

# 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

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## Summary

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The lower Merced River contains Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead/rainbow trout (*O. mykiss*) which are considered species of concern under the federal Endangered Species Act (ESA). From January 23 to June 1, 2007, Cramer Fish Sciences conducted rotary screw trap operations on the lower Merced River (N 37°21'25.963", W 120°57'51.469") 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 ( $\pm 9,122$  SE) and 38,276 ( $\pm 10,987$  SE), respectively. No *O. mykiss* were captured. For Chinook salmon, we found low catch abundance, a compressed migration time and truncated early life history patterns (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

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Since the 1850s Pacific salmon stocks have experienced dramatic declines (Nehlsen 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 considered 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), although limited data exist that document these fish in small numbers (Anderson et al. 2007). 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) began juvenile Chinook salmon and *O. mykiss* population monitoring on the Merced River at George Hatfield State Park (Hatfield) under contract with AFRP. The monitoring effort continued previous work by CDFG at Hagan State Park (rkm 19.3). 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) 19.3 near the town of

Stevinson, and rkm 61.2 near the town of Cressy, respectively (as measured from its confluence with the San Joaquin River). 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 (N 37°21'25.963", W 120°57'51.469") (Figure 1). The river originates in Yosemite National Park, draining a 3,305 km<sup>2</sup> 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 (based CDFG spawning surveys), 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).

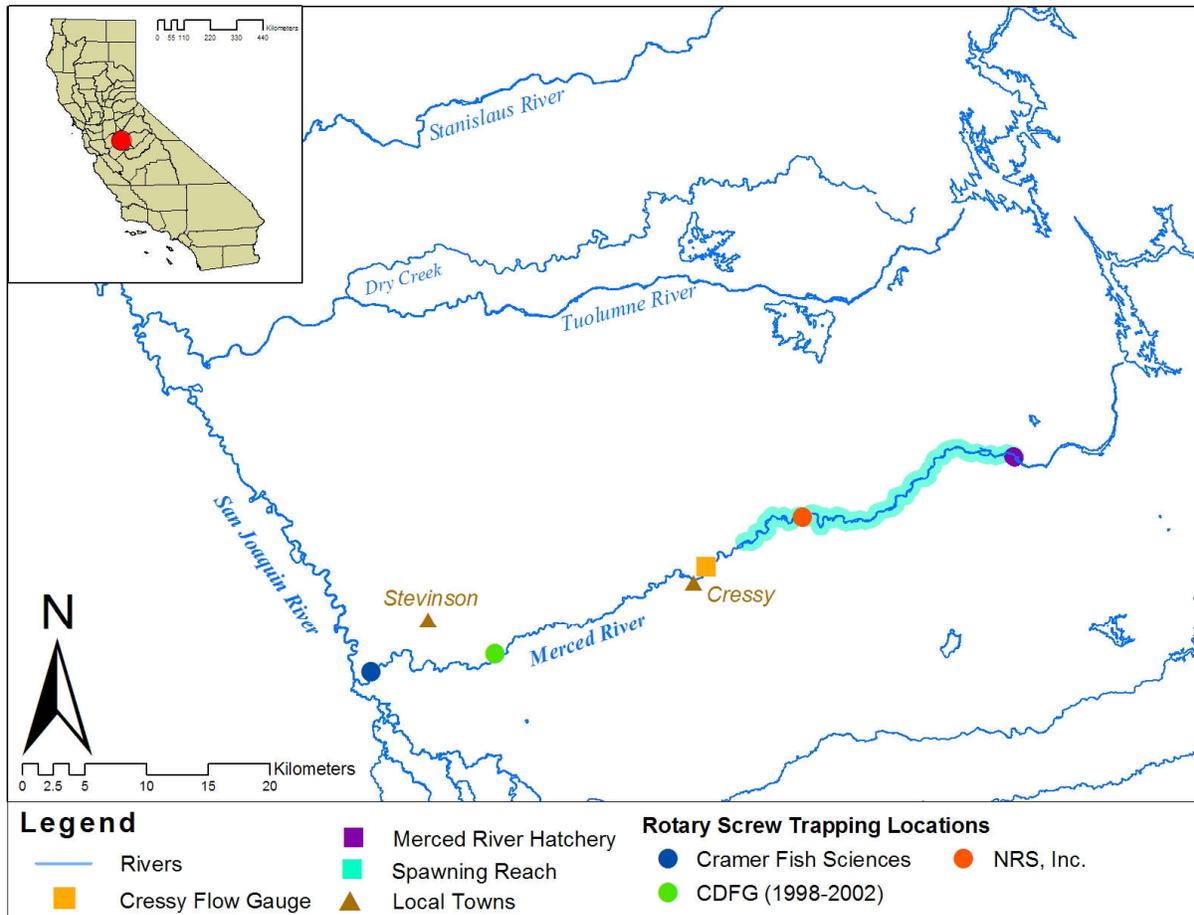


Figure 1. Map of lower Merced River.

Table 1. Description and location of points of interest.

Point	Purpose/Significance	Operator	rkm (RM)
New Exchequer Dam/ Lake McClure	Constructed in 1967	Merced Irrigation District	100.0 (62)
	Large storage capacity and long residence time		
McSwain Dam and Reservoir	Cold water discharge	Merced Irrigation District	90 (56)
	Constructed in 1966		
Merced Falls Dam and Forebay	Short residence time	Pacific Gas and Electric	88.5 (55)
	Constructed in 1901		
	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		
Merced River Hatchery	Upstream terminus of fish migration	CDFG	83.7 (52)
	Constructed in 1970		
Primary Spawning Reach	Only hatchery in San Joaquin basin		52.2 – 83.7 (32.5 – 52)
	The majority of spawning occurs above RM 45.2		
Hopeton Rotary Screw Traps	Below RM 32.5 very little suitable spawning habitat exists	Merced Irrigation District	61.2 (38)
	Salmonid population studies		
Cressy 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)

Since mid-1997 typical regulated flow on the Merced River is approximately 250 ft<sup>3</sup>/s; maximum discharge permitted into the Merced River by the Army Corps of Engineers is 6,000 ft<sup>3</sup>/s; however, flow exceeded 8,000 ft<sup>3</sup>/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 ft<sup>3</sup>/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 area (Table 2).

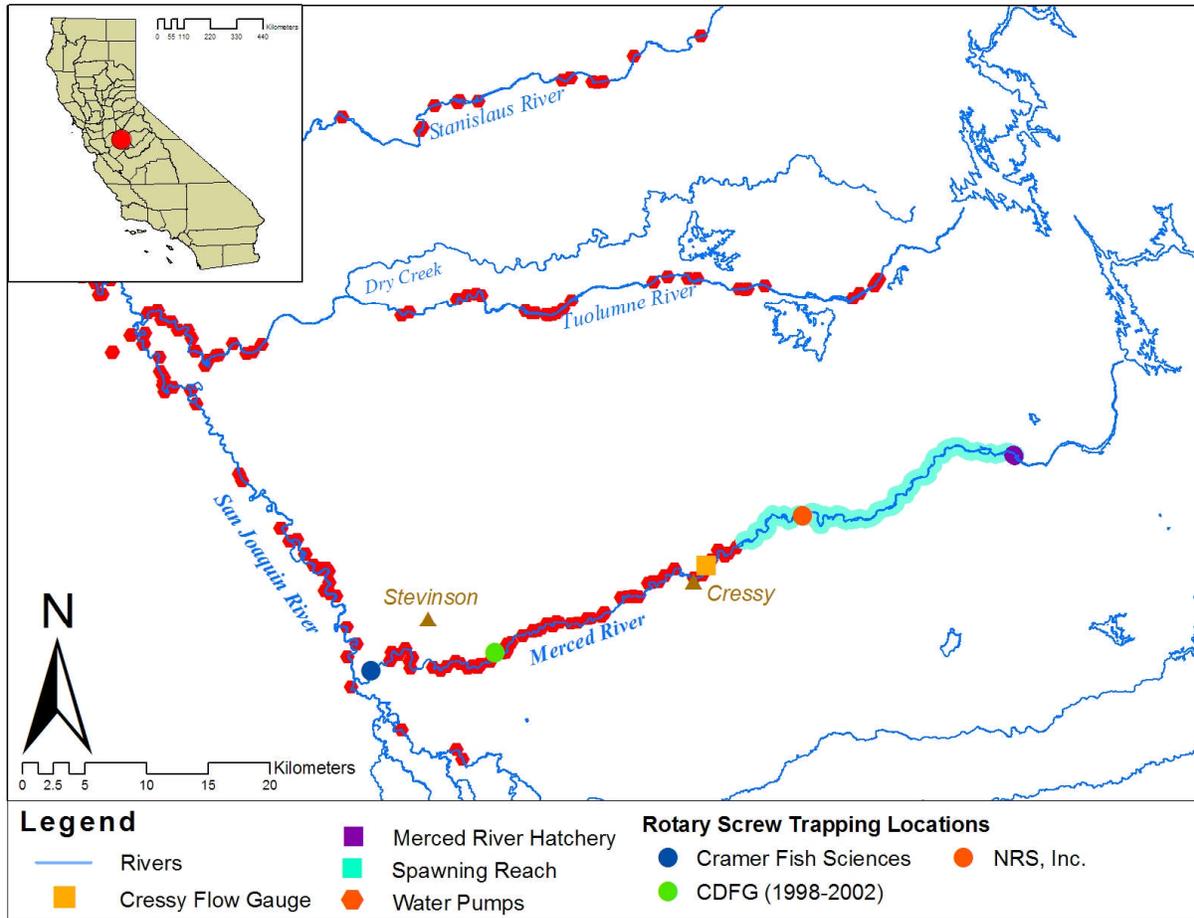


Figure 2. Water pumps on the Merced River and other tributaries of the San Joaquin River.

Table 2. Description of substrate composition (adapted from Stillwater Sciences 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 (Figure 3) 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 expected 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.



Figure 3. Detail map showing Hatfield State Park and RST location.

## Methods

### Trap Operations

Two 1.5 m diameter RSTs, manufactured by EG Solutions, Inc. (Corvallis, OR), were configured to operate side-by-side (Figure 4, *right*). 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 provides a tool for assessing trap operation. The volume and type of debris accumulation on or in the cone can affect rotation rate. We recorded total stoppages which resulted from debris accumulations.

### Safety Measures

Staff members were trained in RST operational safety to meet USFWS standards. 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 4). 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 4. Warning sign (left) and buoys (right) 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 CFS RST protocol (Gray et al. 2007) and established fish handling procedures. During high flows (>500 ft<sup>2</sup>/s) and peak migration times (after flow changes, generally April to May) traps were processed twice per day, in the morning and afternoon. Additionally, traps were processed prior to and an hour 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 *O. mykiss*, 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 *O. mykiss* 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	-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
	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*.

## Environmental Variables

Water temperature was recorded in °F at each trap check with a handheld analog thermometer and converted to °C 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.

## Trap Efficiency and Passage Estimates

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 5). Fish were released approximately one hour after dark in groups of five to ten fish, to prevent schooling, from the north bank 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 the subsequent day's usual trap checks.



Figure 5. Technician marking fish (left) and marked fish (right).

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), as trap efficiency is generally understood to be related to flow.

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 ( $q$ ):

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

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:

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

where  $y$  is the “logit” transform of the observed catch rate ( $q$ ):

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

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

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

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  $\log(\text{flow})$  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,  $\phi$ , 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  $\phi$  when conducting statistical tests and computing confidence intervals.

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

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

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) for measures of total annual passage were computed using methods described in Demko et al. (2000). Approximate confidence intervals were computed based on SE derived from log normal error distributions.

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 4; and, (3) approximately 35,756 unmarked fish released on May 15 (J. Guignard, CDFG, unpublished data).

## Results

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### Environmental Parameters

Flow ranged from 176 ft<sup>3</sup>/s on April 11 to 988 ft<sup>3</sup>/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<sup>3</sup>/s and only exceeded 300 ft<sup>3</sup>/s on three days. During VAMP, flow averaged 615 ft<sup>3</sup>/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 5.3°C to 24.1°C, 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 6). Our daily turbidity records ranged from 0.4 NTU (January 31) to 84.5 NTU (February 14).

### Trap Operations

Traps were installed on January 23, and removed on June 1, 2007. We typically operated traps continuously; however, when catch was low (< 20 fish/d) traps were not operated on the weekends. 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<sup>3</sup>/s and 4.4 revolutions per minute at flows greater than 600 ft<sup>3</sup>/s. Less than optimal trap rotation occurred throughout the majority of the season (Figure 7).

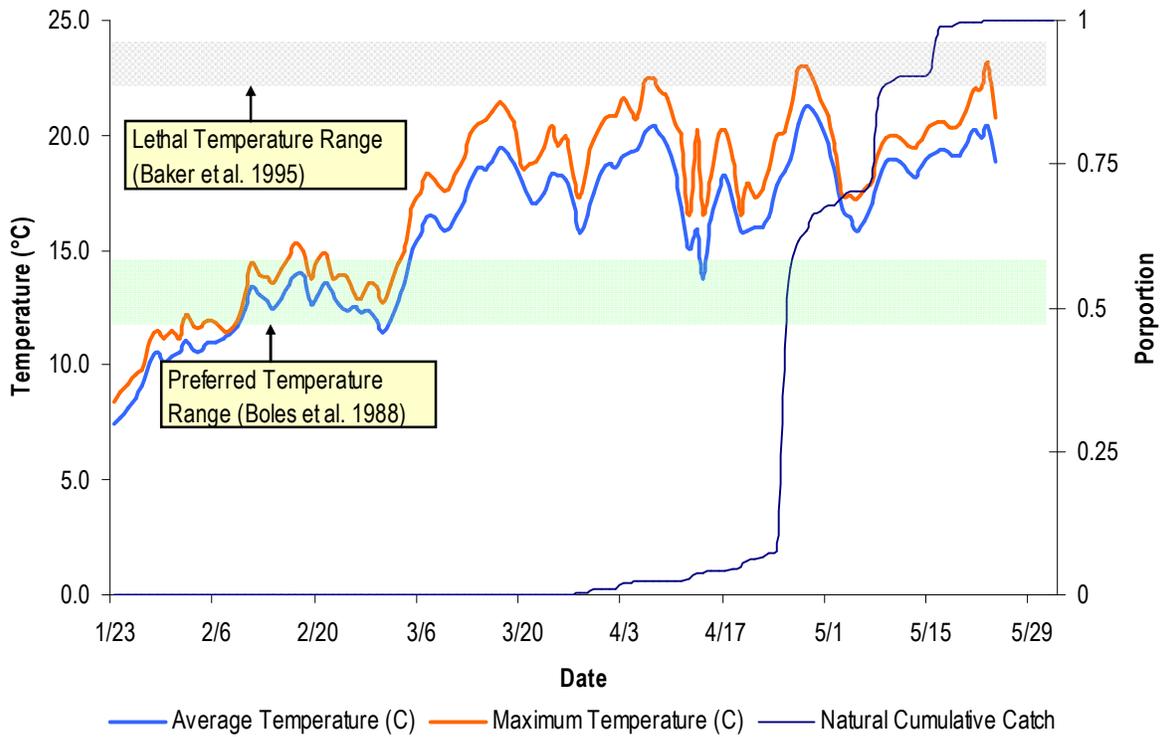


Figure 6. CDFG thermograph temperature located at rkm 0.8 versus proportional catch with preferred temperature range and lethal temperatures for Chinook salmon smolts.

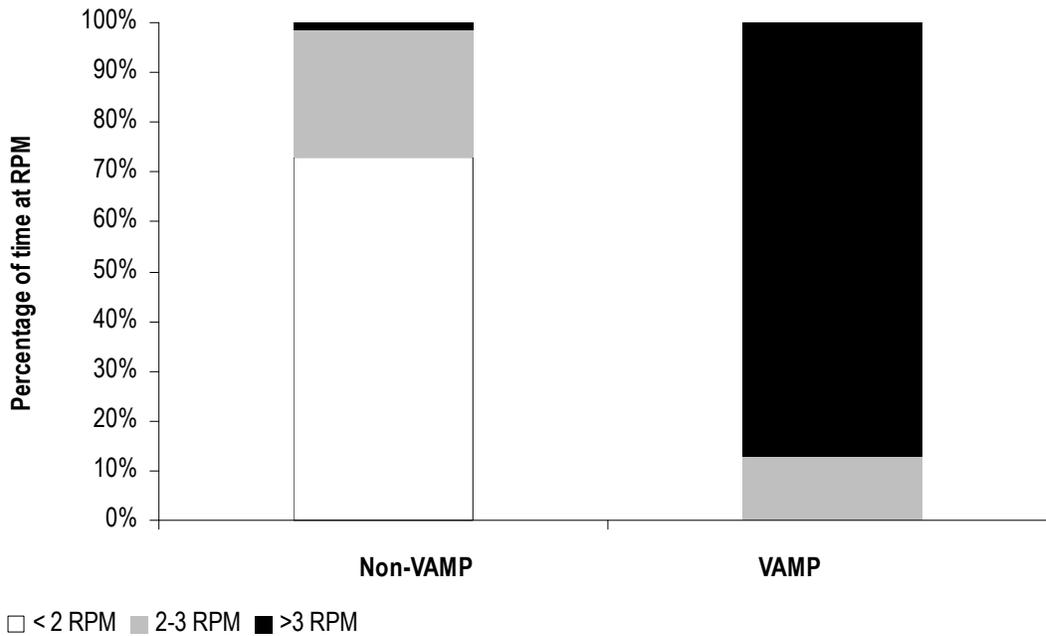


Figure 7. Trap rotations for season during normal flow and VAMP (April 20-May 20) supplemental flow.

## 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, twenty fish were caught. On April 25, we captured 77 natural fish. This was the first of three catch peaks (Figure 8). 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 8 and Figure 9). Fork lengths ranged from 55 to 120 mm (Figure 10 and Figure 11).

Table 4. Natural Chinook salmon catch by life stage.

Life Stage	Count
Yearling	1
Smolt	187
Parr	2
Fry	0
Total	193

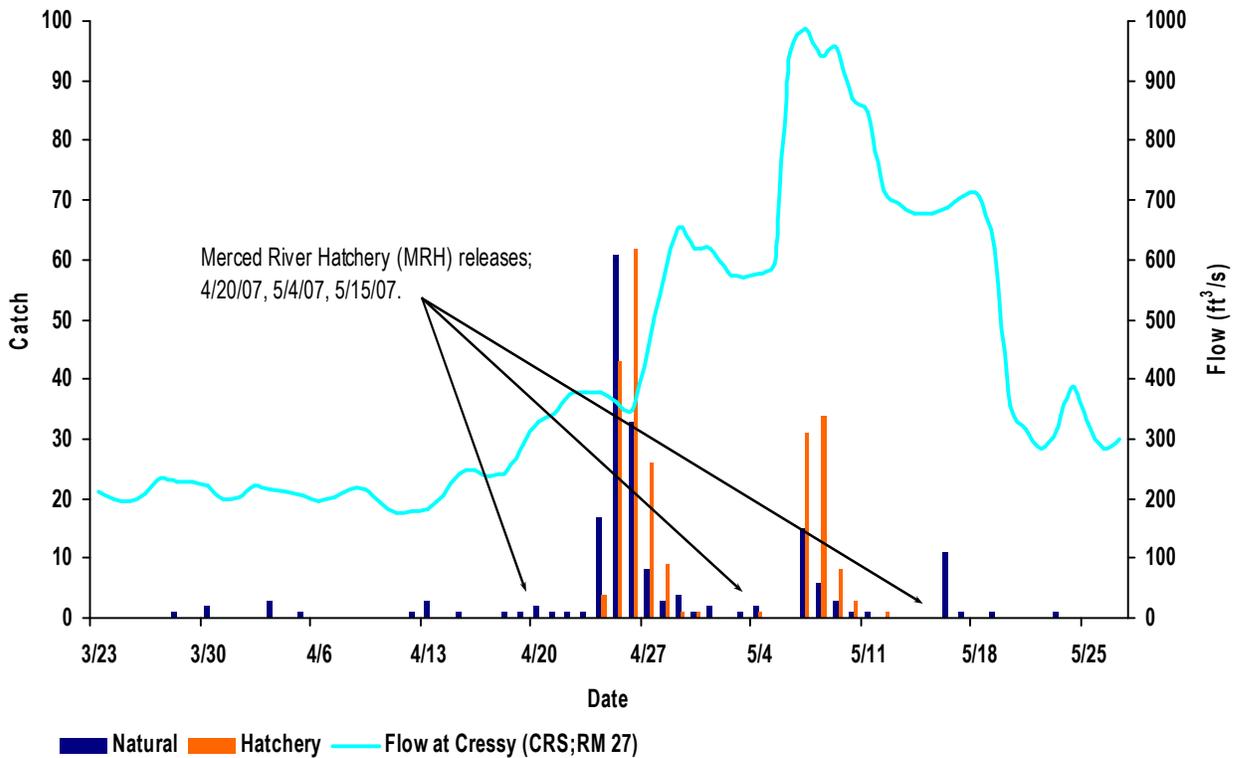


Figure 8. Natural and hatchery catch by date with flow plotted in the foreground.

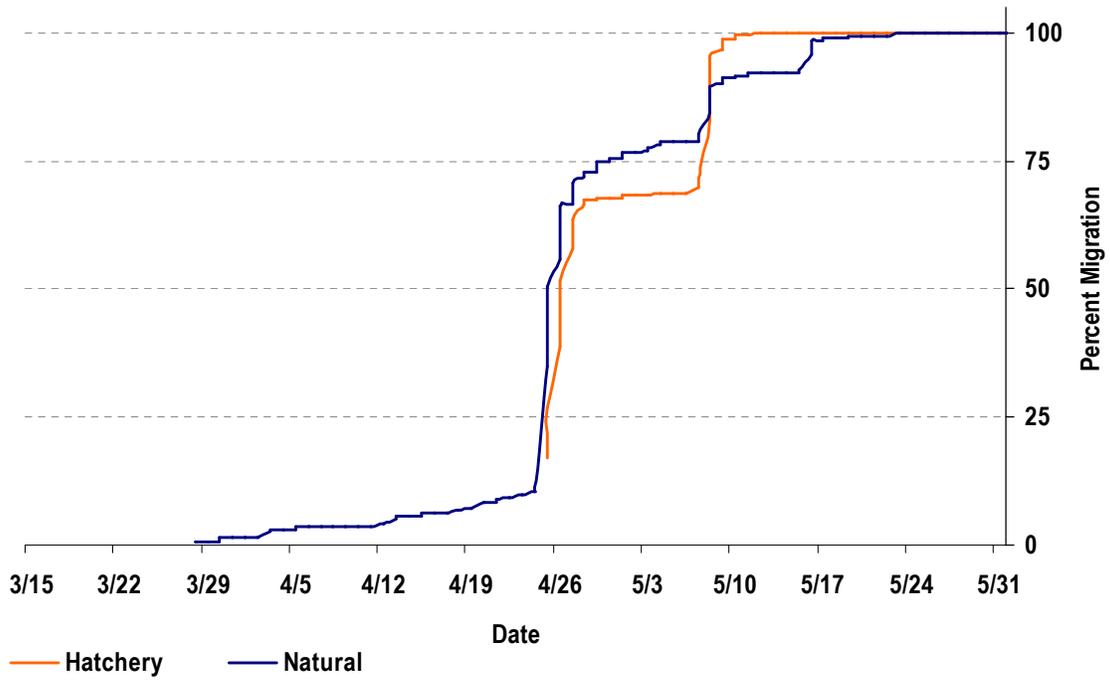


Figure 9. Graph showing percent of total out-migration for natural and hatchery Chinook salmon by date.

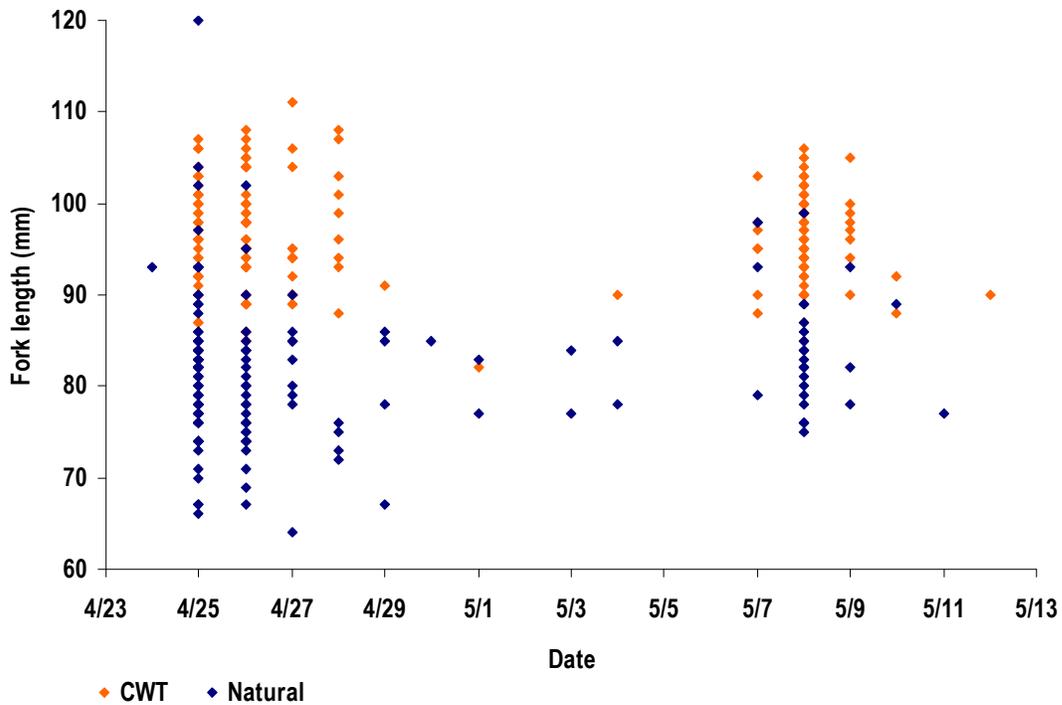


Figure 10. Fork lengths of natural versus hatchery Chinook salmon on days of overlapping catch.

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

Group	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

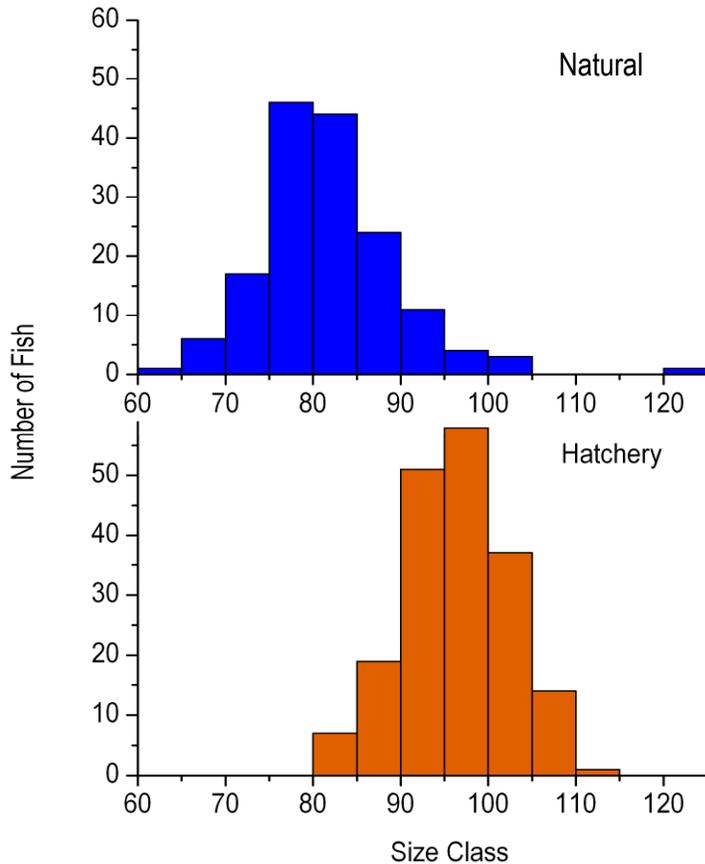


Figure 11. Fork length (mm) frequency for natural and hatchery catch.

### 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 8). 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 9). Fork lengths ranged from 82 to 111 mm (Figure 10 and Figure 11). Mean FLs for hatchery fish were significantly larger than those for natural fish (ANOVA:  $F = 376.0$ ,  $P < 0.0001$ ).

## Trap Efficiency and Passage Estimates

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	59-98	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 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 for both methods in Figure 12 (average) and Figure 13 (flow). A summary of total passage by each method can be found in Table 8.

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.

Model	Natural				Hatchery			
	Estimate	LCI	UCI	SE	Estimate	LCI	UCI	SE
Average Efficiency	34,141	19,255	56,933	9,141	40,789	23,171	67,532	10,771
Flow	28,889	13,218	51,449	9,122	38,276	18,637	64,330	10,987

**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 (see Figure 8). A summary of daily passage can be found in Figure 12 for this method.

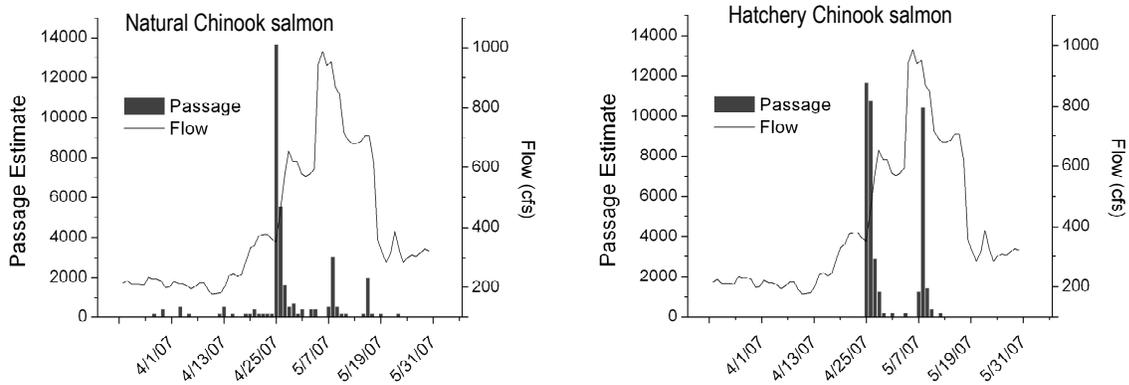


Figure 12. Total daily passage using the average method for natural (left) and hatchery (right) Chinook salmon with flow as measured at Cressy.

**Flow Efficiency Method**

Using the flow 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 (see Figure 8). A summary of daily passage can be found in Figure 13.

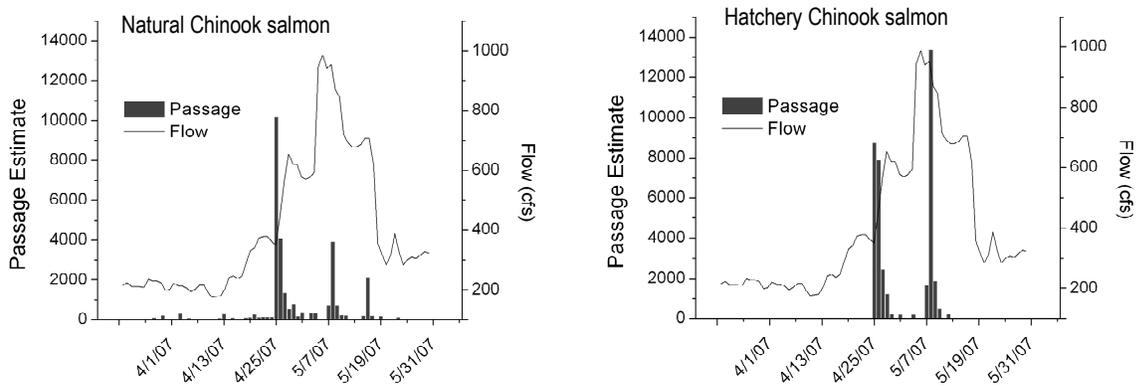


Figure 13. Total daily passage using the flow method for natural (left) and hatchery (right) Chinook salmon with flow as measured at Cressy.

### Non-Target Species

A total of 2,770 incidental fish, composed of 20 different identifiable species, were captured in the traps (Figure 14). 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 15). 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.).

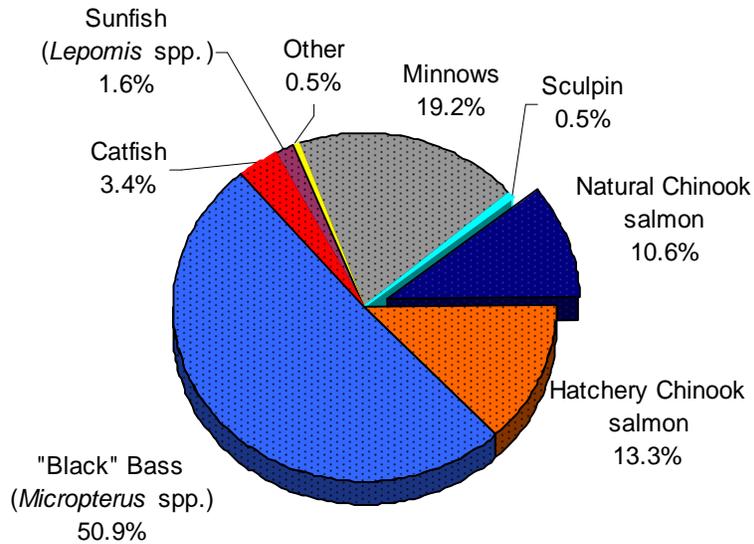


Figure 14. Percent composition of catch of non-target species by common names and Chinook salmon. Note: larval fish were not included.

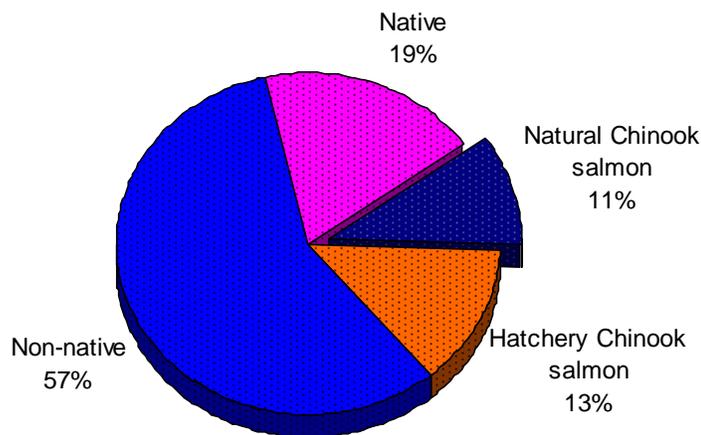


Figure 15. Non-native and native predators versus salmon from the 2007 season. Note: traps select for juvenile fish; 15 of the non-native predators captured were adult-sized.

## 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 could be related to low adult escapement reported during the 2006 fall-run (1,470 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 released fish on two separate occasions, although measures were taken (i.e., releasing in small groups, various locations) to reduce predation. In addition, 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 abundance 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 patterns of 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 (i.e., 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. Trap operations during this pilot year could be improved as low flow resulted in low RPMs and fish for efficiency tests were only available for a short time period. Improvements in trap rotations, passage estimates that include trap rotations, and better availability of hatchery fish for efficiency releases will improve these data in the future. In 2007, our passage estimates were developed using the four efficiency releases and included flow in a regression to determine daily passage. Likely, fish abundances were depressed on the Merced River compared to other tributaries and fry out-migrants were absent; however, with increased trap efficiency in 2008, we aim to provide improved passage estimates.

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, these data will serve to strengthen the validity of management decisions regarding the Merced River.

## Future Work and Recommendations

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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 5 to 6 m 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 calculate water velocity profile; 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 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 “big picture” thinking, critically needed if we are to address the problems of the future.

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