Using Rotary Screw Traps to Determine Juvenile Chinook Salmon Out-migration Abundance, Size and Timing in the lower Merced River, California

2007 Annual Data Report

Prepared by:

John Montgomery, Ayesha Gray, Clark B. Watry and Brian Pyper

Prepared for:

US Fish and Wildlife Service,

Anadromous Fish Restoration Program

Grant No. 813326G009

CRAMER FISH SCIENCES

Corporate Office
600 NW Fariss Road
Gresham, Oregon 97030
(503) 491-9577 | (877) 977-0102

Oakdale Office
636 Hedburg Way, #22
Oakdale, CA 95361
(209) 847-7786

Auburn Office
1119 High Street, #2
Auburn, CA 95603
(530) 888-1443

Idaho Office
121 W. Sweet Ave., #118
Moscow, ID 83843
(208) 883-9730

Table of Contents

List of Figures

List of Tables

Summary

The lower Merced River contains Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead/rainbow trout (*O. mykiss*) which are listed as species of concern under the Endangered Species Act (ESA). From January 23 to June 1, 2007, Cramer Fish Sciences conducted rotary screw trap operations on the lower Merced River near the town of Stevinson, California to enumerate and detail various aspects of juvenile salmonid out-migration for the U.S. Fish and Wildlife Service's Anadromous Fish Restoration Program. Abundance estimates were calculated using a logistic regression model which predicted daily trap efficiency based on average trap efficiency and flow. Seasonal passage estimates for natural and hatchery Chinook salmon were 28,889 (± 9,122) and 38,276 (± 10,987), respectively. No *O. mykiss* were captured. For Chinook salmon, we found low catch abundance, a compressed migration time and truncated life history types (compared to other Central Valley rivers) characteristic of a depressed population. Our natural Chinook salmon catch was 98% smolt-sized (age-0) fish, likely representing one life history strategy. No (age-0) fry and one yearling emigrant were captured. Out-migration timing of natural fish strongly coincided with hatchery releases upstream, and weaker associations were observed with temperature and lunar cycle. Observations this season seem to indicate very poor natural production of Chinook salmon, however subsequent monitoring of population trends over several seasons is required before conclusions or management decisions can be made. A more thorough understanding of *O. mykiss* populations on the Merced River may explain the lack of out-migration observed during the 2007 season. Monitoring at Hatfield State Park rotary screw trap site will provide data on Merced River salmonid populations to help AFRP and CAMP meet their objectives.

Introduction

Since the 1850s Pacific salmon stocks have experienced dramatic declines (Nehlson et al. 1991). Historically, Chinook salmon (*Oncorhynchus tshawytscha*) 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). The San Joaquin River and its tributaries represent the southernmost extent of Chinook salmon distributions in North America, and provide important spawning and rearing habitats for Chinook salmon runs listed as species of concern under the federal Endangered Species Act (ESA). Spring- run Chinook salmon were historically dominant in the San Joaquin and its tributaries. 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. As a result, the spring-run no longer exists on the San Joaquin or its tributaries (Campbell and Moyle 1991; Yoshiyama et al. 2001). Today, fall-run Chinook salmon populations persist in San Joaquin River tributaries, and the Merced River is their southernmost extent (Williams 2006).

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 the CVPIA; however, consistent monitoring of juvenile Chinook salmon and steelhead (*O. mykiss*) emigration has been lacking. Effective monitoring provides a valuable tool for determining optimal management by understanding population dynamics (Adaptive Management Forum Scientific and Technical Panel 2002). This is achieved by documenting trends, setting baseline conditions, and determining the influences of changing environmental variables (i.e., turbidity, flow, temperature, moon phase, day length, etc.). In 2007, Cramer Fish Sciences (CFS) re-initiated juvenile Chinook salmon and *O. mykiss* population monitoring on the Merced River at George Hatfield State Park (Hatfield) under contract with AFRP. We used rotary screw traps, 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 from the Merced River;
2. Determine and evaluate patterns of migration timing and size distribution, along with abundance estimates, as they relate to flow and other environmental variables; and,
3. Compare production estimates to upper river estimates to develop indices of in-river survival.

The following annual report addresses the first two objectives. Previous up-river sampling efforts (California Department of Fish and Game (CDFG); Natural Resource Scientists, Inc.(NRS)) provided estimates of juvenile Chinook salmon abundance at river kilometer (rkm) 61.2 and rkm 19.3, respectively. However, this was the pilot year of sampling at Hatfield State Park (rkm 3.2) and the only sampling effort for 2007 on the Merced River, so no comparisons are possible this year. When additional data are available in future years, determinations of in-river survival will be evaluated and reported.

Study Area

The confluence of the Merced River and the San Joaquin River is located 140 km south of Sacramento at rkm 190 near the town of Stevinson (Figure 1). The river originates in Yosemite National Park, draining a 3,305 km^2 watershed as it flows down the western slope of the Sierra Nevada range into the Central Valley. Elevations in the watershed range from 4,000 m at its headwaters to 15 m at the San Joaquin River confluence. The lower Merced River below Lake McClure is regulated by several dams; including New Exchequer, McSwain, Merced Falls, and Crocker-Huffman. Details and additional points of interest are listed in Table 1. The Merced River Hatchery (MRH), operated by CDFG, is located immediately downstream of Crocker-Huffman Dam. Crocker-Huffman Dam is the upstream terminus of fish migration on the Merced River. The primary spawning reach, located from Crocker-Huffman to rkm 52.3, has undergone significant alteration from gold and gravel mining. Extensive alterations to channel and floodplain morphology have negatively affected salmonid spawning and rearing habitat (Yoshiyama et al. 1998).

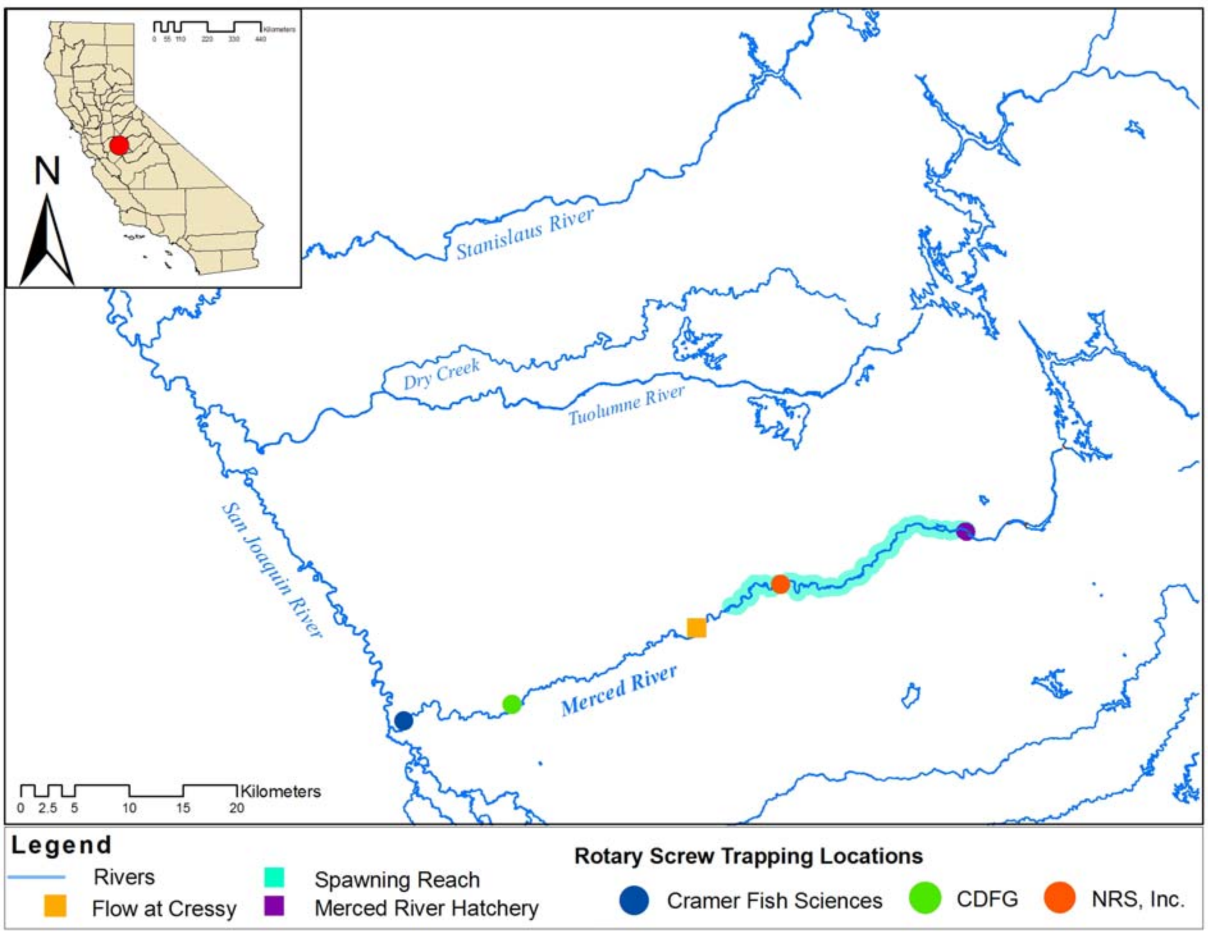

Figure 1. Map of Lower Merced River.

Table 1. Description and location of points of interest

Point	Purpose/Significance	Operator	Rkm
New Exchequer Dam/ Lake McClure	Constructed in 1967 Large storage capacity and long residence time Cold water discharge	Merced Irrigation District	100.0
McSwain Dam and Reservoir	Constructed in 1966 Short residence time	Merced Irrigation District	90
Merced Falls Dam and Forebay	Constructed in 1901 Short residence time Northside Canal diversion point	Pacific Gas and Electric	88.5
Crocker-Huffam Dam and Reservoir	Constructed in 1910 Merced Irrigation District main canal diversion point Upstream terminus of fish migration	Merced Irrigation District	83.7
Merced River Hatchery	Constructed 1970 Only hatchery in San Joaquin basin	CDFG	83.7
Primary Spawning Reach	The majority of spawning occurs above RM 45.2 Below RM 32.5 very little suitable spawning habitat exists		32.5 – 52.3
Hopeton Rotary Screw Traps	Salmonid population studies	Merced Irrigation District	61.2
Cressy Gauge	Primary flow data	United States Geological Survey (USGS)	43.5
Hagaman State Park	Former screw trapping site (1998-2002)	CDFG	19.3
Hatfield State Park	Current screw trapping site	USFWS-AFRP	3.2

Since mid-1997 typical regulated flow on the Merced River is approximately 250 ft^3/s; maximum discharge permitted into the Merced River by the Army Corps of Engineers is 6,000 ft^3/s; however, flow exceeded 8,000 ft^3/s under emergency circumstances created during the 1997 flood (Stillwater 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 ft^3/s contributing 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 (Figure 2). Thermographs are used by CDFG to record temperature at several points along the river. Downstream of Crocker-Huffman Dam substrate is dominated by gravel and cobble with downstream fining to eventual sand and silt below the lowest spawning site (Table 2).

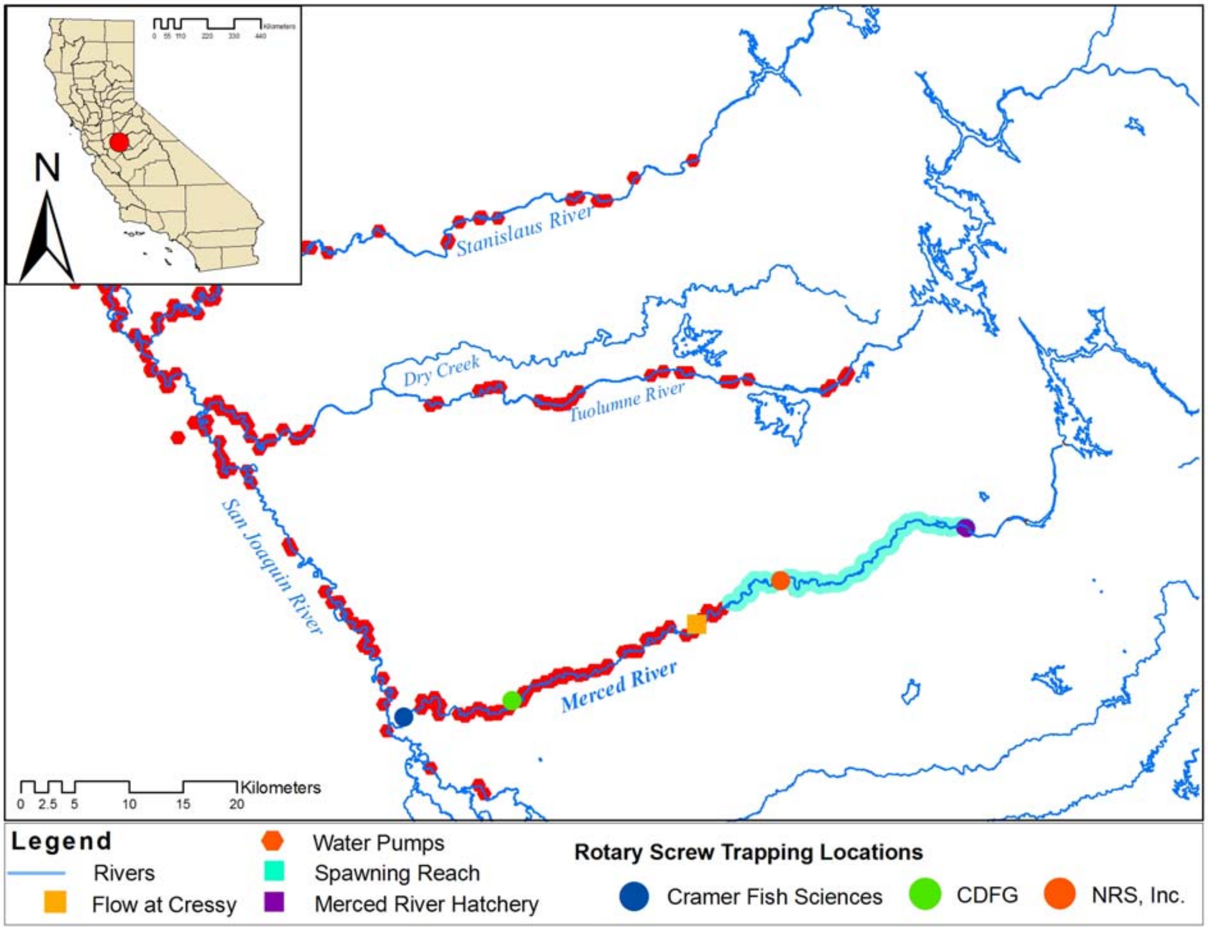

Figure 2. Water pumps on the Merced River and other tributaries of the San Joaquin.

Table 2. Description of substrate composition (adapted from Stillwater 2001)

River Mile (RM)	River Kilometer (rkm)	Substrate Composition
52 - 32.5	83.7 - 52.3	cobble, gravel
32.5 - 8	52.3 - 12.9	gravel, sand
8 - 0	12.9 - 0	sand

The Hatfield trapping site is located at the upstream end of the park day use area and about 300 m downstream of an agricultural diversion pump (see Figure 2). State park permits allowed CFS access to the site by land or boat if necessary. By trapping at Hatfield, we determined a more accurate estimate of the Merced River juvenile salmonid contribution to the San Joaquin River as the site was lower in the river than previous sampling efforts. The site had excellent accessibility; appropriate river morphology to operate RSTs, and was monitored by rangers and an on-site caretaker, which may have deterred vandalism or tampering.

Methods

Trap Operations

Two 1.5 m diameter RSTs, manufactured by EG Solutions, Inc. (Corvallis, OR), were configured to operate side-by-side. The traps were held in place using 6.35 mm galvanized steel cable leaders fastened to large trees upstream on the north bank.

Optimal trap operation required a minimum of two revolutions per minute (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 allowed standardization by fishing effort. The volume and type of debris accumulation on or in the cone affected rotation rate, and total stoppages were occasionally the result of debris accumulations.

Safety Measures

Staff members were trained in RST operational safety. We also posted safety precaution signage on the traps and adjacent land to warn river users and park visitors of the inherent dangers of the RSTs (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. Flashing lights, flagging, and buoys were placed on the traps and along the rigging. Signs were in English and Spanish.

Figure 3. Warning sign and buoys on upstream end of trap and shore.

Fish Capture and Handling

Trapped fish were collected and processed by CFS and USFWS staff at least once per day. We followed the RST protocol (see Rotary Screw Trap Protocol) and established fish handling procedures. During high flows and peak migration times traps were processed twice per day. Additionally, traps were processed prior to and following evening 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. 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 checked with a few fish to determine potency and adjusted if necessary. StressCoat (Aquarium Pharmaceuticals, Inc.), which helps replace the slime coat and scales on a fish, 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.

For Chinook salmon and steelhead/rainbow trout, we recorded fork length (mm FL), total length (mm TL), and life stage for 50 randomly-selected fish each day, any additional fish were counted; weights were recorded for the first 50 fish each week. Life stage was determined by assigning a smolt index value based on morphological characteristics (Table 3). Note, the silvery parr designation is only used to describe steelhead/rainbow trout and not applied to juvenile Chinook salmon. For non-target species, we measured FL, or total length when applicable, of the first 20 fish of each species, all other fish were counted. 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 at in the trap. Night checks were conducted identically to daytime checks, with the exception of only measuring the first 20 fish of any species and counting the remainder.

Table 3. Criteria used to assign smolt index value

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	*Apply only to steelhead/rainbow trout
		Parr marks visible but faded or absent
		Intermediate degree of silvering
5	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
6	Adult	>300 mm fork length
		If <300 mm fork length steelhead/rainbow trout must be extruding eggs or milt

Environmental Variables

Water temperature was recorded in ºF at each trap check with a handheld analog thermometer and converted to ºC for reporting efforts. Additionally, thermograph data was provided by CDFG from various sites along the river. When available, dissolved oxygen (DO) and water temperature were recorded using a digital handheld meter (YSI Model 550A). River stage was recorded daily using an established staff gauge. Water velocity at the cone entrance was measured using a digital water velocity meter (Global Water Instrumentation, Inc.; Model FP101). Turbidity was measured using a nephelometer (LaMott Company, Model 2020) with water samples collected at the first trap check each day. We obtained daily flow data from United States Geological Survey (USGS), Cressy gauge (CRS), located at rkm 43.5.

Analysis of trap efficiency and passage

Determining trap efficiency allows us to estimate the number of migrants (passage). We conducted efficiency tests with fish from MRH. Four releases of approximately 2000 fish each were conducted weekly from April 24 to May 15. Fish were dye-marked using a photonic marking gun (Meda-E-Jet; A1000) with either green or pink dye on the caudal fin (Figure 4). Fish were released after dark in small groups, to prevent schooling, approximately 1000 m upstream of the traps. We processed the traps one hour after the final fish were released to check for immediate recaptures, additional recaptures were recorded with subsequent trap checks.

Figure 4. Technician marking fish and marked fish.

We used logistic regression models to predict daily trap efficiencies, and extrapolated these efficiencies to estimate smolt passage. Because there were only four mark-recapture estimates for 2007, it was not possible to rigorously examine the potential effects of physical and biological variables on trap efficiency. Instead, we used two simple models and compared the results between them. In the first model, referred to as "average model," we simply used the average trap efficiency across the four tests as the estimate of trap efficiency for all days. In the second model, we assumed trap efficiency was a function of flow (the "flow model"). The relationship between trap efficiency and flow was consistent with estimates for screw traps at two sites on the Stanislaus River (Caswell and Oakdale) (Pyper and Simpson, in prep).

Briefly, logistic regression is a form of generalized linear model that is applicable to binomial data (McCullach and Nelder 1989; Dobson 2002). Here, the binomial probability of interest is the observed trap efficiency (q):

(1) $$q = \frac{c}{R} \ ,$$

where c 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:

(2) $$y = \beta_0 + \beta_1 x \ ,$$

where y is the "logit" transform of the observed catch rate (q):

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

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

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

For the "average" model, there was no explanatory variable *x*, and hence, the model was simply $y = \beta_0$ (see equation 2). In the "flow" model, values of log(*flow*) were used as the explanatory variable (*x*). Note that for both models, deviances were greater 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 easily estimated from the fit of a logistic regression and does not affect point estimates of coefficients (Venables and Ripley 1999). However, the variance-covariance matrix for coefficients must be multiplied by the estimate of ϕ when conducting statistical tests and computing confidence intervals.

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

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

where *c* was observed daily count and *q* was the estimated trap efficiency for that day based on either the "average" or "flow" model. Standard errors (SE) and confidence intervals for measures of total annual passage were computed using methods described in Demko et al. (2000).

Passage estimates were computed separately for unmarked and marked fish. Marked fish were adipose-clipped CWT releases from MRH. There were three primary releases of MRH fall-run Chinook salmon smolts: (1) approximately 100,000 marked fish released on April 20th; (2) approximately 100,000 marked fish released on May 4th; and (3) approximately 35,756 unmarked fish released on May 15th (J. Guignard, CDFG, unpublished data).

Results

Environmental Parameters

Flow ranged from 176 ft^3/s on April 11 to 988 ft^3/s on May 7, which corresponded to peak supplemental water releases for the Vernalis Adaptive Management Program (VAMP). Prior to VAMP, flow averaged 221 ft^3/s and only exceeded 300 ft^3/s on three days. During VAMP, flow averaged 615 ft^3/s. We recorded water velocity ranging from 0.66 to 3.61 ft/s, measured May 8 and May 29, respectively, and water temperatures ranging from 5.3ºC to 24.1ºC, measured January 25 and June 1, respectively. We compared water temperature at rkm 0.8 to cumulative catch to evaluate effects on Chinook salmon catch (Figure 5). Our turbidity records ranged from 0.4 to 84.5 NTU, measured January 31 and February 14, respectively.

Trap Operations

We typically operated traps continuously; however, when catch was low (< 20 fish/d) we did not perform weekend trapping. The first Chinook salmon catch occurred on March 28. Traps were operated daily the remainder of the season and trapping ceased on June 1. Eighty-three complete blockages were encountered with 67% (n = 56) occurring in the north trap. Twenty-four partial blockages were encountered with 50% (n = 12) occurring in the north trap. The traps rotated an average of 1.7 revolutions per minute during flows less than 300 ft^3/s and 4.4 revolutions per minute at flows greater than 600 ft^3/s. Less than optimal trap rotation occurred throughout the majority of the season (Figure 6).

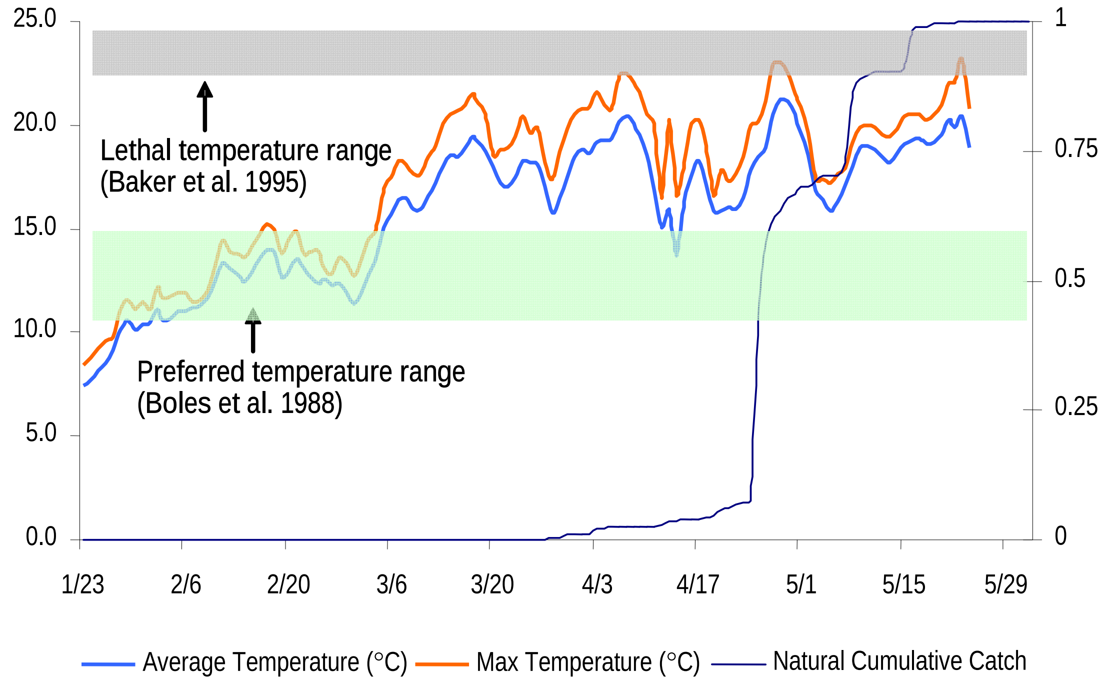

Figure 5. CDFG thermograph temperature located at rkm 0.8 versus proportional catch with preferred temperature range and lethal temperatures for Chinook salmon smolts.

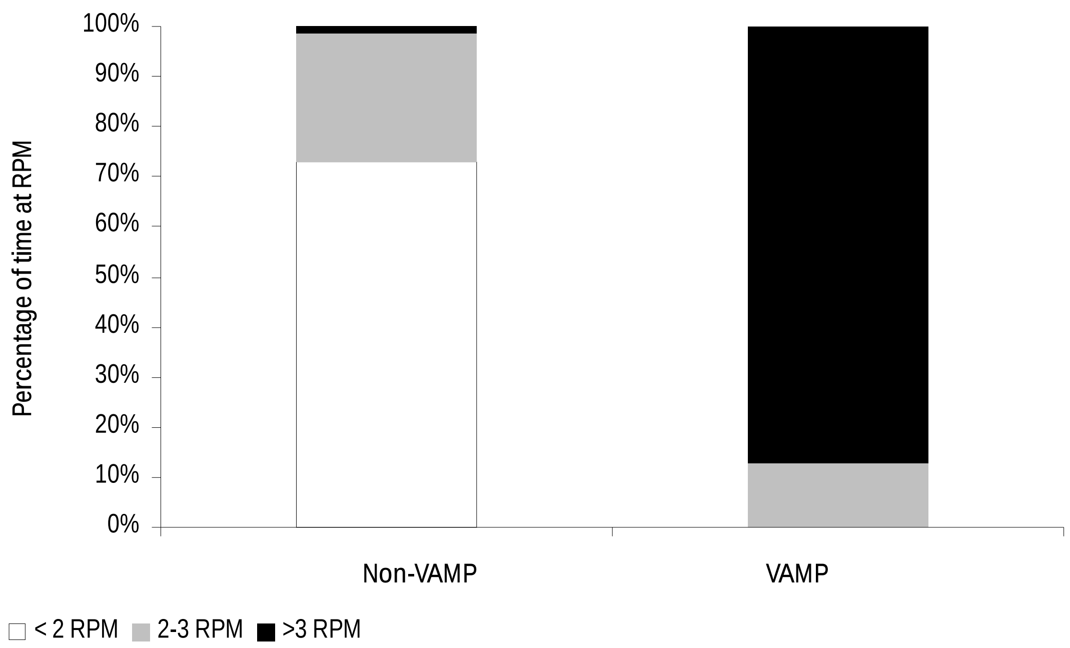

Figure 6. Trap rotation for season during normal flow and VAMP (April 20-May 20) supplemental flow.

Catch

Natural Chinook salmon

The total season catch of natural Chinook salmon was 193 fish (Table 4). The first catch of natural Chinook salmon occurred on March 28, 2007. From March 28 to April 24, 20 fish were caught. On April 25, we captured 77 natural fish. This was the first of three catch peaks (Figure 5). A total of three mortalities occurred during sampling resulting in an overall mortality rate of 1.6%. The entire natural Chinook salmon catch spanned a period of exactly eight weeks (March 28 to May 23). The median out-migration date was April 25 which corresponded with the peak out-migration date (Figure 6 and Figure 7). Fork lengths ranged from 55 to 120 mm (Figure 7 and Figure 8; Table 6).

Table 4. Natural Chinook Salmon catch by life stage.

Life Stage	Count
Yearling	1
Smolt	187
Parr	2
Fry	0
Total	190

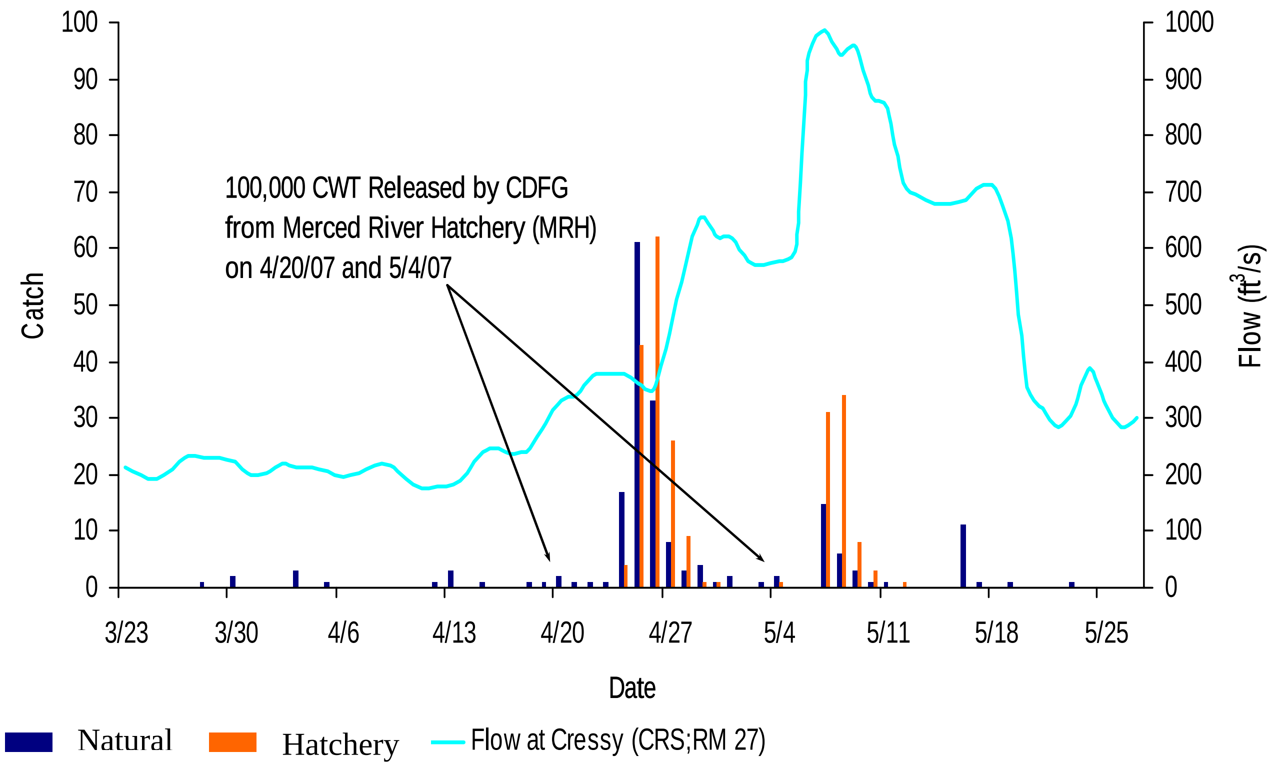

Figure 5. Natural and hatchery catch by date with flow plotted in the foreground.

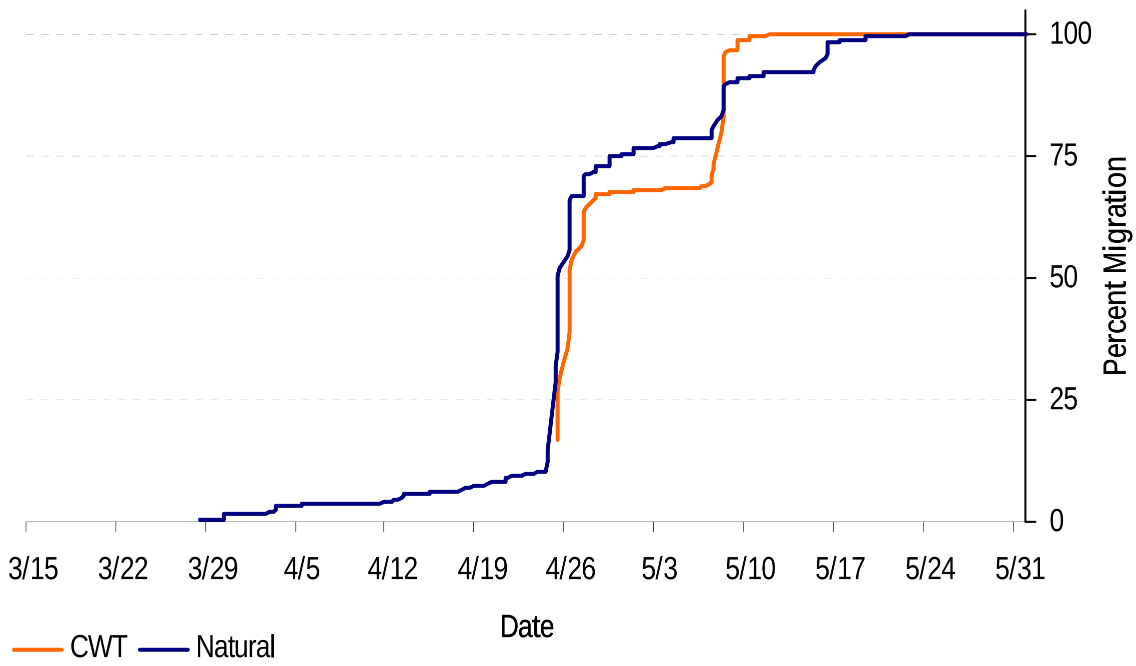

Figure 6. Graph showing percent of total out-migration for natural and hatchery (CWT) salmon by date

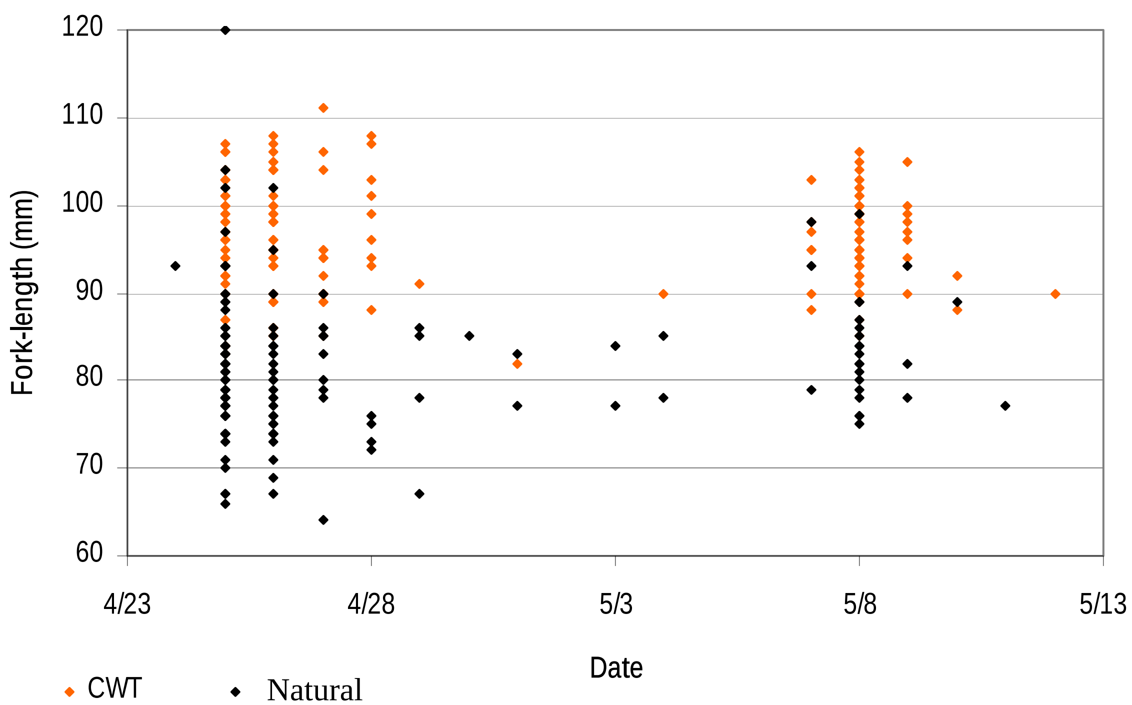

Figure 7. Fork length of natural versus hatchery (CWT) Chinook salmon on days of overlapping catch

Table 5. Average length, standard deviation, confidence intervals and limits for captured Chinook salmon

	Average	Standard Deviation	Count	Confidence Interval	Upper Confidence Limit	Lower Confidence Limit
Natural	82	9	193	1	83	81
Hatchery	96	6	189	1	97	95
Combined	89	10	382	1	90	88

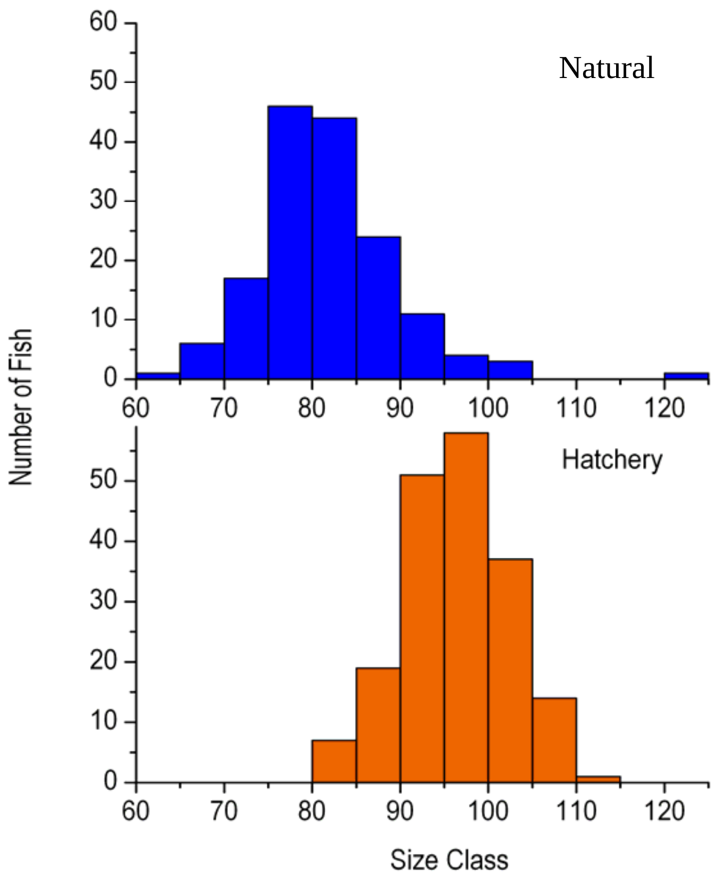

Figure 8. Fork length frequency for natural and hatchery catch

Hatchery Chinook salmon

In all, 242 hatchery Chinook salmon were captured between April 25 and May 12. The first catch of hatchery Chinook salmon occurred when 65 fish were captured. This first period of increased hatchery catch occurred between April 25 and May 1, while the second period occurred between May 7 and May 12 (Figure 5). A large (475 mm) channel catfish (*Ictalurus punctatus*) present in the live-box on April 27 regurgitated 13 hatchery Chinook salmon. Two other mortalities occurred on April 28, likely caused by stress or injury from a high volume of debris in live-box. This resulted in a combined overall mortality rate of 6.2% for the season. The peak out-migration date occurred on April 25 and the median out-migration date was April 26 (Figure 6). Fork lengths ranged from 82 to 111 mm (Figure 7 and Figure 8; Table 6). Mean FLs for hatchery fish were significantly larger than those for natural fish ($F = 376.0$, $P < 0.0001$)

Analysis of trap efficiency and passage

Four efficiency tests were conducted during the period of peak migration. Flow increased between the first three tests and decreased between the third and fourth test due to VAMP discharges. Trap efficiency decreased as flow increased with the exception of the third test conducted on May 7. Hatchery smolts were used for efficiency tests during the time period when natural smolts were passing the trap. A summarization of FL and efficiency results can be found in Table 6 and Table 7, respectively. Trap efficiencies ranged between 0.25% and 0.89%.

Table 6. Fork length (FL) of efficiency fish at pre-release and at time of recapture.

Date	Pre-Release		Recaptured	
	FL (mm) Range	Average FL (mm)	FL (mm) Range	Average FL (mm)
4/24/07	82-114	99	87-105	99
5/1/07	59-88	87	85-98	89
5/7/07	88-118	103	95-115	104
5/15/07	53-105	93	91-99	95

All four estimates of trap efficiency were less than 1%, and ranged from 0.25% to 0.89%, and for comparison, the proportion of river flow sampled by both traps was estimated (Table 7). These values ranged from 4.9% to 8.9%, roughly 10 times greater than trap efficiency estimates. Thus, the proportion of flow sampled cannot be used as a surrogate for trap efficiency at the Merced River trap location.

Table 7. Summary of efficiency releases of marked, natural juvenile Chinook salmon in the Merced River, 2007. Trap efficiency estimates and corresponding upper (UCI) and lower (LCI) 95% confidence intervals (based on binomial distribution) were calculated for each experimental release, along with the estimated proportion of flow sampled by both traps.

Release Date	Flow at Cressy (cfs)	Released	Recaptured	Efficiency			Flow Sampled (cfs)	Proportion Flow Sampled (cfs)
				Estimate	LL	UL		
4/24/2007	378	2,025	18	0.89%	0.49%	1.33%	33.8	8.9%
5/1/2007	619	2,037	9	0.44%	0.20%	0.74%	40.1	6.5%
5/7/2007	988	2,010	13	0.65%	0.30%	1.00%	48.0	4.9%
5/15/2007	679	2,014	5	0.25%	0.05%	0.50%	39.6	5.8%

The trap efficiency data were used to estimate daily fish passage based on two different models: (1) the "average" model in which efficiency was equal to the estimated average for all days, and (2) the "flow" model in which trap efficiency declined as flow increased. These two models produced similar estimates of total passage. Daily passage estimates for natural (unmarked) fish and marked hatchery fish are shown in Figure 9.

Average Efficiency Method

Using the average efficiency method passage estimates for the sampling period were 34,141 natural and 40,789 hatchery Chinook salmon. Each hatchery release corresponded to a period of increased catch of both hatchery and natural Chinook salmon (Figure 5). A summarization of total passage and daily passage can be found in Table 8 and Figure 9.

Table 8. Natural and Hatchery (CWT) juvenile Chinook salmon passage estimates with their corresponding lower (LCI) and upper (UCI) 95% confidence intervals for the Merced River, 2007. Passage was estimated using two methods: (1) using average trap efficiency of four experimental releases; and 2) using a logistic relationship between efficiency estimates and river flow.

	Natural			Hatchery		
Model	Estimate	LCI	UCI	Estimate	LCI	UCI
Average Efficiency	34,141	19,255	56,933	40,789	23,171	67,532
Flow	28,889	13,218	51,449	38,276	18,637	64,330

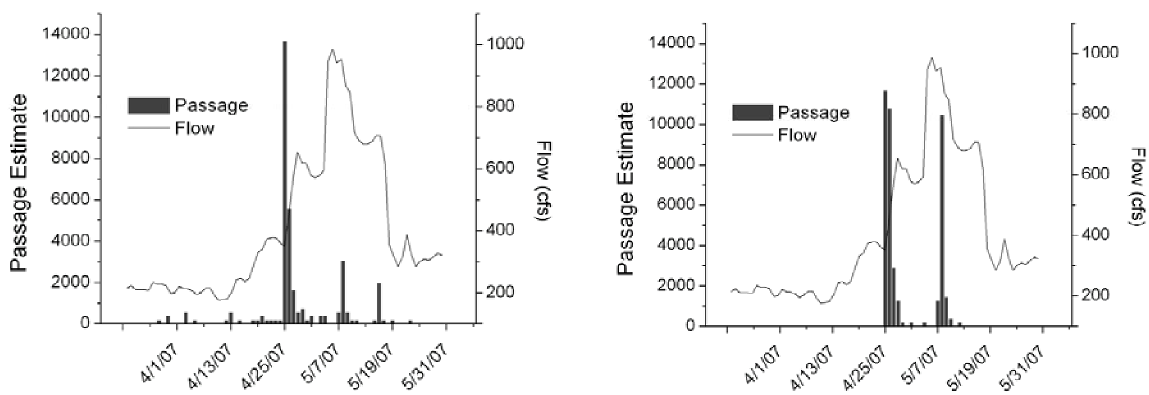

Figure 9. Total daily passage using the average method for hatchery (left) and natural (right) Chinook salmon

Log$_e$ Flow Method

Using the Log$_e$ efficiency method passage estimates for the sampling period were 28,889 natural and 38,276 hatchery Chinook salmon. Each hatchery release corresponded to a period of increased catch of both hatchery and natural Chinook salmon (Figure 10). A summarization of total passage and daily passage can be found in Table 8 and Figure 9.

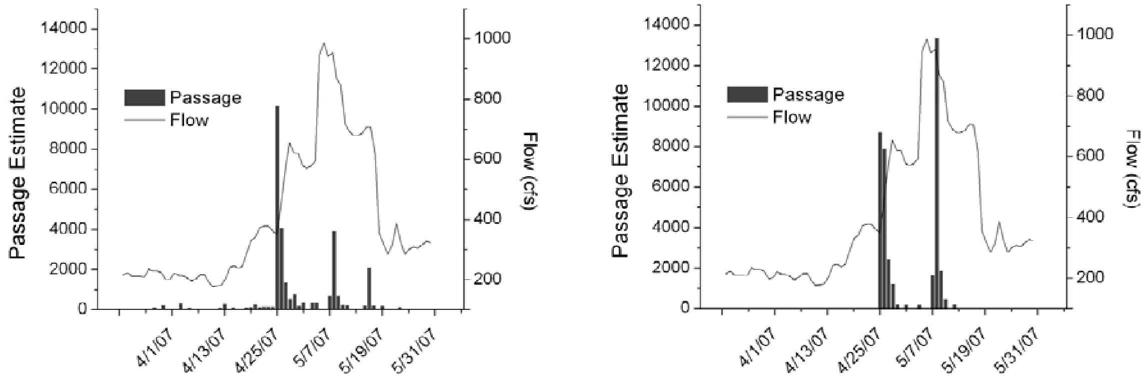

Figure 10. Total daily passage using Log$_e$ flow for hatchery (left) and natural (right) Chinook salmon

Non-Target Species

A total of 2,770 incidental fish, composed of 20 different identifiable species, were captured in the traps (Figure 11). No O. *mykiss* were captured during the season. We captured 600 fish too small to identify. Of the 20 different species, 14 were piscivorous (Moyle 2002) and we assume potential juvenile salmonid predators, only three of the fourteen were native to the Central Valley (Figure 12). Native predators included Sacramento pikeminnow (*Ptychocheilus lucius*), prickly sculpin (*Cottus asper*) and riffle sculpin (*Cottus gulosus*). Centrarchids (*Micropterus* spp. and *Lepomis* spp.) composed nine of the eleven, and the other two were from the Family *Ictaluridae* (*Ameiurus* spp. and *Ictalurus* spp.).

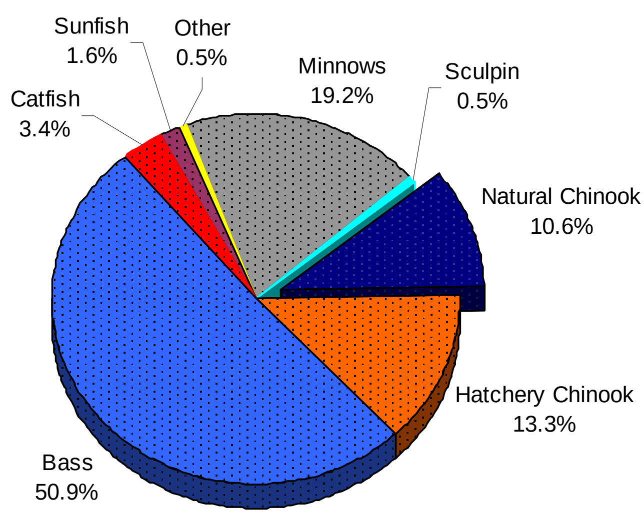

Figure 11. Percent composition of catch of non-target species by common and Chinook salmon. Note: larval fish were not included.

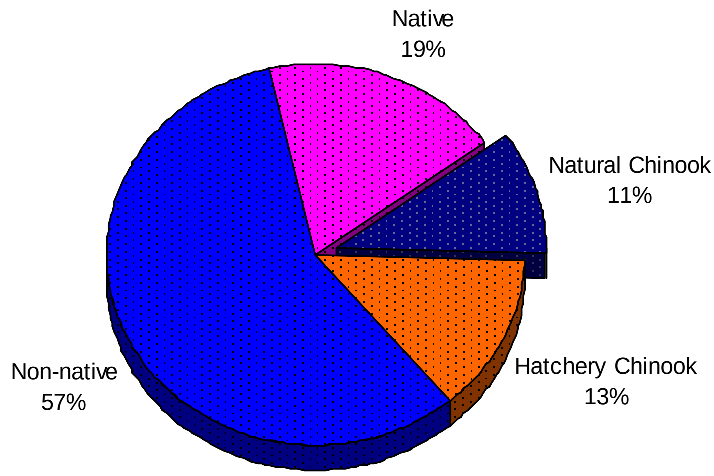

Figure 12. Non-native and native predators versus salmon from the 2007 season. Note: traps select for juvenile fish; 15 of the introduced predators captured were adult-sized.

Discussion

In 2007, we re-initiated the RST monitoring of juvenile salmonid out-migration in the lower Merced River that was previously performed by CDFG at Hagaman State Park (rkm 19.3). The new site was established at Rkm 3.2 to obtain a more accurate estimate of fish contribution to the San Joaquin River. We also partnered with USFWS staff for trap monitoring, conducted staff trainings (CFS and USFWS), developed operational protocols, and documented abundance and timing patterns for juvenile Chinook salmon on the Merced River. Our overall catch of 190 natural and 227 hatchery smolts for the entire season apparently represents depressed population abundance and truncated life history strategies. It should be noted that the trap operated below optimal revolutions per-minute a large proportion of the season, likely affecting efficiency. For comparison, a total of 2,909 natural Chinook salmon were captured on the Stanislaus River (another San Joaquin tributary) compared to the 190 natural Chinook salmon on the Merced River. Our low abundance numbers are likely related to low adult escapement during the 2006 fall-run (1470 fish; J. Guignard, CDFG, personal communication), but may also reflect other parameters not monitored in this study. For instance, during efficiency fish releases we observed predation on test fish during on two separate occasions. Also, much of the season water temperatures were consistently above preferred ranges and entered lethal ranges on more than one occasion. Additional research is needed to better understand the critical mechanisms causing poor juvenile Chinook salmon in the Merced River.

Typically Chinook salmon emigrate in a variety of life stages, generally fry, parr and smolt for age-0 salmon in Central Valley rivers. Our catch on the Merced River was dominated by the smolt life stage, with only two parr and no fry captured in the 2007 season. Reimers (1973) and Quinn (2005) identified five distinct juvenile Chinook salmon life history types (Table 9).

Table 9. Juvenile Chinook salmon life history types as described by Quinn (2005).

Life History Type	Life History Description
Type-1	Fish migrated through the river and out to sea as newly emerged fry.
Type-2	Fish reared in the river or in it's tributaries until early summer, reared for a short time in the estuary, and moved out to sea in midsummer.
Type-3	Fish reared in freshwater until early summer and in the estuary until fall.
Type-4	Fish reared in freshwater until fall and then migrated out to sea without significant use of the estuary.
Type-5	Fish spent a year rearing in freshwater and migrated directly to sea as yearling smolts.

Each life history strategy exhibited different migration timing and utilized distinct habitats. Estuary use is a prevalent feature in some life history types (Type-2 and Type-3), and although historically these strategies would have been very successful considering the productivity of the California Delta; in current times, Chinook salmon utilizing degraded estuaries, like that found in the San Joaquin River, have substantially lower survival rates than those in 'pristine' estuaries (Magnusson and Hilborn 2003). Anthropogenic effects in the Delta may have selected for life history types in the Merced River with longer river residence. Past poor estuary survival and subsequent loss of representative reproduction could explain the prevalence of the (age-0) smolt life stage. Merced River fish are exposed to an additional emigration through 92 km of the much warmer San Joaquin River than fish from the Tuolumne River to the north, and may be more successful making that emigration as smolts versus fry. The existence of multiple life history types provides resilience to a population by buffering the effects of changing conditions over time. The truncated life history types observed may indicate depressed resilience in the natural population.

During this sampling season on the Merced River, we observed an interesting out-migration pattern for juvenile Chinook salmon. Each MRH release was followed by subsequent increased catches of natural and hatchery fish. This may have resulted from density-dependent effects (e.g., schooling) with hatchery fish or some other influence. CFS has made similar observations on the Stanislaus and Tuolumne Rivers; however, a review of the literature suggests this phenomenon is either uncommon or poorly documented. A correlation between natural out-migrations and hatchery releases may provide important information to consider when managing natural Chinook salmon populations on rivers with hatcheries. For example, hatchery production can have a significant effect on naturally-produced salmon in that large hatchery salmon concentrations may attract predators to naturally-produced salmon (Collis et al. 2001; Ryan et al. 2003). This effect can be further compounded because hatchery salmon may cause naturally-produced juveniles to leave their normal habitat and join the school of hatchery fish migrating downstream (Hansen and Jonsson 1985; Hillman and Mullan 1989).

Other influences to migration timing may be temperature and lunar cycles (Baker et al. 1995; Vogel 2003). Høgåsen et al. (1998) found that water temperature regulated migratory readiness and lunar cycles influenced migration timing. This is supported by Grau et al. (1981) who found that smolts tend to emigrate during new or waning moon phases influenced by peaks in hormonal cycles occurring during the new moon. Our first Chinook salmon catch occurred on March 28, three weeks after temperatures rose above preferred ranges, established by Boles et al. (1988), for Chinook salmon smolts, and nine days after the new moon. Large catches occurred on April 25 and May 16 all near the new moon. The final peak, observed on May 16, occurred on the same day as the new moon and one day after the release at MRH, indicating a rapid out-migration which may have been influenced by environmental or biological factors. Unfortunately, we cannot evaluate the proportion of natural and hatchery fish in our last peak catch as all hatchery fish released on May 15 were unmarked.

The Merced River Chinook salmon population, during this pilot season, may have dissimilar characteristics (e.g., low abundance, truncated life history strategies) when compared to other San Joaquin river tributaries, and understanding the effect of management decisions in this system may provide valuable feedback information for managers. However, a broader understanding is needed to make conclusions or management decisions.

Previous years' data are available from CDFG sampling at Hagaman Park; their analysis will determine out-migration abundance and patterns from 1998-2002. In combination with current and future monitoring, this data will serve to strengthen the validity of management decisions regarding the Merced River.

Future Work and Recommendations

Our recommendations for future work on the Merced River include continued and improved RST monitoring at Hatfield, re-established sampling in the upper river (i.e., by NRS), standardized trapping efforts (i.e., dual 2.4 m traps in both locations) and sampling protocols, and coordination with CDFG, NRS, and hatchery personnel to insure robust efficiency testing. Moving the traps approximately 15 m to a deeper downstream area will help accommodate larger traps. However, even though it is established that the larger traps rotate easier under low water velocities (M. Wade, EG Solutions, Inc., personal communication) we may still need to divert some flow to improve operational conditions. This could be accomplished by placing a temporary rigid weir structure upstream of the traps extending from the south bank approximately five to six meters into the river. Preliminary work to address permitting needs for such changes is currently underway.

In the future, we suggest the following protocol changes and adjustments:

1. 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. Adjust field data collection protocols to improve measures of trap effort and include trap effort in passage estimate analysis;
3. Install TidBit™ temperature loggers (Onset Technology, Inc.) at the trap and in the live-box to continuously monitor water temperature conditions experienced by passing and trapped fish;
4. Perform pre- and post-sampling cross channel elevation transects to determine river morphology changes due to trapping and/or temporary structure; and,
5. Revise and streamline sampling protocols to optimize data collection and improve efficiency in field operations.

We plan to work with CAMP and AFRP to revise and standardize protocols for all RST out-migration monitoring projects throughout the basin. These revisions include, but are not limited to: (1) the time of day trap processing occurs; (2) days of operation for sub-sampling; and, (3) efficiency testing procedures. By 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 "big picture" thinking, critically needed if we are to address the problems of the future.

References

Adaptive Management Forum Scientific and Technical Panel. 2002. Merced River adaptive management forum report. U.S. Fish and Wildlife Service, Anadromous Fish Restoration Program, CALFED Bay-Delta Program.

Baker, P. F., T. P. Speed, and F. K. Ligon. 1995. Estimating the influence of temperature on the survival of Chinook salmon smolts *(Oncorhynchus tshawytscha)* migrating through the Sacramento-San Joaquin River Delta of California. Canadian Journal of Fisheries and Aquatic Sciences 52(4):855-863.

Boles, G. L., S. M. Turek, C. D. Maxwell, and D. M. McGill. 1988. Water temperature effects on Chinook salmon *(Oncorhynchus tshawytscha)* with emphasis on the Sacramento River - a literature review. State of California Department of Water Resources, Northern District.

Comprehensive Assessment and Monitoring Program (CAMP). 1997. Standard protocol for rotary screw trap sampling of out-migrating juvenile salmonids. Sacramento, California. 10 pp.

Campbell, E. A. and P. B. Moyle. 1991. Historical and recent population sizes of spring-run Chinook salmon in California. Pages 155-216 in T. J. Hassler, editor. Proceedings of the 1990 Northeast Pacific Chinook and coho salmon workshop. American Fisheries Society, California Cooperative Fishery Research Unit, Humboldt State University, Arcata, California.

Collis, K., D. D. Roby, D. P. Craig, B. A. Ryan, and R. D. Ledgerwood. 2001. Colonial waterbird predation on juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary: vulnerability of different salmonid species, stocks, and rearing types. Transactions of the American Fisheries Society 130:385-396.

Demko, D. B. and S. P. Cramer. 2000. Effects of pulse flows on juvenile Chinook migration in the Stanislaus River. Report of S. P. Cramer & Associates, Inc. to South San Joaquin Irrigation District, Manteca, California and Oakdale Irrigation District, Oakdale, California.

Dobson, A.J. 2002. An Introduction to Generalized Linear Models (second edition). Chapman and Hall, London.

Grau, E. G., R. S. Nishioka, H. A. Bern, and L. C. Folmar. 1981. Lunar phasing of the thyroxine surge preparatory to seaward migration of salmonid fishes. Science 211:607-609.

Hansen, L. P. and B. Jonsson. 1985. Downstream migration of reared smolts of Atlantic salmon (*Salmo salar L.*) in the River Imsa. Aquaculture 45:237–248.

Hillman, T. W. and J. W. Mullan. 1989. Effect of hatchery releases on the abundance and behavior of wild juvenile salmonids. Pages 265-285 in Don Chapman Consultants, editors. Summer and winter ecology of juvenile Chinook salmon and steelhead trout in the Wenatchee River, Washington. Report to Chelan County Public Utility District, Wenatchee, Washington.

Høgåsen, H. R. 1998. Physiological changes associated with the diadromous migration of salmonids. Canadian Special Publication of Fisheries and Aquatic Sciences 127.

Magnusson, A. and R. Hilborn. 2003. Estuarine influence on survival rates of coho *(Oncorhynchus kisutch)* and Chinook salmon *(Oncorhynchus tshawytscha)* released from hatcheries on the U.S. Pacific Coast. Estuaries 26(4B):1094-1103.

McCullagh, P., and Nelder, J.A. 1989. Generalized Linear Models (second edition), Chapman and Hall, London.

Moyle, P.B. 2002. Inland Fishes of California. University of California Press. Berkeley and Los Angeles, California. 502pp.

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4-21.

Pyper, B. J., and M. Simpson. In prep. Factors influencing catch rates of juvenile Chinook salmon by rotary screw traps in the Stanislaus River, California. Cramer Fish Sciences. Gresham, Oregon.

Quinn, T. P. 2005. The behavior and ecology of Pacific salmon and trout. University of Washington Press, Seattle.

Reimers, P. E. 1973. The length of residence of juvenile fall Chinook salmon in Sixes River, Oregon. Fish Commission of Oregon, Research Reports of the Fish Commission of Oregon 4(2), Portland.

Ryan, B. A., S. G. Smith, J. M. Butzerin, and J. W. Ferguson. 2003. Relative vulnerability to avian predation of juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary, 1998-2000. Transactions of the American Fisheries Society 132:275-288.

Stillwater Sciences. 2001. Merced River corridor restoration plan baseline studies. Volume II: geomorphic and riparian vegetation investigations report, final report. Stillwater Sciences, Berkeley, California.

Venables, W.N. and Ripley, B.D. 1999. Modern Applied Statistics with S-PLUS. Springer-Verlag, New York.

Vogel, D. A. 2003. Merced River Water Temperature Feasibility Investigation Reconnaissance Report. Report of Natural Resource Scientists, Inc. to the U.S. Fish and Wildlife Service, Anadromous Fish Restoration Program, Stockton, California.

Williams, J. G. 2006. Central Valley salmon: a perspective on Chinook and steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science 4(3): Article 2. Available: http://repositories.cdlib.org/jmie/sfews/vol4/iss3/art2/. (July 2007).

Yoshiyama, R. M., F. W. Fisher, and P. B. Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18:487-521.

Yoshiyama, R. M., E. R. Gerstung, F. W. Fisher, and P. B. Moyle. 2001. Historical and present distribution of Chinook salmon in the Central Valley drainage of California. Pages 71-176 in R. L. Brown, editor. Contributions to the Biology of Central Valley Salmonids, Fish Bulletin 179. California Department of Fish and Game, Sacramento.