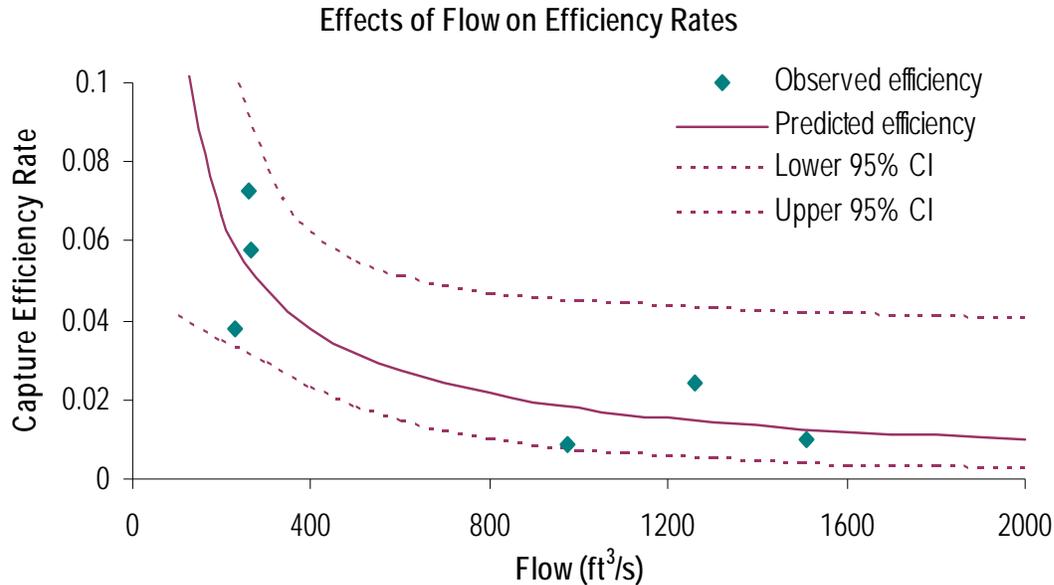


Figure 12. Effects of flow on observed and predicted trap capture efficiency rates at Hatfield, 2008.

Passage Estimates

The number of juvenile Chinook salmon passing the trapping site on the Merced River near Hatfield totaled 4,273 fish (95% CI = [1,593 to 11,460]) (Table 9). Most fish migrated past the trap site between 25 April and 9 May 2008, with peak (median) passage occurring on 26 April 2008. Migration timing appeared to coincide with dramatic increases in river discharge (Figure 13).

Table 9. Summary of total passage estimates and associated standard errors and 95% confidence intervals assuming lognormal error distributions.

Method	Total Passage Estimate	SE	Lower 95% CI	Upper 95% CI
Lognormal distribution	4,273	2,243	1,593	11,460



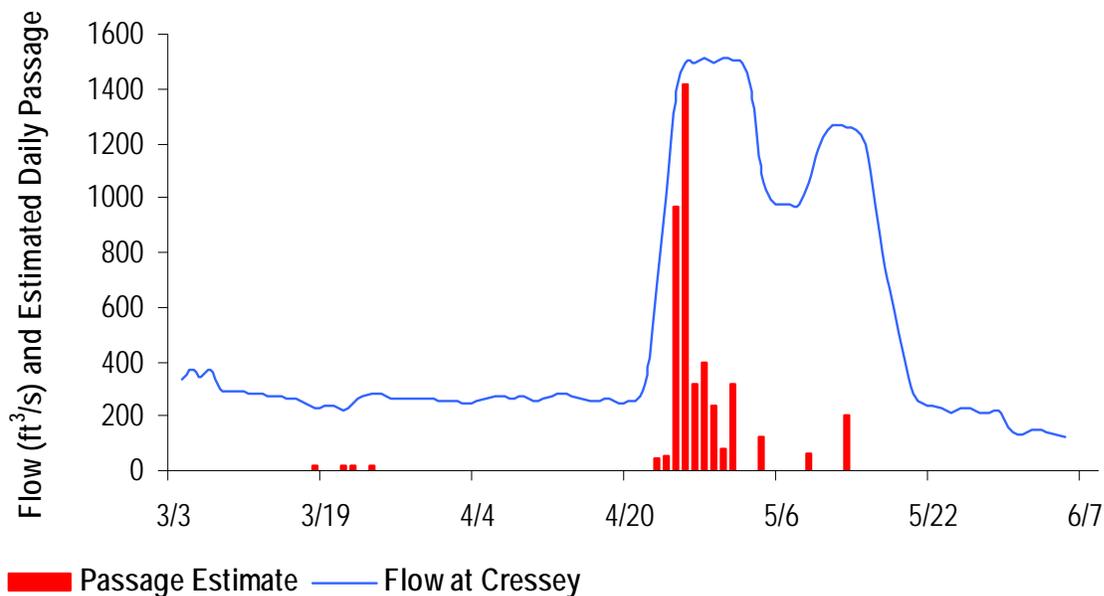


Figure 13. Daily passage of juvenile Chinook salmon and flow at Cressey in the Merced River at Hatfield, 2008.

DISCUSSION

On 5 June 2008, we completed the second consecutive year of RST monitoring at Hatfield to determine the abundance, size, and timing of juvenile salmonid out-migrants from the lower Merced River to the San Joaquin River. This effort occurred in partnership with USFWS and was funded by AFRP after CDFG discontinued juvenile salmonid monitoring operations at Haganan in 2002. Out-migrant abundance was expected to be low in 2008, due to the collapse of the West Coast Chinook salmon fishery (NOAA 2008), and results were consistent with these expectations. Catch for the 2008 out-migration season was very low. We caught 60 juvenile Chinook salmon and no *O. mykiss*, and estimated juvenile Chinook salmon migrant passage as 4,273 (SE 2,243). Sub-yearling out-migrants dominated in 2008, with 98% of fish emigrating as sub-yearling smolts and with few fish collected from fry, parr, or yearling-smolt life history types. 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. The absence of significant fry, parr, and yearling out-migration from the Merced River may signal problems with habitat quality and contribute to instability of Chinook salmon 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 also found significant differences in 2007 and 2008 mean daily flow, by month, for all months except



June; however, June data was incomplete for both years. Neither year could be classified as clearly drier than the other; 2007 was classified as 'Critical year type' (Available: <http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST>), and 2008 conditions were comparable. Migration timing was found to be limited as the majority of juvenile salmon were collected during a two-week period, and the majority of fish collected were from the same size class and life stage indicating limited diversity in life history types for juvenile Chinook salmon in the Merced River. 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.

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). During the 2008 sampling season, our low catch and passage estimate reflect the extremely low escapement of 497 adult Chinook salmon in the Merced River (Available: http://www.delta.dfg.ca.gov/afrp/documents/2008_DRAFT-3-1-08_GrandTab.xls; August 2008). 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 Merced 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 effects on growth and development (Holtby et al. 1989; Sommer et al. 2001).



Effective actions are essential on the Merced River, which may include habitat rehabilitation and improvement in outflow conditions. Continued work, especially more detailed analysis of available data, may provide critical insight for fisheries managers concerned with population recovery. 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 Merced River.

ACCOMPLISHMENTS AND RECOMMENDATIONS

In 2008, low flow conditions ($< 300 \text{ ft}^3/\text{s}$) required us to make several adjustments to trap location and configuration to improve overall trap function. As our main action, we moved traps to an upstream location where conditions were more conducive for trap operation (i.e., suitable flow and defined thalweg, increased velocities, narrower channel, etc.). We used efficiency rate to assess the level of improvement. Our goal was to achieve 2% to 3% efficiency under ‘normal’ (i.e., $200 - 300 \text{ ft}^3/\text{s}$) flow conditions as detailed in our letter submitted to AFRP (dated 14 December 2007). Our efficiency rate at flow levels between $240 - 274 \text{ ft}^3/\text{s}$ during our first three calibrations ranged from 3.77% to 7.28%, exceeding the minimum aforementioned standards. These results were attained with simultaneous reductions in the overall release group size (i.e., from 2000 fish per release in 2007 to 1000 fish per release in 2008). Additionally, we used 2.5 m and 1.5 m diameter traps side-by-side. The trap manufacturer recommended the use of the larger diameter trap in low flow conditions. Our dual-size trap operation was required due to a channel constriction at the new location, and necessary to provide safe boat navigation past the traps (meeting permit requirements). Finally, if needed, we had planned on placing rigid weir flow deflectors upstream of the traps to improve water velocities entering the cone. During the process of trap installation and positioning we attained acceptable trap function (i.e., continuous cone revolutions and adequate velocities $> 1.9 \text{ ft/s}$) without the addition of in-channel rigid weir flow deflector structures; consequently, we chose not to install these structures.

Valid abundance estimates for depressed populations are even more critical during low production years. We improved our estimates by increasing the number of test releases and improving trap operation, which decreased variation in trap efficiency, improved model fit, and reduced error in our abundance estimates (typically greater when catch abundances are low). As a result of these actions we developed more robust abundance estimates for Merced River juvenile salmonid out-migration in 2008. These monitoring efforts have provided valuable information during a year of unprecedented low abundance levels throughout the San Joaquin basin.



Our recommendations for future work on the Merced River include continued and improved RST monitoring at Hatfield, standardized trapping efforts and sampling protocols, and coordination with CDFG, NRS, and hatchery personnel. In the future, we suggest the following protocol changes and adjustments:

1. Continue to work closely with CDFG and hatchery personnel to obtain an allotment of hatchery fish for conducting efficiency tests throughout a variety of life stages, time, and environmental conditions;
2. Obtain high quality flow meter to calculate river discharge at Caswell, in addition to continuing pre- and post-sampling cross channel elevation transects; and,
3. Continue to review and streamline sampling protocols (as appropriate) to optimize data collection and improve efficiency in field operations.

We will continue to work with CAMP and AFRP to improve our data collection and analysis. Currently, we are participating ongoing work to revise and standardize protocols for all RST out-migration monitoring projects throughout the Central Valley. By participating in standardizing monitoring methods, we may also facilitate the development of standardized analysis protocols and reporting guidelines. These efforts will greatly enhance reporting efforts and communication between scientists and managers, may improve efficiency in salmon fisheries management and support, and allow for the development of broad-scale approaches to management, critically needed if we are to address the problems of the future.

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APPENDIX 1: MERCED RIVER POINTS OF INTEREST

Point	Purpose/Significance	Operator	rkm (RM)
New Exchequer Dam/ Lake McClure	Constructed in 1967	Merced Irrigation District	100.0 (62)
	Large storage capacity and long residence time		
	Cold water discharge		
McSwain Dam and Reservoir	Constructed in 1966	Merced Irrigation District	90 (56)
	Short residence time		
Merced Falls Dam and Forebay	Constructed in 1901	Pacific Gas and Electric	88.5 (55)
	Short residence time		
	Northside canal diversion point		
Crocker-Huffam Dam and Reservoir	Constructed in 1910	Merced Irrigation District	83.7 (52)
	Merced Irrigation District main canal diversion point		
	Upstream terminus of fish migration		
Merced River Hatchery	Constructed in 1970	CDFG	83.7 (52)
	Only hatchery in San Joaquin basin		
Primary Spawning Reach	The majority of spawning occurs above RM 45.2		52.2 – 83.7 (32.5 – 52)
	Below RM 32.5 very little suitable spawning habitat exists		
Hopeton Rotary Screw Traps	Salmonid population studies	Merced Irrigation District	61.2 (38)
Cressey Gauge	Primary flow data	United States Geological Survey (USGS)	43.5 (27)
Hagaman State Park	Former screw trapping site (1998-2002)	CDFG	19.3 (12)
Hatfield State Park	Current screw trapping site (2007)	USFWS-AFRP	3.2 (2)



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:

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

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:

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

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

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

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):

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

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:

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

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:



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

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):

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

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

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

Here, x is the daily value of $\log(\text{flow})$. Note that the variance-covariance matrix for the logistic regression coefficients is multiplied (i.e., scaled) by the estimated dispersion parameter ($\hat{\phi}$) 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 $nq(1-q)$. 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:

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

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 (\hat{N}) of juveniles across days ($i = 1, 2, 3, \dots, k$) of the sampling season is the sum:

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

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



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

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:

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

where

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

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:

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

where

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

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.



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