Outmigrant Trapping of Juvenile Salmon in the Lower Tuolumne River, 2013

Submitted To:
Turlock Irrigation District
Modesto Irrigation District

Prepared By:
Chrissy L. Sonke

FISHBIO
1617 S. Yosemite Ave.
Oakdale, CA 95361
209.847.6300
www.fishbio.com

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INTRODUCTION

Study Area Description

The Tuolumne River is the largest of three major tributaries (Tuolumne, Merced, and Stanislaus Rivers) to the San Joaquin River. The Tuolumne River originates in Yosemite National Park, in the central Sierra Nevada Mountains, and flows west between the Merced River to the south and the Stanislaus River to the north (Figure 1). The San Joaquin River itself flows north and joins the Sacramento River in the Sacramento-San Joaquin Delta within California's Central Valley. The Tuolumne River is dammed at several locations for the purposes of power generation, water storage, and flood control – the largest impoundment is Don Pedro Reservoir.

The lower Tuolumne River corridor extends from the confluence with the San Joaquin River to La Grange Dam at river mile (RM) 52.2. The La Grange Dam site has been the upstream limit for anadromous fish migration since at least 1871.

Purpose and History of Study

Rotary screw traps (RST) have been operated since 1995 at various locations in the Tuolumne River during the winter/spring period. RST monitoring was intended to meet several objectives including estimating abundance and migration characteristics of juvenile salmonids and other fishes, and evaluating reach survival relative to environmental conditions (Figure 1). The Turlock Irrigation District and Modesto Irrigation District ('Districts'), and the City and County of San Francisco have funded the majority of the RST monitoring efforts in the Tuolumne River.

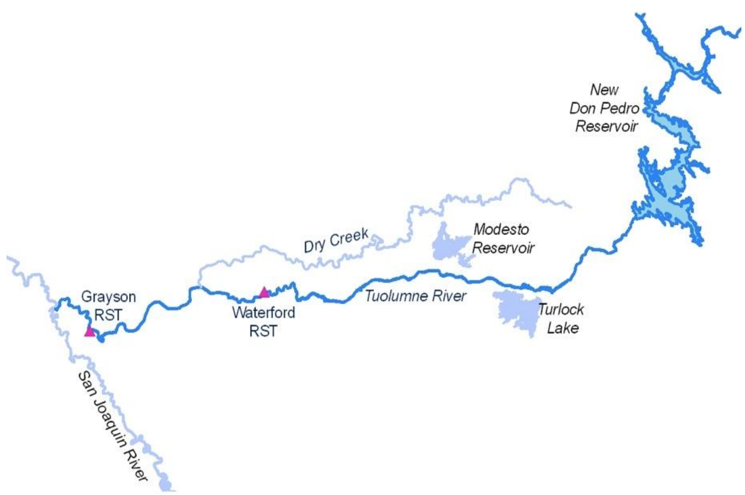

Figure 1. Location map of study area on the Tuolumne River.

Current sampling locations are Grayson River Ranch (Grayson – RM 5.2) near the mouth of the Tuolumne River and a site downstream of the City of Waterford (RM 29.8). Rotary screw trapping has been conducted annually near the mouth of the Tuolumne River since 1995 (Shiloh from 1995-1998; and Grayson from 1999-2013). Since 2006, sampling has also been conducted annually near Waterford, approximately 25 miles upstream of the Grayson site, to provide comparative information on the size, migration timing, and production of juvenile fall-run Chinook salmon, as well as data on other fishes.

Table 1. Rotary screw trap monitoring in the Lower Tuolumne River, 1995-2013.

Year	*Site*	*Period Sampled*	*Proportion of Outmigration Period Sampled*	*Total Catch*	*Total Estimated Passage*	*Results Reported In*
1995	Shiloh (RM 3.4)	Apr 25-Jun 01	24%	141	15,667[1]	Heyne and Loudermilk 1997
1996	Shiloh	Apr 18 - May 29	27%	610	40,385[1]	
1997	Shiloh	Apr 18 - May 24	24%	57	2,850[1]	Heyne and Loudermilk 1998
1998	Turlock Lake State Rec. (RM 42.0)	Feb 11-Apr 13	41%	7,125	259,581[1]	Vick and others 1998
	7/11 (RM 38.5)	Apr 15-May 31	31%	2,413		
	Charles Road (RM 25.0)	Mar 27-Jun 01	43%	981	66,848[1]	
	Shiloh	Feb 15-Jul 01	70%	2,546	1,615,673[1]	Blakeman 2004a
1999	7/11	Jan 19-May 17	79%	80,792	1,737,052[1]	Vick and others 2000
	Hughson (RM 23.7)	Apr 08-May 24	31%	449	7,175[1]	
	Grayson (RM 5.2)	Jan 12-Jun 06	93%	19,327	869,636[2]	Vasques and Kundargi 2001
2000	7/11	Jan 10-Feb 27	32%	61,196	298,755[1]	Hume and others 2001
	Deardorff (RM 35.5)	Apr 09-May 25	31%	634	15,845[1]	
	Hughson	Apr 09-May 25	31%	264	2,942[1]	
	Grayson	Jan 09-Jun 12	95%	2,250	107,617[2]	Vasques and Kundargi 2001
2001	Grayson	Jan 03-May 29	97%	6,478	106,580[2]	Vasques and Kundargi 2002
2002	Grayson	Jan 15-Jun 06	91%	436	13,928[2]	Blakeman 2004b
2003	Grayson	Apr 01-Jun 06	40%	359	9,074[2]	Blakeman 2004c
2004	Grayson	Apr 01-Jun 09	40%	509	17,600[2]	Fuller 2005

[1] Passage estimate reported in the annual report cited.
[2] Passage estimate derived from multiple regression equation based on data collected from 1999-2006 and 2008.

Year	*Site*	*Period Sampled*	*Proportion of Outmigration Period Sampled*	*Total Catch*	*Total Estimated Passage*	*Results Reported In*
2005	Grayson	Apr 02-Jun 17	39%	1,317	254,981[2]	Fuller and others 2006
2006	Waterford 1 (RM 29.8)	Jan 25-Apr 12	79%	8,648	364,494[3]	Fuller and others 2007
	Waterford 2 (RM 33.5)	Apr 21-Jun 21		458	134,872[3]	
	Grayson	Jan 25-Jun 22	84%	1,594	84,987[3]	
2007	Waterford (RM 29.8)	Jan 11-Jun 05	93%	3,312	52,841[3]	Fuller 2008
	Grayson	Mar 23-May 29	45%	27	952[3]	
2008	Waterford	Jan 8-Jun 2	96%	3,350	49,527[3]	Palmer and Sonke 2008
	Grayson	Jan 29-Jun 4	82%	193	3,020[3]	
2009	Waterford	Jan 7- Jun 9	96%	3,725	54,517[3]	Palmer and Sonke 2010
	Grayson	Jan 8-Jun 11	95%	155	4,072[3]	
2010	Waterford	Jan 5-Jun 11	97%	2,281	74,520[3]	Sonke and others 2010
	Grayson	Jan 6-Jun 17	97%	52	2,056[3]	
2011	Waterford	Dec 5-Jun 30	100%	4,394	365,904[3]	Sonke and others 2012
	Grayson	Jan 6-Jun 30	97%	1,645	95,156[3]	
2012	Waterford	Jan 3-Jun 15	99%	3,696	62,076[3]	Sonke and others 2013
	Grayson	Jan 3-Jun 15	99%	85	2,268[3]	
2013	Waterford	Jan 2-May 31	99.3%	3,103	40,387[3]	This report
	Grayson	Jan 3-May 23	93.3%	35	642[3]	

[3] Estimates derived using a linear regression model reported in Robichaud and English 2013.

METHODS

Juvenile Outmigrant Monitoring

Sampling Gear and Trapping Site Locations

Rotary screw traps (E.G. Solutions, Eugene, OR) were installed and operated at the Waterford and Grayson sites. The traps consist of a funnel-shaped core suspended between two pontoons. Traps are positioned in the current so that water enters the 8 ft wide funnel mouth and strikes the internal screw core, causing the funnel to rotate. As the funnel rotates, fish are trapped in pockets of water and moved rearward into a livebox where they remain until they are processed by technicians.

The single Waterford trap was located at RM 29.8, approximately two miles downstream of the Hickman Bridge. The trap was held in place by a 3/8-inch overhead cable strung between two large trees located on opposite banks. Cables fastened to the front of each pontoon were attached to the overhead cable. For public safety reasons, warning signs, flashing safety lights and buoys marked the location of the trap and cables. Sufficient velocity at the trap during 2010-2013 precluded the need for the “weir” structure used to increase catch efficiency during 2008 and a portion of 2009.

At Grayson two traps were fastened together in a side-by-side configuration, with ½ inch Ultra High Molecular Weight (UHMW) plastic strips that were bolted to each inner-pontoon at the cross-bars. The traps were positioned and secured in place by two 50 lb plow-style anchors (Delta Fast-Set model, Lewmar, Havant, UK). The anchors were fastened to the outer-pontoons of the traps using 3/8-inch stainless steel leader cables (each outer-pontoon was attached to a separate in-line anchor) and the length of each leader cable was adjusted using a manual winch that was bolted to the outer-pontoon. The downstream force of the water on the traps kept the leader cables taut. The “weir” structure used to increase catch efficiency during the 2008, 2009, and 2012 season was installed on February 13, 2013, and remained in place for the remainder of the season.

Trap Monitoring

Sampling at Waterford began on January 2, 2013. The trap was operated continuously (24 hours per day, 7 days per week) until May 31, 2013, when sampling was terminated due to low catch.

Sampling at Grayson began on January 3, 2013. The traps were operated continuously (24 hours per day, 7 days per week) until sampling was terminated on May 23, 2013 due to low catch.

Traps at both locations were checked at least every morning throughout the sampling period, with additional trap checks conducted as conditions required. During each trap check, the contents of the liveboxes were removed, all fish were identified and enumerated, and any marked fish were noted. In addition, random samples of fish were collected to assess size and growth rate. At each RST, up to 50 Chinook salmon and 20 individuals of each non-salmon species were randomly collected during each morning check, and up to 20 Chinook salmon and 10 individuals of each non-salmon species were collected during each evening check. These fish were anesthetized with Tricaine-S, measured (fork length in millimeters), and recorded. Chinook salmon were assigned to a lifestage category based on a fork length scale, where <50 mm = fry, 50-69 mm = parr, and $\geq$ 70 mm = smolt. In addition, the smolting appearance of all measured Chinook salmon and *O. mykiss* was rated based on a seven category scale, where 1 = yolk-sac fry, 2 = fry, 3 = parr, 4 = silvery parr, 5 = smolt, 6 = mature adult, and IAD = immature adult (Interagency Ecological Program, unpublished). Weights (to nearest tenth of a gram) were taken from up to 50 Chinook salmon each week (i.e., Monday through Sunday) and from all *O. mykiss* using a digital balance (Ohaus Corporation, Pine Brook, NJ). Fish were weighed in a small, plastic container partially filled with stream water, which was tared prior to measuring each individual fish. Fish were then placed in a bucket with freshwater and allowed to recover before release.

Daily salmon catch was equivalent to the number of salmon captured during a morning trap check, plus the number of salmon captured during any trap check(s) that occurred within the period after the previous morning check. For example, the daily salmon catch for April 10 is the sum of salmon from the morning trap check on April 10 and the evening trap check conducted on April 9. Separate daily catch data was maintained for marked (i.e., dye inoculated fish used for trap efficiency tests) and unmarked Chinook salmon.

After all fish were measured and recorded, the traps were cleaned to prevent accumulation of debris that might impair trap rotation or cause fish mortality within the liveboxes. Trap cleaning included removal of debris from all trap surfaces and from within the liveboxes. The amount of debris load in the livebox was estimated and recorded whenever a trap was checked.

Trap Efficiency Releases

Trap efficiency releases using naturally produced juvenile salmon were conducted to estimate the probability of capturing Chinook salmon at the Waterford trap. Juvenile salmon captured in the trap were used to conduct releases whenever catches were sufficient. Twelve groups of naturally produced juvenile salmon (ranging in number from 34 to 144 fish) were marked and released at RM 30 (approximately 0.2 miles upstream of the Waterford trap) between January 13 and March 4 to estimate trap efficiency at the Waterford trap. Catches of naturally produced juvenile salmon at Waterford after March 4 were insufficient for trap efficiency releases. Likewise, catches of natural fish throughout the study period were insufficient for trap efficiency releases to be conducted at Grayson. Hatchery produced fish were not available for releases during 2013.

Marking Procedure

At the Waterford trapping site, naturally produced juvenile salmon were marked onshore immediately adjacent to the trap, and were then transported to the release site where they were held until release. A photonic marking system was used for marking all of the release groups because of the high quality of marks and the ability to use the marking equipment in rapid succession. All fish were anesthetized with Tricaine-S before the appropriate mark was applied. A marker tip was placed against the caudal fin and orange photonic dye was injected into the fin rays. The photonic dye (DayGlo Color Corporation, Cleveland, OH) was chosen because of its known ability to provide a highly visible, long-lasting mark.

Holding Facility and Transport Method

Juvenile salmon were transported from the marking sites to the release sites in either 5-gallon buckets or 20-gallon insulated coolers depending on the number of fish, temperature, and distance traveled.

At the release sites, fish were held in livecars constructed of 15” diameter PVC pipe cut into 34” lengths (Figure 2). A rectangle approximately 6” wide by 23” long was cut longitudinally along the pipe and fitted with aluminum or stainless steel mesh. Livecars were tethered to vegetation or other structures and kept in areas of low water velocity to reduce fish stress.

Figure 2. Livecar used for holding trap efficiency test fish.

Pre-release Sampling

Prior to release, marked fish were sampled for length and mark retention. Fifty fish (or the entire release group if fewer than 50 fish) were randomly selected from each release group, anesthetized, and examined for marks; the remaining fish in each group were enumerated. Mark retention was rated as present or absent. A total of zero fish in 2013 were found to have lost their marks upon examination. Consequently, all fish released were presumed to have visible marks.

Release Procedure

All marked fish were released after nightfall. Livecars were located several feet away from the specific release point, and fish were poured from the live cars into buckets for release. Fish were released by placing a dip net into the bucket, scooping up a "net-full" of fish, and then emptying the fish into the river and allowing them to swim away. After releasing a "net-full" of fish, approximately 30 seconds to 3 minutes time elapsed before another "net-full" was released. The amount of time between “net-full” releases varied depending on how fast fish swam away after they were released. Depending on the group size, total release time for marked groups ranged from eight minutes to 30 minutes.

Monitoring Environmental Factors

Flow Measurements and Trap Speed

Provisional daily average flow for the Tuolumne River at La Grange was obtained from USGS, as downloaded from http://waterdata.usgs.gov. Provisional daily average flow for the Tuolumne River at Modesto was obtained from the USGS, as downloaded from http://waterdata.usgs.gov. The Modesto flow station is below Dry Creek, the largest seasonal tributary entering the river downstream of La Grange Dam. As a result, that site includes flow associated with major winter runoff events. Two methods were used to measure the velocity of water entering the traps. First, instantaneous measurements were taken daily with a Global Flow Probe (Global Water, Fair Oaks, CA). Second, an average daily trap rotation speed was calculated for each trap, by recording the time (measured in seconds) for three continuous revolutions of the cone, once before, and once after, the morning trap cleaning. The average of the two times was considered the average daily trap rotation speed.

River Temperature, Relative Turbidity, and Dissolved Oxygen

Instantaneous water temperature was measured daily with a mercury thermometer at the trap site. Temperature data was also available from hourly recording thermographs maintained by the Districts at both trapping sites. To measure daily instantaneous turbidity, a water sample was collected each morning and later tested at the field station using a LaMotte turbidity meter (Model 2020e, LaMotte Company, Chestertown, MD). Turbidity was recorded in nephelometric turbidity units (NTU). Instantaneous dissolved oxygen was measured during each trap check with an ExStik® II D600 Dissolved Oxygen Meter (Extech Instruments Corporation, Waltham, MA) at the trapping sites and recorded in milligrams per liter (mg/L).

Estimating Chinook Salmon Abundance

The number of fish passing each site each day was estimated using either a linear regression model (Waterford and Grayson 2006-2013), or multiple regression model (Grayson 1999-2005). Annual abundance estimates at each trapping location are presented in Table 1.

Linear regression model

Trap efficiency data collected at Waterford (2006-2013) and Grayson (1999-2013) was used to create a linear regression model in order to predict daily Chinook abundance at each trapping location. Abundance estimates were calculated for Waterford and Grayson using methods described in Robichaud and English (2013). Below is a brief summary of calculations used to estimate abundance.

For each trap efficiency release, the mean fish fork length at release and recapture were calculated. For each release (i) at each trap (t), the percent of flow sampled (Φ_{ti}) was calculated as the ratio of flow through the RST ($F_{RST_{ti}}$) to that of whole-river flow ($F_{RIVER_{ti}}$):

$$(\Phi_{ti}) = F_{RST_{ti}} / F_{RIVER_{ti}} \qquad \text{(Eq. 1)}$$

Flow through each RST was calculated by multiplying the water velocity at the RST by the surface area of the trap. Trap efficiency (i.e., catchability) was calculated as the proportion of the total adjusted number of individuals released that were recaptured. The mean length at release was used to statistically separate the releases by life-history stage. Thus, trap efficiencies were calculated for fry (mean length at release < 50 mm), parr (50 mm ≥ fork length < 69 mm) and smolts (≥ 70 mm).

For each life stage (s) at each trap (t), if sample-size sufficed, catchability (C_{tsi}) was regressed against percent of flow sampled (Φ_{ti}) during trap efficiency release i. Linear regression was used to estimate the slope of the line (m_{ts}), with the intercept forced through 0, as

$$C_{tsi} = (m_{ts} \cdot \Phi_{ti}) \qquad \text{(Eq. 2)}$$

Daily counts of fry, parr, and smolts were summed at each trapping location for all days the traps were sampled each year. The percent of the flow sampled was estimated for each day at each trap as described above. Missing velocity observations were interpolated from adjacent values (except during a short period in 2007 and two long data gaps in 2010; linear regressions were performed on the available 2007 and 2010 data to estimate missing velocity values from flow). Instantaneous measurements of turbidity were also recorded daily at the traps, and daily average water temperatures were obtained from hourly recording thermographs deployed at or near each trap site.

To account for varying catchability, a four-stage process was used to estimate total fish passage (N) from catch numbers, as follows. First, proportional catch contributions (ρ_{jw}) were calculated for the three life stages for each week (w) as:

$$\rho_{tsw} = \frac{A_{tsw}}{\sum_s^3 A_{tsw}} \quad \text{(Eq. 3)}$$

Where

$$A_{tsw} = \frac{\sum_d^7 O_{tswd}}{\left(m_{ts} \cdot \frac{\sum_d^7 \Phi_{twd}}{7}\right)} \quad \text{(Eq. 4)}$$

and where O_{tswd} was the observed catch of life stage s at trap t on day d in week w, and Φ_{twd} was the percent flow sampled by trap t on day d in week w. Average catchability was then calculated for each day at each trap, weighted by the proportional life-stage-specific catch contributions, as:

$$\overline{C_{twd}} = \sum_s^3 \left[\rho_{tsw} \cdot (m_{ts} \cdot \Phi_{td}) \right] \quad \text{(Eq. 5)}$$

Third, daily total Chinook salmon passage was calculated by dividing total observed catch (of all life stages combined) by the weighted average catchability:

$$N_{twd} = \frac{\sum_s^3 O_{tswd}}{\overline{C_{twd}}} \quad \text{(Eq. 6)}$$

Lastly, the daily total Chinook salmon passage was partitioned into the three life stages, based on the proportional catch rates from Equation 3:

$$N_{tswd} = N_{twd} \cdot \rho_{tsw} \quad \text{(Eq. 7)}$$

If total fish passage on a given day was below the level of measurement error (i.e., the inverse of catchability for that day), this method produced passage estimates of zero fish.

Multiple Regression Model

Juvenile salmon abundance at Grayson prior to 2006 was estimated using a multiple regression equation developed from trap efficiency data collected from 1999 through 2008 and 2011. Specifically, average daily river flow at Modesto, average fish size at release, and proportions of fish (natural log transformed) recovered from each release event, were used in order to develop the following trap efficiency predictor equation (adjusted R^2 =0.62):

> Daily Predicted Trap Efficiency= EXP(-0.479988+(-0.00043*flow at MOD)+(-0.03153* fish size))

Where flow at MOD= daily average river flow (cfs) at Modesto and fish size= daily average fork length (mm) of fish captured at Grayson
These daily predicted trap efficiencies (DPTE) were then applied to the daily catch (DC) to estimate daily passage as follows:

Estimated Daily Passage= DC/DPTE

RESULTS AND DISCUSSION

Chinook Salmon

Number of Unmarked Chinook Salmon Captured

The fall-run juvenile salmon outmigration in the San Joaquin Basin typically occurs during the winter and spring, extending primarily from January through May. The outmigration consists primarily of fry in winter (typically <50 mm fork length), and smolts in spring (typically >69 mm fork length). It is not uncommon to observe some larger fish migrating in winter and some fry migrating in late spring. These fish may be the progeny of individuals that spawned outside the reproductive period typical of fall-run Chinook salmon.

During 2013, daily catches of juvenile salmon at Waterford ranged from zero to 158 fish (Figure 3), with a total catch of 3,103 salmon (Table 2). Catches of juvenile Chinook salmon at Waterford were highest from mid-January to mid-March (peaking on February 25), and primarily consisted of fry (<50 mm; Figure 3) Daily salmon catch during this period was variable and did not correlate with trends in flow or turbidity which were both low and realtively stable (Figure 3). During late-April catches increased in response to brief pulse flow spikes of approximately 600 cfs and 800 cfs.

At Grayson, daily catches of juvenile salmon ranged from zero to 9 fish (Figure 4), with a total catch of 35 juvenile salmon captured (Table 2). Nearly all (94%) juvenile salmon captured at Grayson during 2013 were smolts, and were captured during the pulse flow period between mid-April and early May.

Table 2. Catch by lifestage at Waterford and Grayson, 2013.

Trapping Site	*Fry (<50 mm)*	*Parr (50-69 mm)*	*Smolt (≥ 70 mm)*
Waterford	2,230	305	568
Grayson	1	1	33

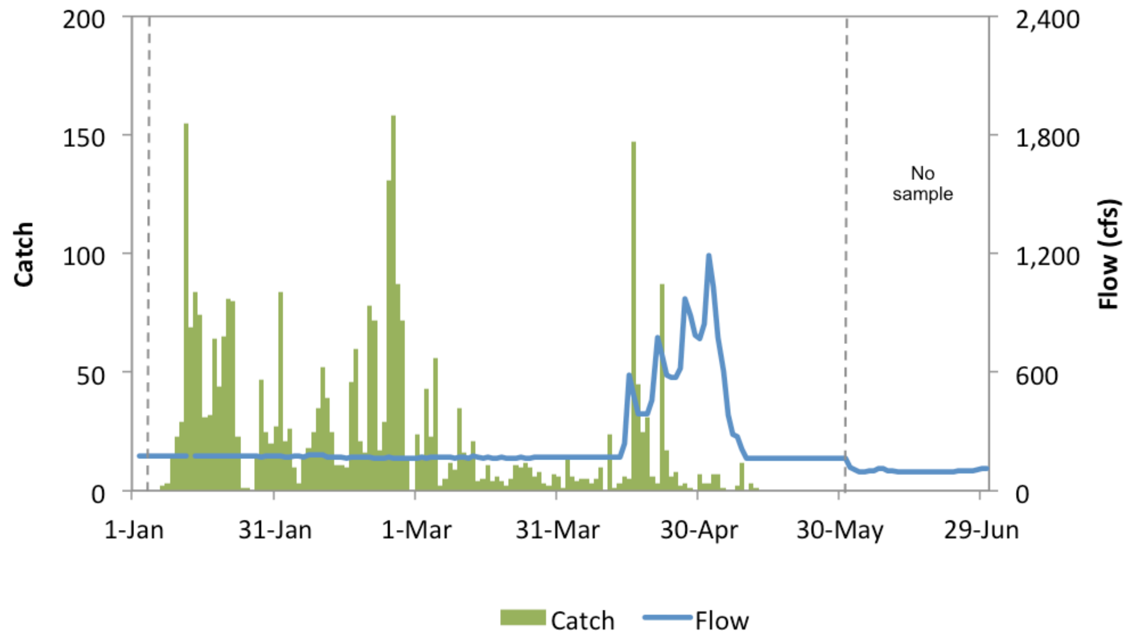

Figure 3. Daily catch of unmarked Chinook salmon at Waterford and river flow at La Grange (LGN) during 2013.

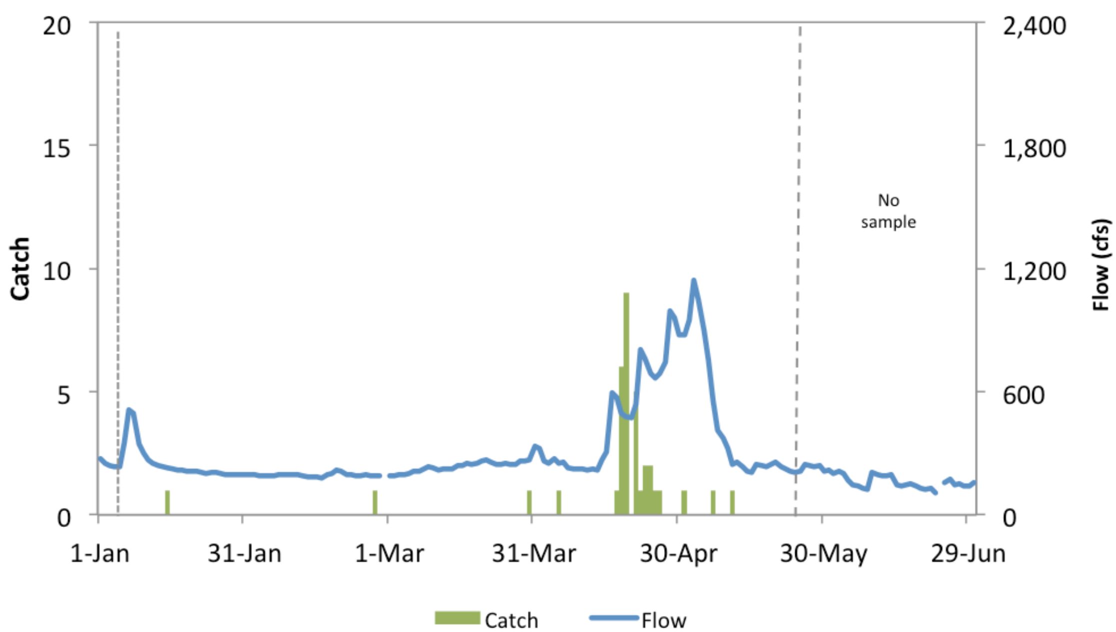

Figure 4. Daily catch of unmarked Chinook salmon at Grayson and river flow at Modesto (MOD) during 2013.

Trap Efficiency Releases

Twelve trap efficiency releases were conducted during 2013 at Waterford using naturally produced salmon fry and parr/smolt at low flows (i.e., less than 1,000 cfs). Resulting efficiency estimates from these releases ranged from 1.9% to 22.2% at flows (La Grange) between 166 cfs and 176 cfs (Table 3). Results from trap efficiency releases at Waterford from 2006-2013 were used to derive the linear regression model for predicting Chinook abundance, and the observed efficiencies ranged from 0% to 34.4% at flows (La Grange) between 165 cfs and 8,870 cfs (Table 3; Figure 5).

No trap efficiency tests were conducted at Grayson in 2013. Observed trap efficiency estimates from 1999-2008 and 2011 were used to derive the linear regression model for predicting daily Chinook abundance, and the observed efficiencies ranged from zero to 21.2% at flows (Modesto) between 280 cfs and 7,942 cfs (Figure 6).

Daily catch, predicted catchability, and estimated passage at Waterford and Grayson during 2013 are provided in Appendices A and B, respectively.

Table 3. Trap efficiency results from 2013 used to update the linear regression model at Waterford.

Release Date	Origin	Mark	Adjusted # Released	Number Recaptured	% Recaptured	Length at Release (mm)	Length at Recap. (mm)	Flow (cfs) LGN
1/13/13	WILD	CFO	144	32	22.2%	34.6	34.7	176
1/14/13	WILD	CFO	68	9	13.2%	35.0	35.7	176
1/21/13	WILD	CFO	63	6	9.5%	35.7	35.2	174
1/22/13	WILD	CFO	74	5	6.8%	36.3	35.8	175
2/2/13	WILD	CFO	83	8	9.6%	36.3	37.6	172
2/11/13	WILD	CFO	47	3	6.4%	37.7	37.3	173
2/12/13	WILD	CFO	34	7	20.6%	36.9	36.7	173
2/18/13	WILD	CFO	54	1	1.9%	38.0	37.0	169
2/21/13	WILD	CFO	69	5	7.2%	37.2	37.0	167
2/25/13	WILD	CFO	126	19	15.1%	44.6	46.4	167
2/26/13	WILD	CFO	117	10	8.5%	37.3	37.3	166
3/4/13	WILD	CFO	38	2	5.3%	41.2	47.5	168

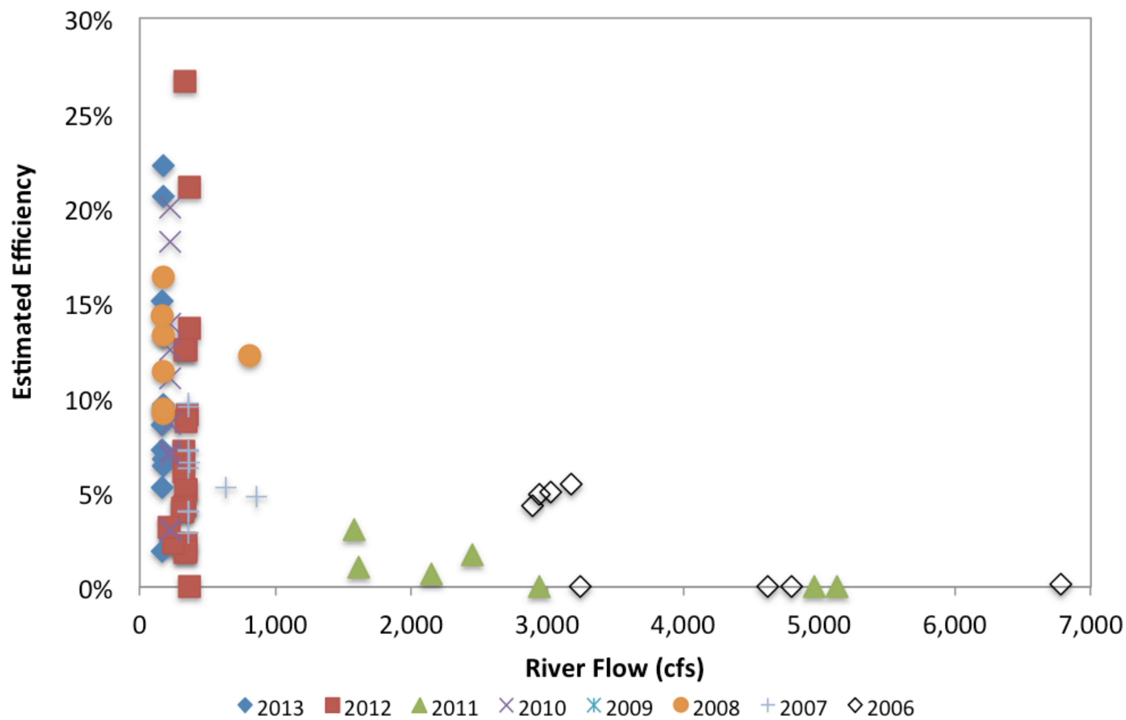

Figure 5. Trap efficiency estimates at Waterford relative to river flow at La Grange (LGN) during 2006-2013.

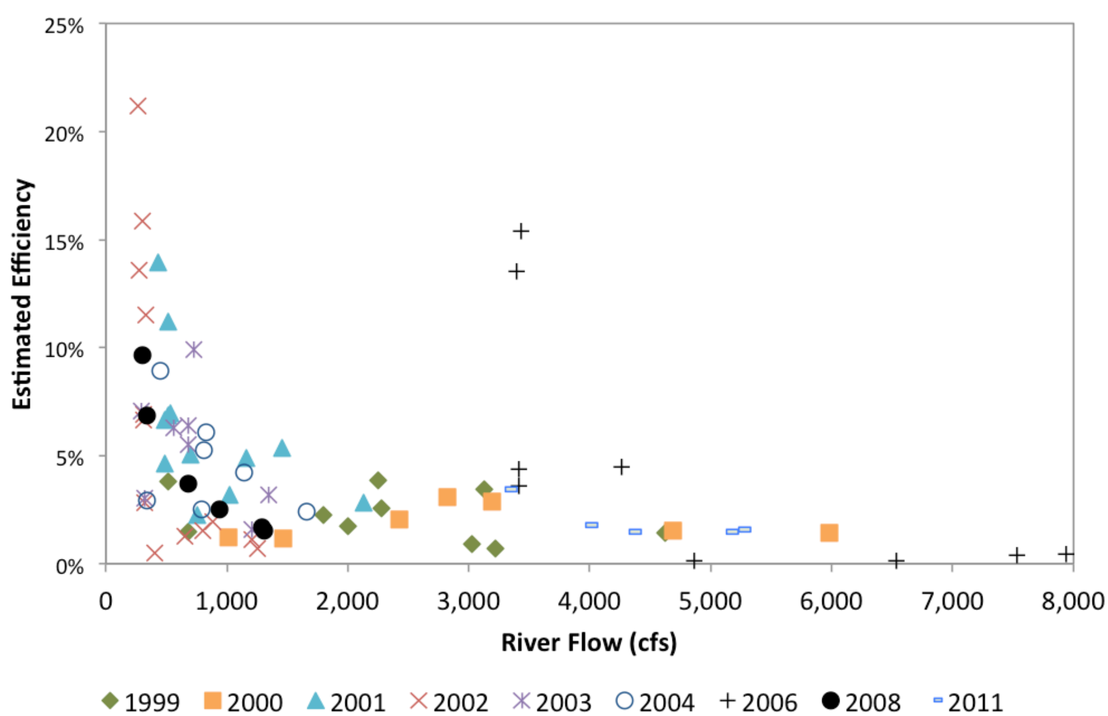

Figure 6. Trap efficiency observations at Grayson relative to river flow at Modesto (MOD), 1999-2008 and 2011.

Estimated Chinook Salmon Abundance

Based on daily passage estimates, an estimated 40,387 Chinook salmon passed Waterford during 2013, of which 42.4% were smolts (Table 4). In 2013, as in previous years, a majority of the salmon observed passing Waterford prior to mid-March were fry; passage was then dominated by smolts from late-March through June (Table 4; Figure 7). The peak in daily passage for fry occurred on January 16, and smolt passage peaked on April 16 (Figure 7). Daily estimated Chinook salmon passage at Waterford ranged from 0 to 4,020. In previous years sampled at Waterford (i.e., 2006-2013), total estimated passage ranged from as high as 499,366 in 2006, to as low as 40,387 in 2013 (Figure 8). The proportion of passage as smolts ranged from 20.7% in 2011 to 84.4% in 2010 (Table 4). In 2006, sampling efforts were affected by high spring flows resulting in passage estimates that were likely underestimated (particularly for smolts).

An estimated 642 unmarked Chinook salmon passed Grayson during 2013 and of these, 1.0% were fry, 1.0% were parr, and 98.0% were smolts (Table 4). Daily estimated passage at Grayson ranged from 0 to 144 salmon. Peak daily passage for smolts occurred on April 17 (Figure 9). During comparable seasonal sampling in previous years at Grayson (i.e., winter/spring sampling in 1999-2002, 2006, and 2008-2013), total estimated passage ranged from a high of 869,636 in 1999 to a low of 642 in 2013 (Table 1; Figure 10). The proportion of passage as smolts was the highest in 2013 (98.0%) and the lowest in 1999 (2.9%). In spring-only sampling years at Grayson/Shiloh (i.e., 2003-2005 and 2007 at Grayson and 1995-1997 at Shiloh), total estimated passage ranged from a high of 254,539 in 2005 to a low of 952 in 2007 (Table 1; Figure 10). The majority of migrants in all spring-only years were smolts (≥95.0%; Table 4). Among all years, estimated passage was the highest during 1998 (Table 1; Figure 10), when sampling effort was intermediate, and the proportion passing as smolts was low (5.7%). However, the 1998 passage estimate of 1,615,673 fish may be inflated and the proportion passing as smolts may be underestimated because no trap efficiency tests were conducted with fry. In 1998, estimates for trap efficiency only existed for smolts, which were subsequently applied to other life stages. The use of smolt-specific (low) capture probability to extrapolate on fry captures may result in drastic overestimation of fish passage.

Juvenile Chinook salmon sampled in the 2013 RST operation were the progeny of an estimated 2,120 adult Chinook salmon (806 females) that spawned in the fall of 2012 (Wright et al. 2013). During the 2012-13 spawning season, approximately 50 juveniles were produced per female spawner, based on the estimated 806 female spawners, and the total estimated passage at the Waterford trap. This is low compared to 1,118 juveniles per female in 2011, 857 juveniles per female in 2010, 257 in 2009, 619 in 2008, and 635 in 2007 (Table 5). However, this estimate is similar to 2012 when each spawner produced an estimated 87 juveniles. Approximately 60% of the female Chinook salmon observed at the Tuolumne River weir in 2013 were less than 700 mm, indicating they were most likely two-year old fish (Wright et al 2013). The young age and smaller size of the returning females may explain the low female spawner to juvenile ratio observed in 2013.

Table 4. Estimated passage by lifestage at Waterford and Grayson during 1995-2013.

		Sampling Period	Fry		Parr		Smolts		Total
			Number	%	Number	%	Number	%	
Waterford	2006	w/s	323,170	64.7%	16,261	3.3%	159,934	32.0%	499,366
	2007	w/s	12,375	23.4%	4,993	9.4%	35,472	67.1%	52,840
	2008	w/s	17,806	36.0%	1,921	3.2%	29,800	60.2%	49,527
	2009	w/s	17,492	32.1%	7,306	13.4%	29,719	54.5%	54,517
	2010	w/s	10,595	14.2%	1,049	1.4%	62,876	84.4%	74,520
	2011	w/s	284,444	77.7%	5,689	1.6%	75,771	20.7%	365,904
	2012	w/s	29,907	48.2%	7,568	12.2%	24,601	39.6%	62,076
	2013	w/s	21,312	52.8%	1,971	4.9%	17,105	42.4%	40,387
Grayson	1995	spring	-	-	-	-	22,067	100%	22,067
	1996	spring	-	-	-	-	16,533	100%	16,533
	1997	spring	-	-	-	-	1,280	100%	1,280
	1998	intermediate	1,196,625	74.1%	327,422	20.3%	91,626	5.7%	1,615,673
	1999	w/s	830,064	95.4%	14,379	1.7%	25,193	2.9%	869,636
	2000	w/s	55,309	51.4%	21,396	19.9%	30,912	28.7%	107,617
	2001	w/s	65,845	61.8%	26,620	25.0%	14,115	13.2%	106,580
	2002	w/s	75	0.5%	5,705	41.0%	8,147	58.5%	13,928
	2003	spring	26	0.3%	128	1.4%	8,920	98.3%	9,074
	2004	spring	155	0.9%	727	4.1%	16,718	95.0%	17,600
	2005	spring	-	-	442	0.2%	254,539	99.8%	254,981
	2006	w/s	47,688	56.1%	2,420	2.8%	34,879	41.0%	84,987
	2007	spring	-	-	-	-	952	100%	952
	2008	w/s	1,251	41.4%	25	0.8%	1,744	57.7%	3,020
	2009	w/s	57	1.4%	138	3.4%	3,877	95.2%	4,072
	2010	w/s	92	4.5%	0	0.0%	1,964	95.5%	2,056
	2011	w/s	71,071	74.7%	2,130	2.2%	21,955	23.1%	95,156
	2012	w/s	72	3.2%	10	0.5%	2,186	96.4%	2,268
	2013	w/s	6	1.0%	7	1.0%	629	98.0%	642

Table 5. Estimated number of juvenile salmon at Waterford produced per female spawner, 2006-2013.

Outmigration Year	Females[4]	Juveniles/female spawner
2006	478	1,045
2007	282	179
2008	80	619
2009	212	257
2010	87	857
2011	326	1,118
2012	712	87
2013	806	50

[4] Based on estimated abundance and gender ratios from carcass surveys during 2005-2008 (Blakeman 2006-2008; O'brien 2009), and number of female Chinook salmon observed (excluding salmon of undetermined gender) at the Tuolumne River weir during 2009-2012 (Wright et al 2013; Cuthbert et al 2012; Becker et al 2011; Cuthbert et al 2010).

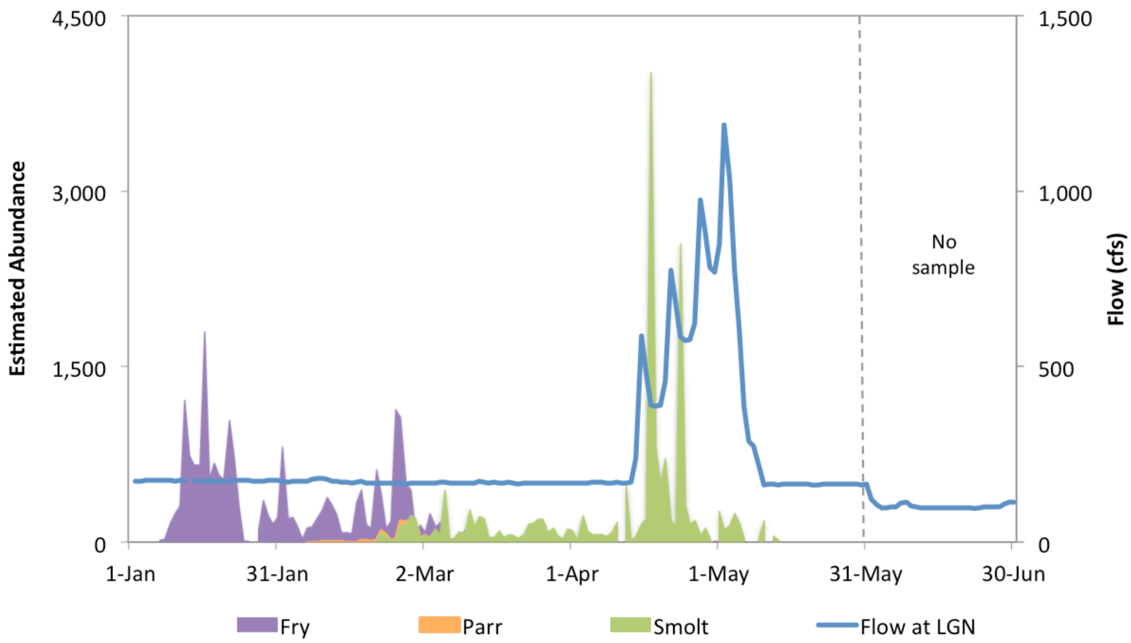

Figure 7. Juvenile salmon passage by lifestage at Waterford during 2013.

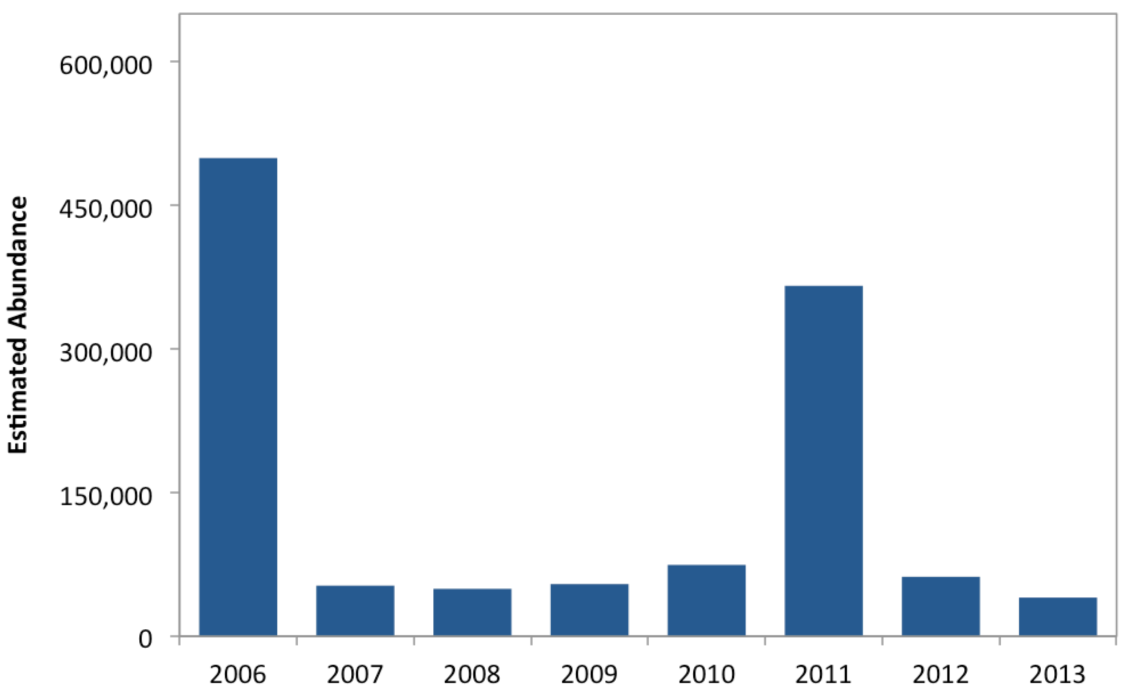

Figure 8. Total estimated Chinook passage at Waterford, 2006-2013.

Estimated Chinook Salmon Abundance and Environmental Factors

Discharge in the Tuolumne River, downstream of La Grange Dam, was approximately 170 cfs during January through mid-April. During this time there were no obvious correlations between peaks in salmon passage and changes in flow, rainfall, or turbidity at Waterford. River flow near Grayson during this period was slightly more variable as a result of storm run-off early in the season, particularly from Dry Creek, and ranged from 181 cfs to 510 cfs at Modesto. The few passages at Grayson during this time occurred concurrent to or shortly after brief and relatively low magnitude run-off events.

Between April 15 and May 9 there was a series of four short pulse flows designed by the U.S. Fish and Wildlife Service (USFWS) to mimic the natural run-off pattern in the Tuolumne River prior to impoundment. Peaks in flow during the spring pulse period ranged from 588 cfs on 15 April to 1,190 cfs on 2 May. Following the pulse period, flows decreased to approximately 100 cfs by early June. Peaks in smolt migration activity were observed at both the Waterford and Grayson traps in response to the spring pulse flows (Figure 7 and Figure 9).

During 2013 monitoring, daily average water temperatures ranged from 44.5°F to 74.0°F at the Waterford trap (Figure 11) and from 44.3°F to 76.6°F at the Grayson traps (Figure 12). Water temperatures generally increased throughout the outmigration season. There were no obvious correlations between trends in fry passage and water temperature during 2013 (Figure 11), but smolt passage appeared to peak with slight fluctuations in temperature at both traps during the spring (Figure 11 and Figure 12).

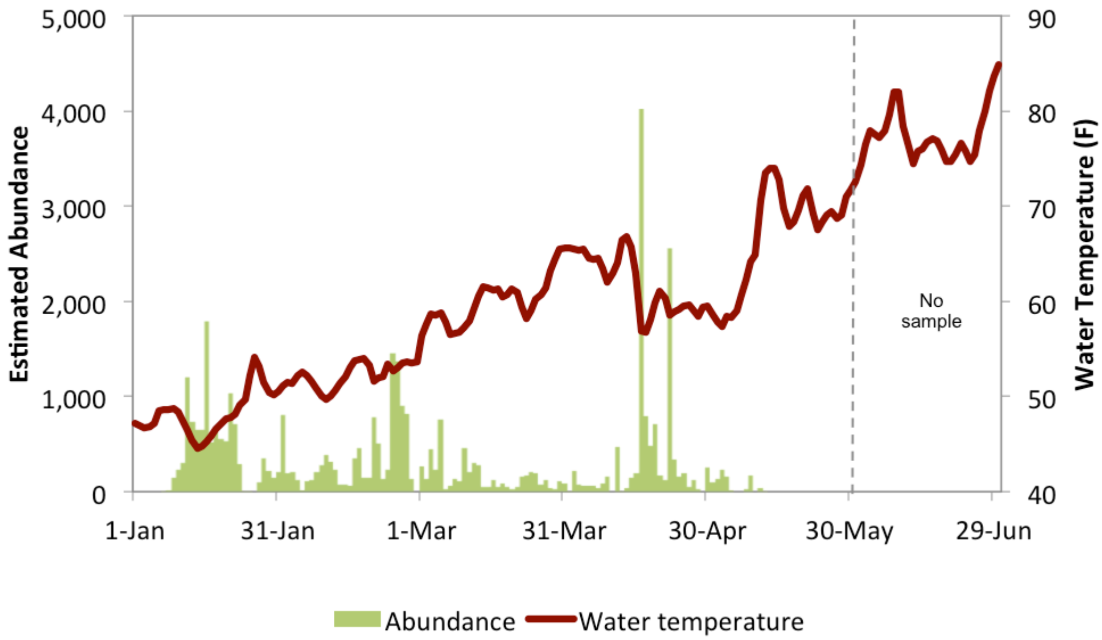

Figure 11. Daily estimated passage of unmarked Chinook salmon and daily average water temperature at the Waterford trap during 2013.

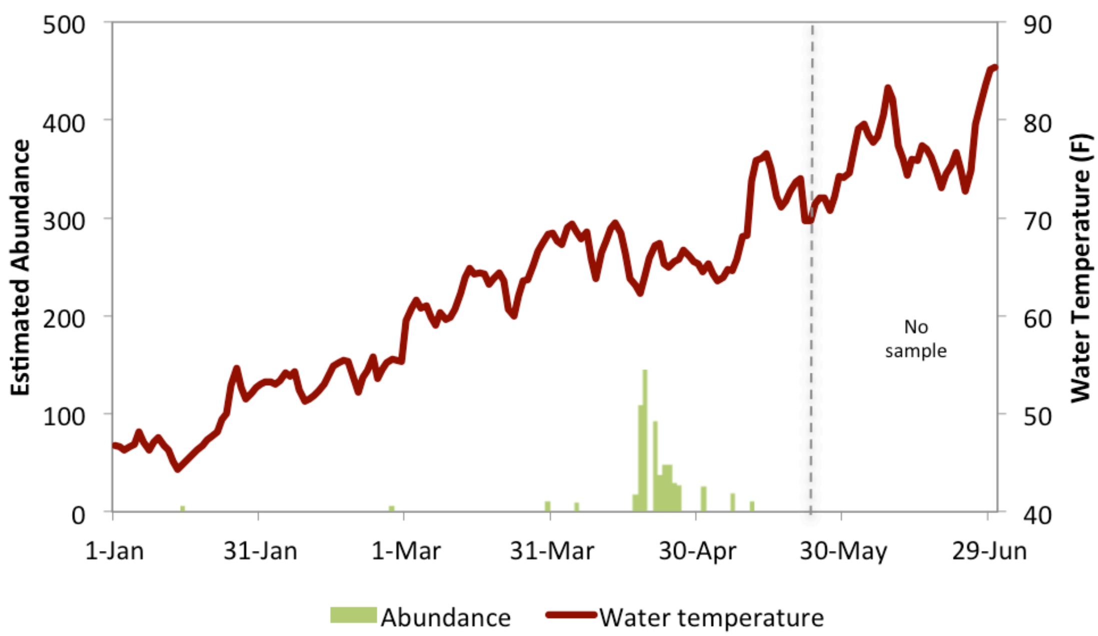

Figure 12. Daily estimated passage of unmarked Chinook salmon and daily average water temperature at the Grayson trap during 2013.

Background turbidity was generally less than 4.5 NTU at Waterford (Figure 13) and less than 10 NTU at Grayson (Figure 14) during the 2013 monitoring period. During a run-off event in early January (Figure 15) turbidity increased to as much as 6.8 NTU at Waterford and 33.7 NTU (Figure 14). There was no apparent increase in juvenile migration activity at either site in relation to this run-off event and increased turbidity.

The ratio of estimated total passage at Grayson relative to the estimated total passage at Waterford provides an index of annual juvenile survival through the river between the sites (24.6 miles) during years when the majority of the outmigration period is sampled at both sites (2008-2013). Total juvenile survival indices have ranged from a high of 26% in 2011 to a low of 1.6% in 2013, and with the exception of 2011 have been lower than 8% (Table 6). During 2011, when heavy run-off and flood control releases resulted in flows approaching 7,500 cfs at Modesto, approximately 78% of juveniles passed Waterford as fry (Table 4) and an estimated 25% of the fry passing Waterford survived to pass Grayson (Table 6). In contrast, both the proportion of juveniles migrating as fry and the proportion of fry surviving to Grayson were substantially lower in years without flood control releases, with 14-53% (Table 4) migrating as fry and generally less than 1% estimated to have survived to Grayson (Table 6). Estimated fry survival was 7% in 2008 (Table 6), and a key difference between this year and other years without flood control releases was the occurrence of five run-off events from Dry Creek resulting in peak flows ranging from approximately 750 cfs to 1,700 cfs as measured at Modesto.

Using relative passage of Chinook salmon smolts, survival indices ranged from a high of 29% in 2011 to a low of 3.1% in 2010, and the smolt survival index for 2013 was 3.7% (Table 6). Spring pulse flows, designed to stimulate salmon migration and improve juvenile survival out of the lower river, occur annually. In some years, such as 2011, spring flows are driven by flood control operations. With the exception of 2011, peak spring pulse flows measured at La Grange have ranged from approximately 900 cfs in 2007 to approximately 3,200 cfs in 2010 with no clear correlation between total smolt survival indices and peak pulse flow magnitudes (Table 6).

Analyses of event-specific smolt survival indices calculated from relative passage between Waterford and Grayson during discrete flow periods found positive relationships between survival and river flow measured at La Grange (Robichaud and English 2013). Further, abundance of smolts, duration of the pulse flow, and turbidity also appear to explain variations in the calculated survival indices. In 2012, a pulse flow of 2,100 cfs for approximately one week resulted in the highest smolt survival (18.7%) observed during any of the pulses in the 2007-2013 period. A similar, but lower magnitude pulse of approximately 1,000 cfs in 2009 resulted in an estimated smolt survival of 16.2% during the pulse flow event. During 2013, the majority (66%) of smolt migration occurred during a shaped pulse flow event with ascending steps, and approximately 5% of these smolts were estimated to survive to Grayson. Smolt response was highest during the first four days when brief pulses of approximately 600 cfs and 800 cfs occurred, and there was diminishing response to subsequent higher magnitude pulses of 1,000 cfs and 1,200 cfs (Figure 7 and Figure 9). While this design appeared to provide an emigration trigger to smolts in response to the initial flow increase, there are indications that changing the pulse flow shape to provide a larger initial pulse flow peak may provide for greater survival than the ascending design used in 2013. Additional years of monitoring will improve understanding of the influence of flow and other factors on migration timing and success.

Table 6. Survival indices through the lower Tuolumne River between Waterford and Grayson.

Year	Total Survival Index	Fry Survival Index	Peak Fry Flow	Smolt Survival Index	Peak Smolt Flow
2007	-	-	957	2.7	869
2008	6.1	7.0	1,690	5.9	1,310
2009	7.5	0.3	1,300	13.0	955
2010	2.8	0.9	767	3.1	3,300
2011	26.0	25.0	7,490	29.0	8,380
2012	3.7	0.2	599	8.9	2,120
2013	1.6	<0.1	510	3.7	1,190

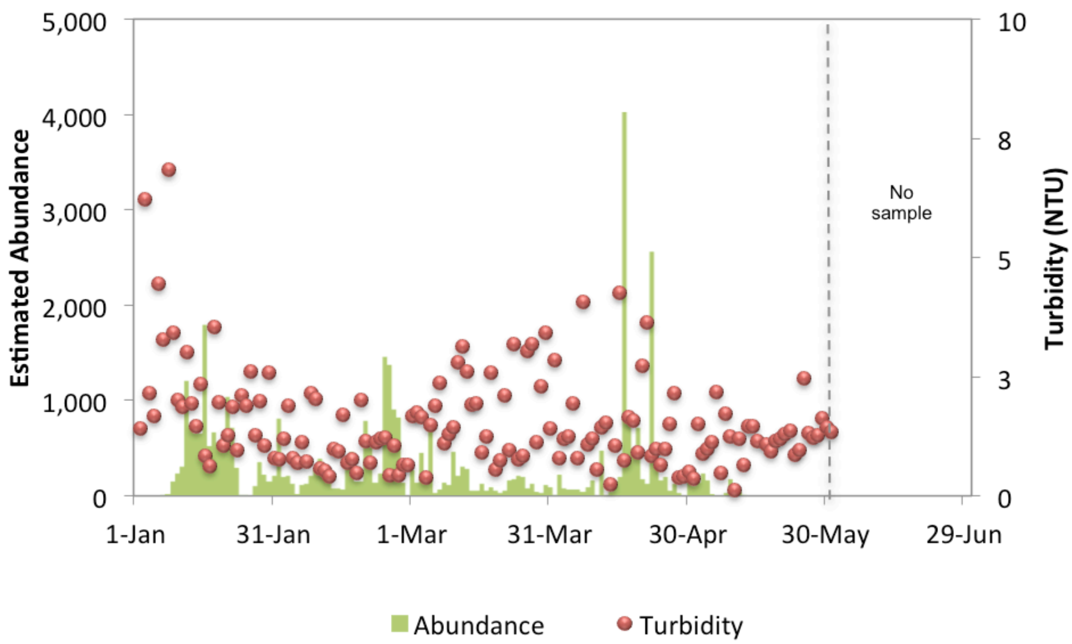

Figure 13. Daily estimated passage of unmarked Chinook salmon and instantaneous turbidity at Waterford during 2013.

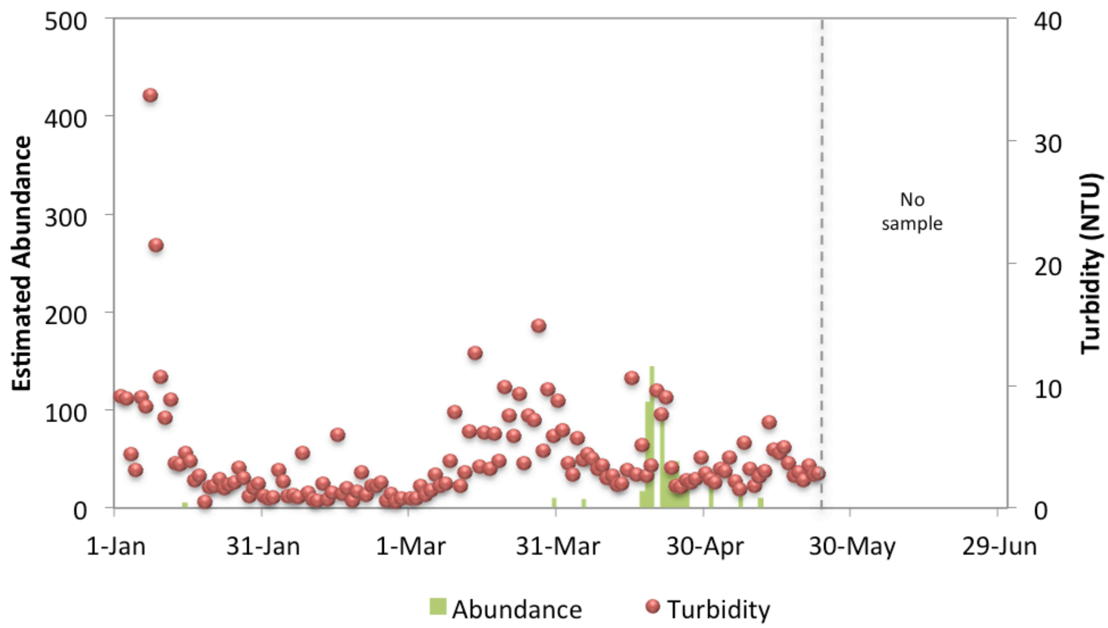

Figure 14. Daily estimated passage of unmarked Chinook salmon and instantaneous turbidity at Grayson during 2013.

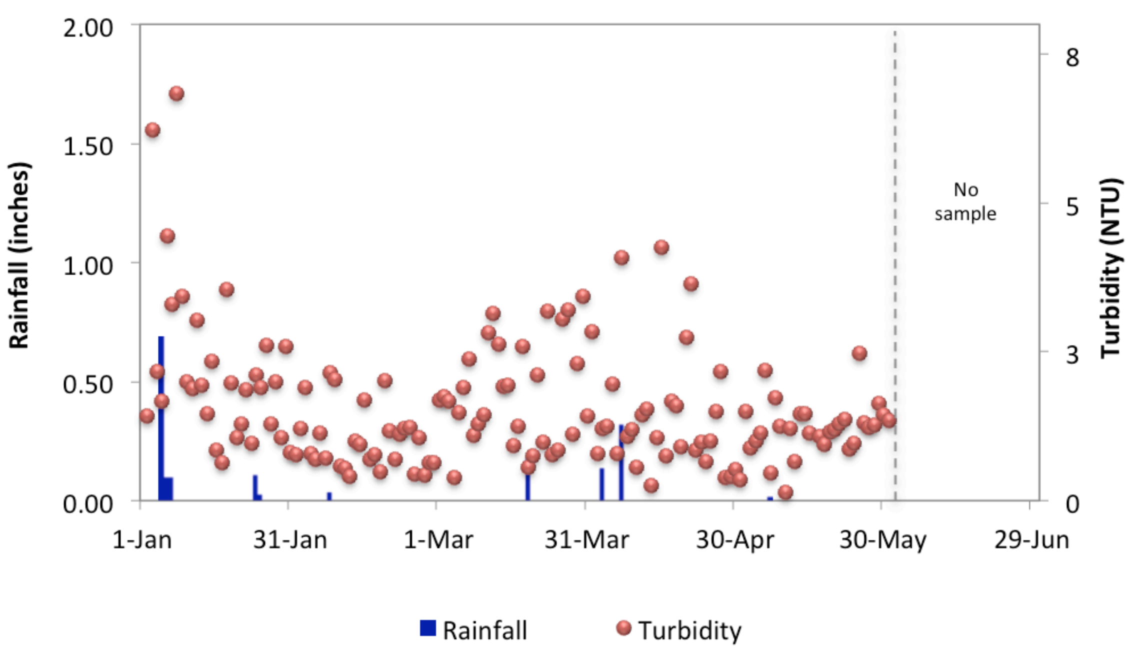

Figure 15. Daily rainfall measured at Don Pedro Reservoir and instantaneous turbidity at Waterford during 2013.

Chinook Salmon Length at Migration

Individual fork lengths of unmarked salmon captured at Waterford during 2013 ranged from 28 mm to 120 mm (Figure 16). Daily average length gradually increased from approximately 34 mm to 100 mm during the course of the sampling period (Figure 17 and Figure 18). Most of the juvenile salmon passing Waterford during 2013 were fry measuring 30-39 mm (Figure 19). In total, it is estimated that 21,312 fry (<50 mm), 1,971 parr (50-69 mm), and 17,105 smolts (>70 mm) passed Waterford during 2013 (Table 4). Individual fork lengths of unmarked Chinook salmon captured at Grayson during 2013 ranged from 30 mm to 99 mm (Figure 20), and daily average length ranged between 30 mm and 99 mm during the sampling period (Figure 18 and Figure 21). Approximately 98% of the salmon estimated to have passed Grayson during 2013 were smolts (Figure 22). In total, it is estimated that 6 fry (<50 mm), 7 parr (50-69 mm), and 629 smolts (>70 mm) passed Grayson during 2013 (Table 4).

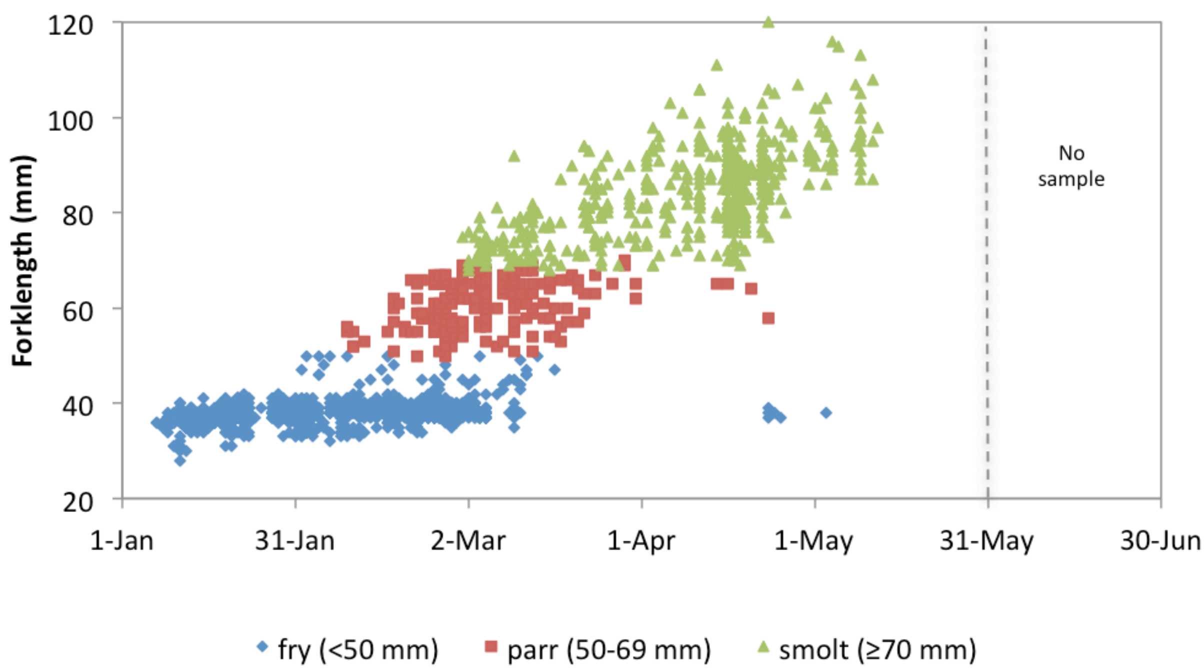

Figure 16. Individual fork lengths of juvenile salmon captured at Waterford during 2013.

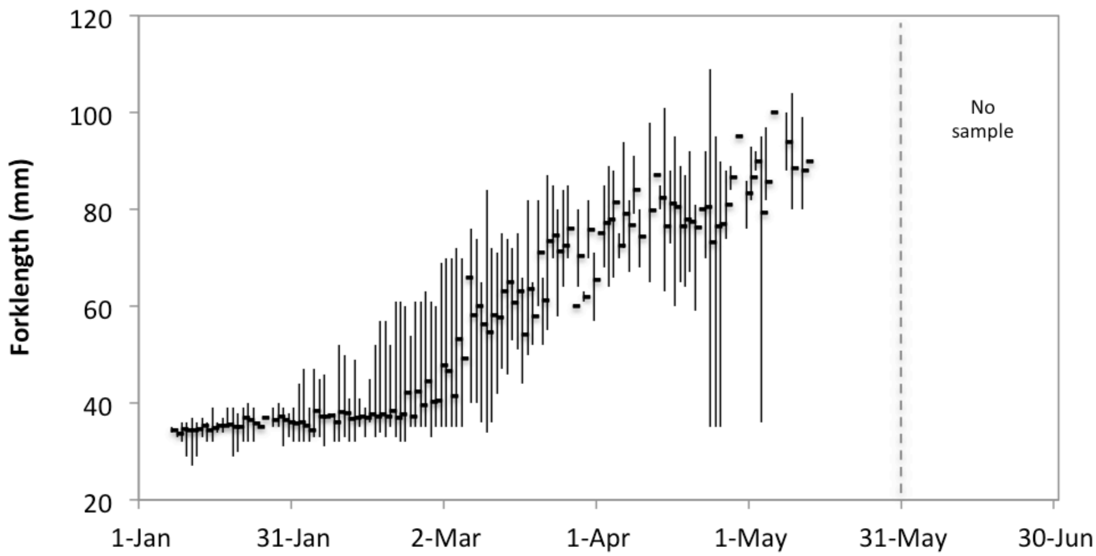

Figure 17. Daily minimum, average, and maximum fork lengths of unmarked Chinook salmon captured at Waterford during 2013.

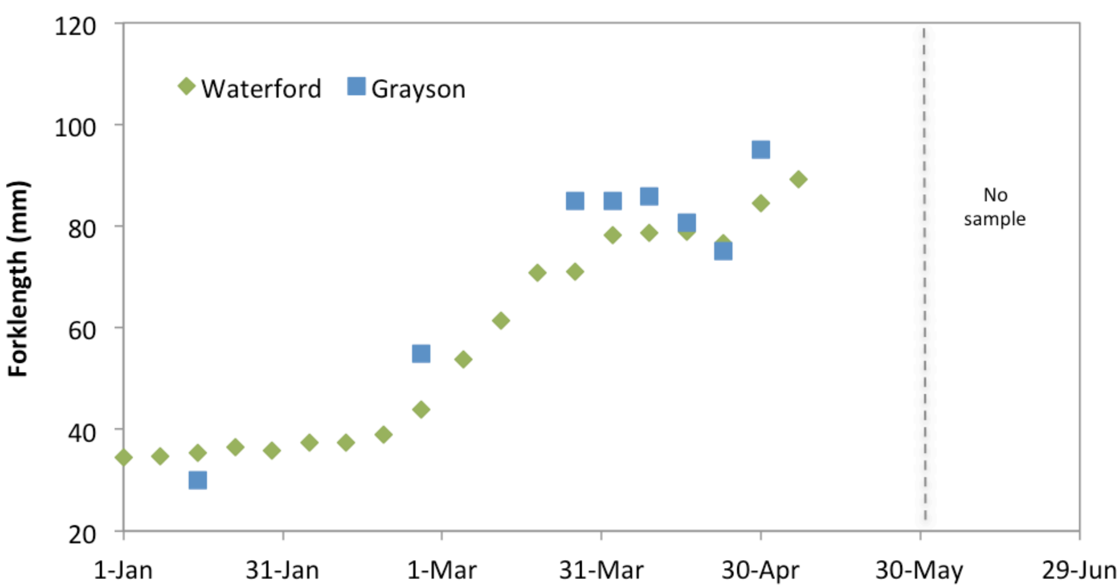

Figure 18. Average fork length of juvenile Chinook salmon captured at Waterford and Grayson by julian week during 2013.

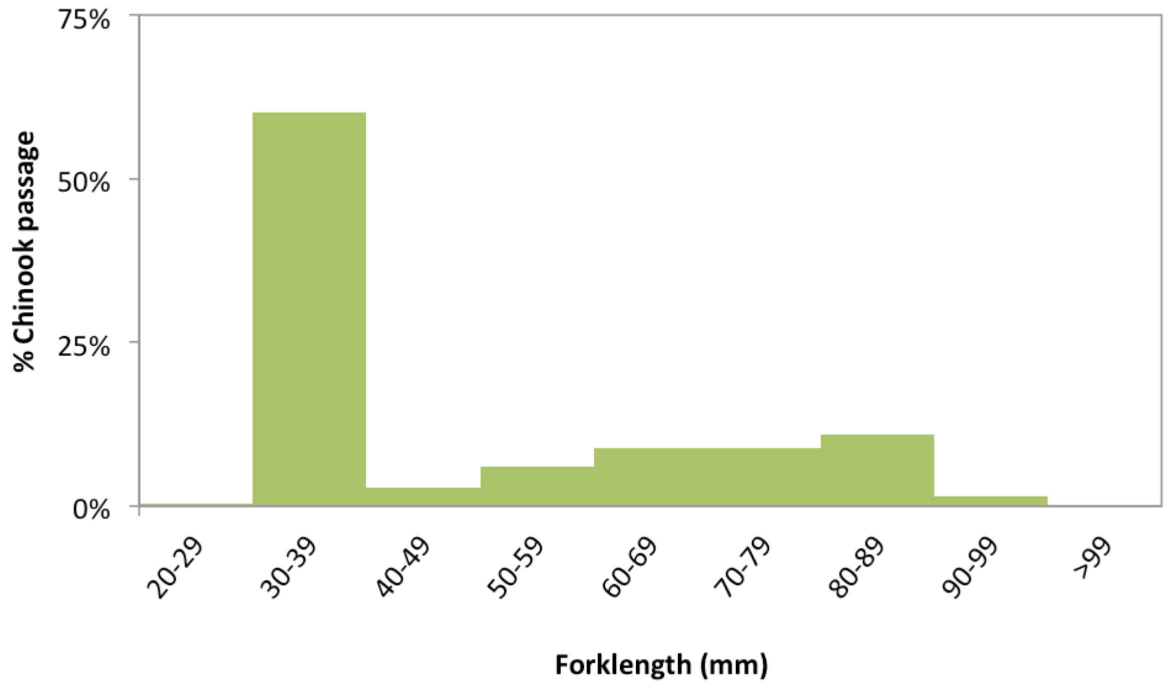

Figure 19. Length-frequency histogram of estimated Chinook passage (10 mm fork length bins) at Waterford during 2013.

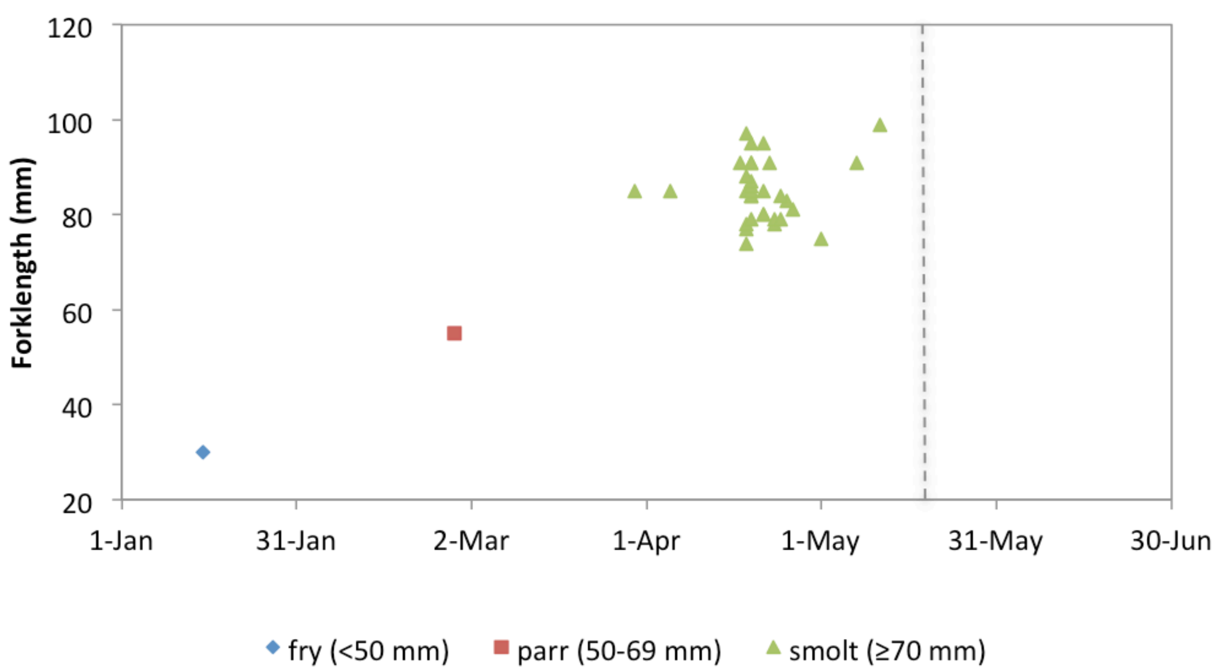

Figure 20. Individual fork lengths of juvenile salmon captured at Grayson during 2013.

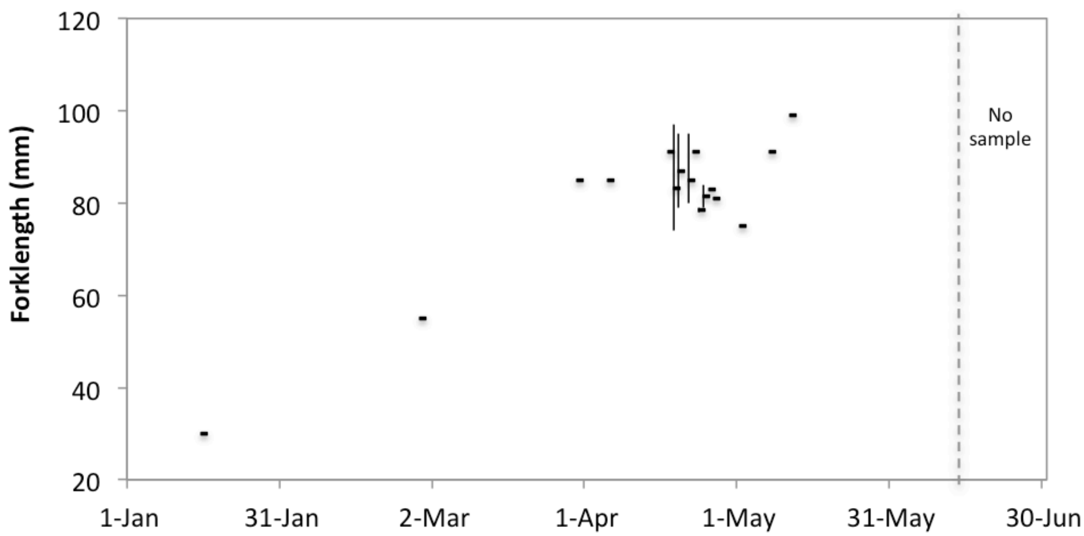

Figure 21. Daily minimum, average, and maximum fork lengths of unmarked Chinook salmon captured at Grayson during 2013.

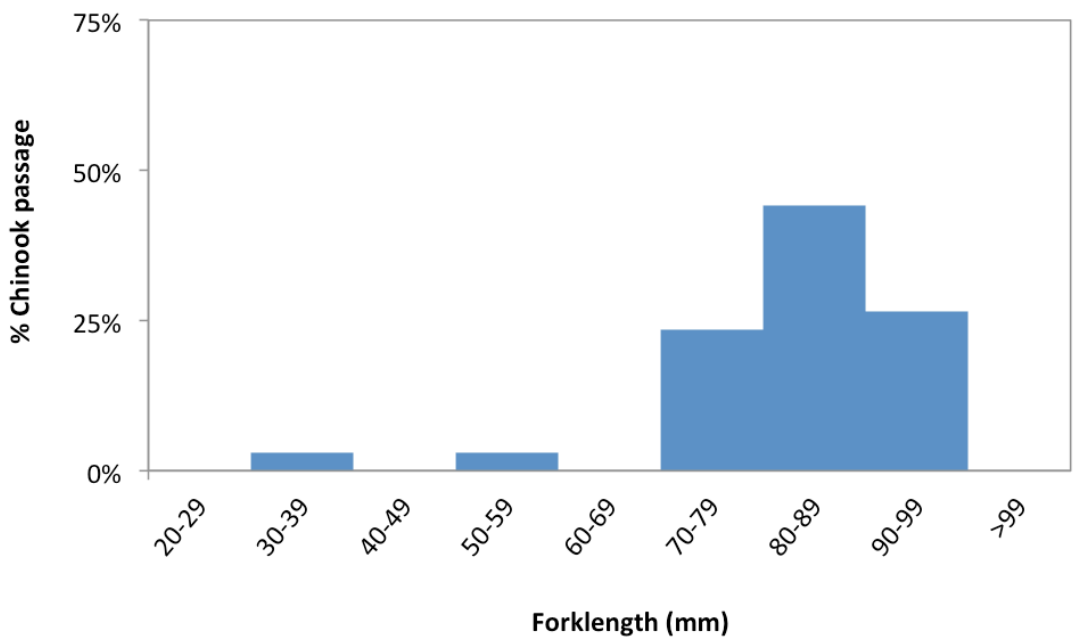

Figure 22. Length-frequency histogram of estimated Chinook passage (10 mm fork length bins) at Grayson during 2013.

Chinook Salmon Condition at Migration

Juvenile salmon captured at both Waterford and Grayson during 2013 appeared healthy without visually discernible signs of disease or stress. Salmon smolts collected in the RSTs during March and April 2013 were sampled by the USFWS National Wild Fish Health Survey (NWFHS) to monitor health and physiology changes that may affect smolt survival (Nichols 2103). Juvenile salmon from the Tuolumne River were found to be in good conditions with no bacterial or viral pathogens detected. Length-weight relationships were similar between sites (Figure 23 and Figure 24).

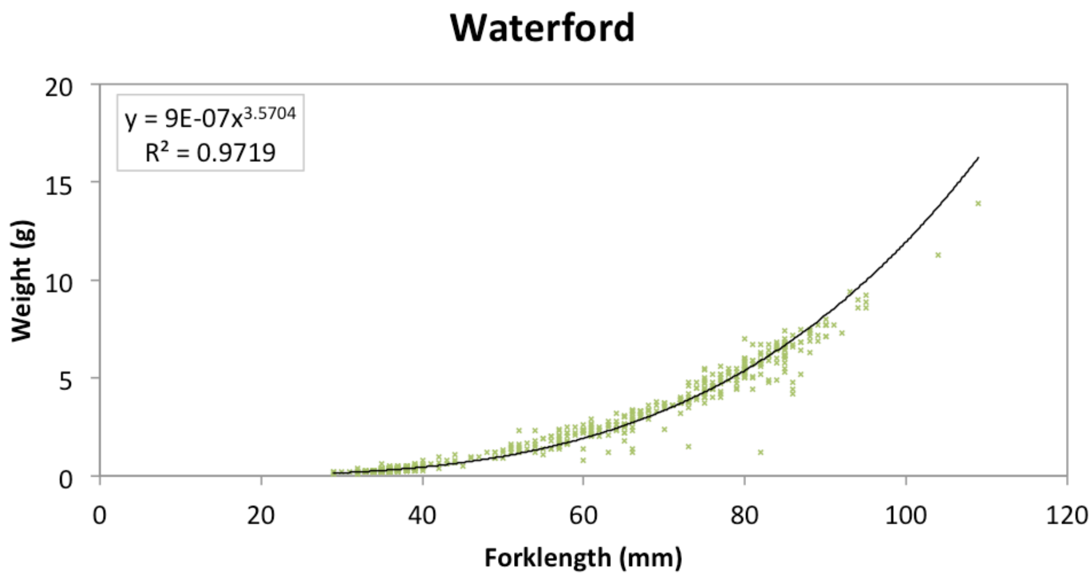

Figure 23. Length-weight relationship of fish measured at Waterford during 2013.

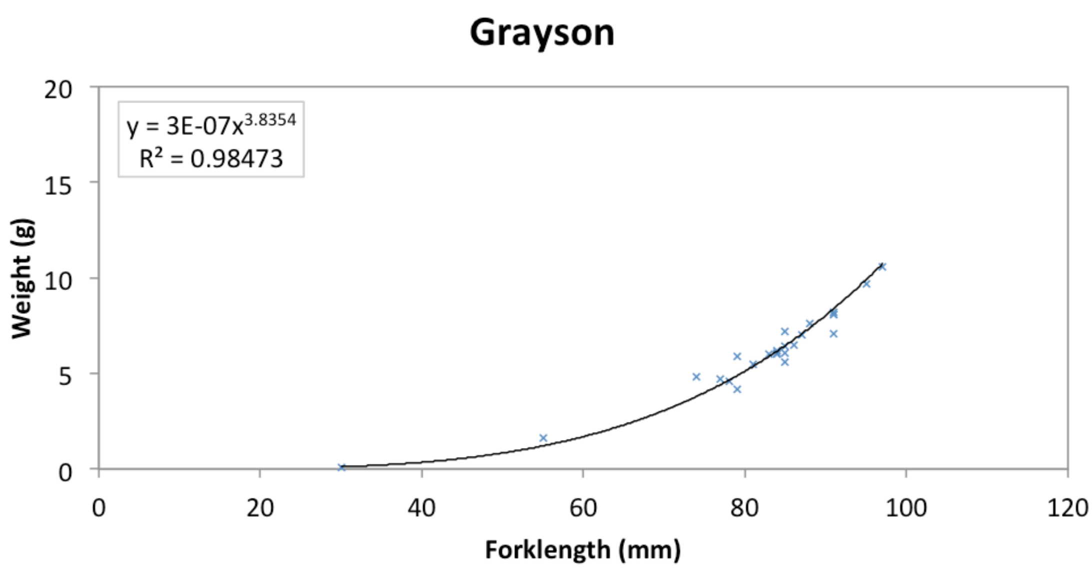

Figure 24. Length-weight relationship of fish measured at Grayson during 2013.

Oncorhynchus mykiss **(Rainbow Trout/Steelhead)**

Zero *O. mykiss* were captured at Waterford and Grayson in 2013. Total annual *O. mykiss* catch at the Grayson and Waterford traps between 2000 and 2013 ranged from 0 to 11 (Figure 25).

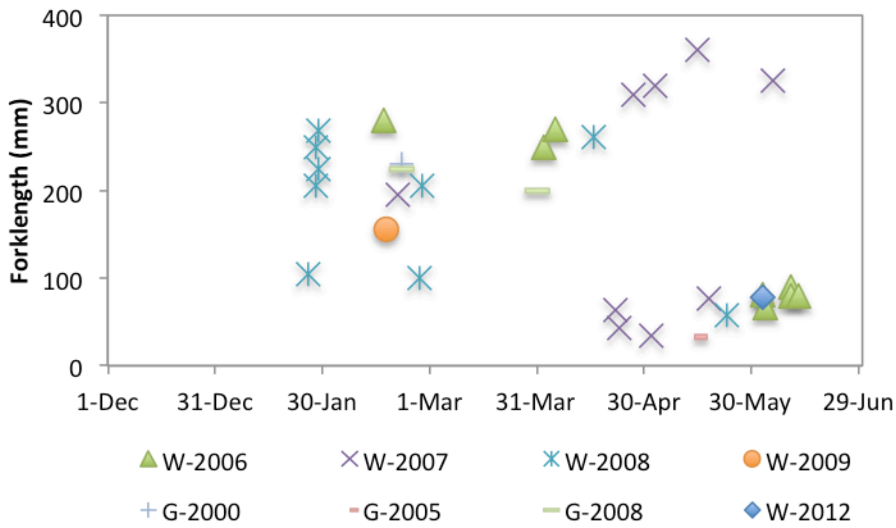

Figure 25. Date, size, and location of *O. mykiss* captured at Waterford (W) and Grayson (G).

Other Fish Species Captured

A total of 2,346 non-salmonids representing at least 26 species (7 native, 19 introduced) were captured during operation of the Waterford and Grayson traps in 2013 (Table 7; Appendices C and D). The same species were generally observed at both sites, with the exception of goldfish, which were only observed at Waterford, and black bullhead, brown bullhead, carp, hitch, inland silverside, striped bass, and tule perch only observed at Grayson. Native species comprised only 31% of the total non-salmonid catch, consisting primarily of lamprey (n=80). Lampreys captured in the traps were primarily ammocoetes and were not identified to species or measured. No adult lamprey were captured at either trapping location.

Table 7. Non-salmonid species captured at Waterford and Grayson during 2013. Native species are indicated in bold.

			Waterford				Grayson			
	Common Name	**Scientific Name**	**Total Catch**	**Minimum Length (mm)**	**Average Length (mm)**	**Maximum Length (mm)**	**Total Catch**	**Minimum Length (mm)**	**Average Length (mm)**	**Maximum Length (mm)**
Catfish Family										
	Black bullhead	*Ameiurus melas*	0	-	-	-	6	182	199	217
	Brown bullhead	*Ameiurus nebulosus*	0	-	-	-	3	217	235	252
	Channel catfish	*Ictalurus punctatus*	4	56	70	82	23	55	79	142
	White catfish	*Ictalurus catus*	53	44	114	290	414	45	80	320
	Unidentified catfish	Not applicable	0	-	-	-	1	-	-	-
Lamprey Family										
	Lamprey - unidentified	Not applicable	3	-	-	-	80	-	-	-
Livebearer Family										
	Mosquitofish	*Gambusia affinis*	10	27	33	41	46	21	35	47
Minnow Family										
	Carp	*Cyprinus carpio*	0	-	-	-	3	225	239	253
	Goldfish	*Carassius auratus auratus*	1	195	195	195	0	-	-	-
	Golden shiner	*Notemigonus crysoleucas*	7	7	58	76	121	22	53	120
	Hardhead	*Mylopharodon conocephalus*	15	52	71	114	1	134	134	134
	Hitch	*Lavinia exilicauda*	0	-	-	-	5	57	78	100
	Red shiner	*Cyprinella lutrennsis*	1	43	43	43	33	27	41	57
	Sacramento pikeminnow	*Ptychochelius grandis*	21	27	73	165	23	27	46	109
Sculpin Family										
	Prickly Sculpin	*Cottusasper*	44	53	76	111	7	80	94	110
Silverside Family										
	Inland silverside	*Menidia beryllina*	0	-	-	-	15	29	69	100

	Common Name	Scientific Name	Waterford Total Catch	Waterford Minimum Length (mm)	Waterford Average Length (mm)	Waterford Maximum Length (mm)	Grayson Total Catch	Grayson Minimum Length (mm)	Grayson Average Length (mm)	Grayson Maximum Length (mm)
Sucker Family										
	Sacramento sucker	*Catostomus occidentalis*	20	25	50	187	3	25	27	30
Sunfish Family										
	Bluegill	*Lepomis macrochirus*	67	35	54	73	29	23	91	165
	Black crappie	*Pomoxis annularis*	1	78	78	78	4	92	123	162
	Green sunfish	*Lepomis cyanellus*	1	71	71	71	4	75	102	155
	Largemouth bass	*Micropterus salmoides*	4	77	132	239	12	95	119	144
	Pumpkinseed	*Lepomis gibbosus*	1	71	71	71	1	82	82	82
	Redear sunfish	*Lepomis microlophus*	7	44	71	89	1	49	49	49
	Smallmouth bass	*Micropterus dolomieu*	10	72	166	375	129	90	127	265
	Striped bass	*Morone saxatilis*	0	-	-	-	1	nd	nd	nd
	Warmouth	*Lepomis gulosus*	13	56	72	82	1	155	155	155
	Unidentified bass	Not applicable	87	13	62	159	1,001	15	34	242
	Unidentified sunfish	Not applicable	2	51	51	51	0	-	-	-
	Unidentified species	Not applicable	2	20	20	20	4	17	36	50
Surfperch Family										
	Tule perch	*Hysterocarpus traskii*	0	-	-	-	1	110	110	110
Total Species Captured = 26 (19 introduced, 7 native)			374				1,972			
Total Native Individuals Captured = 718 (103 at Waterford; 615 at Grayson)										

REFERENCES CITED

Becker, C., R. Cuthbert, and A. Fuller. 2011. Fall/winter migration monitoring at the Tuolumne River weir 2010 annual report. FISHBIO Environmental, Oakdale, CA. Final Report submitted to Turlock and Modesto Irrigation Districts. March 2011.

Blakeman, D. 2008. 2007 Spawning Survey Report. California Department of Fish and Game, La Grange Field Office, CA. Federal Energy Regulatory Commission annual report, FERC project No. 2299.

Blakeman, D. 2007. 2006 Tuolumne River Fall Chinook Salmon Escapement Survey. California Department of Fish and Game, La Grange Field Office, CA. Federal Energy Regulatory Commission annual report, FERC project No. 2299.

Blakeman, D. 2006. 2005 Tuolumne River Fall Chinook Salmon Escapement Survey. California Department of Fish and Game, La Grange Field Office, CA. Federal Energy Regulatory Commission annual report, FERC project No. 2299.

Blakeman, D. 2004a.1998 juvenile Chinook salmon capture and production indices using rotary-screw traps on the lower Tuolumne River. California Department of Fish and Game, Technical report submitted to Tuolumne River Technical Advisory Committee, Turlock, CA.

Blakeman, D. 2004b.2002 juvenile Chinook salmon capture and production indices using rotary-screw traps on the lower Tuolumne River. California Department of Fish and Game, Technical report submitted to Tuolumne River Technical Advisory Committee, Turlock, CA.

Blakeman, D. 2004c.2003 juvenile Chinook salmon capture and production indices using rotary-screw traps on the lower Tuolumne River. California Department of Fish and Game, Technical report submitted to Tuolumne River Technical Advisory Committee, Turlock, CA.

Cuthbert, R., C. Becker, and A. Fuller. 2012. Fall/winter migration monitoring at the Tuolumne River weir 2011 annual report. FISHBIO Environmental, Oakdale, CA. Final Report submitted to Turlock and Modesto Irrigation Districts. March 2012.

Cuthbert, R., A. Fuller, and S. Snider. 2010. Fall/winter migration monitoring at the Tuolumne River weir 2009/10 annual report. FISHBIO Environmental, Oakdale, CA. Final Report submitted to Turlock and Modesto Irrigation Districts. March 2010.

Fuller, A.N. 2005. Outmigrant trapping of juvenile salmonids in the lower Tuolumne River at Grayson 2004. S.P. Cramer & Associates, Gresham, OR. Final Report submitted to Turlock and Modesto Irrigation Districts.

Fuller, A.N. 2008. Outmigrant trapping of juvenile salmonids in the lower Tuolumne River, 2007. Prepared by FISHBIO Environmental, Chico, California for Turlock Irrigation District and Modesto Irrigation Districts.

Fuller, A.N., M. Simpson, and C. Sonke. 2006. Outmigrant trapping of juvenile salmonids in the lower Tuolumne River at Grayson 2005. S.P. Cramer & Associates, Gresham, OR. Final Report submitted to Turlock and Modesto Irrigation Districts.

Fuller, A.N., M. Simpson, and C. Sonke. 2007. Outmigrant trapping of juvenile salmonids in the lower Tuolumne River 2006. FISHBIO Environmental, Chico, CA. Final Report submitted to Turlock and Modesto Irrigation Districts.

O’brien, J. 2006. 2005 Tuolumne River Fall Chinook Salmon Escapement Survey. California Department of Fish and Game, La Grange Field Office, CA. Federal Energy Regulatory Commission annual report, FERC project No. 2299.

Palmer, M., and C. Sonke. 2008. Outmigrant trapping of juvenile salmonids in the lower Tuolumne River 2008. FISHBIO Environmental, Chico, CA. Final Report submitted to Turlock and Modesto Irrigation Districts.

Palmer, M., and C. Sonke. 2010. Outmigrant trapping of juvenile salmonids in the lower Tuolumne River 2009. FISHBIO Environmental, Chico, CA. Final Report submitted to Turlock and Modesto Irrigation Districts.

Robichaud, D. and K. English. 2013. Analysis of Tuolumne River Rotary Screw Trap Data to examine the relationship between river flow and survival rates for Chinook smolts migrating between Waterford and Grayson (2006-12). LGL Limited, British Columbia, Canada. Draft Report submitted to Turlock and Modesto Irrigation Districts.

Sonke, C., S. Ainsley, and A. Fuller. 2010. Outmigrant trapping of juvenile salmonids in the lower Tuolumne River 2010. FISHBIO Environmental, Chico, CA. Final Report submitted to Turlock and Modesto Irrigation Districts.

Sonke, C., S. Ainsley, and A. Fuller. 2012. Outmigrant trapping of juvenile salmonids in the lower Tuolumne River 2011. FISHBIO Environmental, Chico, CA. Final Report submitted to Turlock and Modesto Irrigation Districts.

Heyne, T. and W. Loudermilk. 1997. Rotary screw trap capture of Chinook salmon smolts on the Tuolumne River in 1995 and 1996: Contribution of assessment of survival and production estimates. Federal Energy Regulatory Commission annual report, FERC project #2299-024.

Heyne, T. and W. Loudermilk. 1998. Rotary screw trap capture of Chinook salmon smolts with survival and production indices for the Tuolumne River in 1997. Federal Energy Regulatory Commission annual report, FERC project #2299-024.

Nichols K, 2013. FY2013 Technical Report: San Joaquin, Stanislaus, Tuolumne and Merced River Chinook Smolt Quality Assessment. US Fish and Wildlife Service California-Nevada Fish Health Center, Anderson, CA.

Stillwater Sciences. 2001. 2000 Tuolumne River smolt survival and upper screw traps report. Report 2000-4 in 2000 Lower Tuolumne River annual report, Project No. 2299. Prepared by Noah Hume, Peter Baker, Anthony Keith and Jennifer Vick of Stillwater Ecosystem, Watershed & Riverine Sciences, Berkeley, CA and Tim Ford, Turlock and Modesto Irrigation Districts with assistance from S.P. Cramer and Associates. March 2001.

Vasques, J. and K. Kundargi. 2001. 1999-2000 Grayson screw trap report. California Department of Fish and Game Anadromous Fisheries Project, San Joaquin Valley Southern Sierra Region (Region 4). March 2001.

Vasques, J. and K. Kundargi. 2002. 2001 Juvenile Chinook capture and production indices using rotary screw traps on the lower Tuolumne River. California Department of Fish and Game, San Joaquin Valley Southern Sierra Region, Anadromous Fisheries Program.

Vick, J., P. Baker, and T. Ford. 1998. 1998 Lower Tuolumne river annual report, Report 98-3, 1998 Tuolumne River Outmigrant Trapping Report. December 1998

Vick, J., A. Keith, and P. Baker. 2000. 1999 Lower Tuolumne River annual report, Report 99-5, 1999 Tuolumne River Upper Rotary Screw Trap Report. March 2000.

Wright, T., J. Guignard, and A. Fuller. 2013. Fall migration monitoring at the Tuolumne River weir 2012 annual report. FISHBIO Environmental, Oakdale, CA. Final Report submitted to Turlock and Modesto Irrigation Districts. March 2013.

Appendix A. Daily Chinook catch, length, predicted catchability, and estimated passage at Waterford and associated environmental data from 2013.

	Unmarked Chinook Salmon									*Environmental Conditions*			
		Fork Length (mm)			-	Estimated Passage				Flow (cfs)			
Date	Catch	Min	Avg	Max	Average Catchability	Fry	Parr	Smolt	Total	La Grange	Velocity (ft/s)	Temp at Trap (F)	Turbidity
1/2/13	0	-	-	-	9.5%	0	0	0	0	174	1.1	47.0	1.42
1/3/13	0	-	-	-	11.2%	0	0	0	0	174	1.3	46.7	6.22
1/4/13	0	-	-	-	12.8%	0	0	0	0	176	1.5	46.9	2.16
1/5/13	0	-	-	-	11.1%	0	0	0	0	176	1.3	47.2	1.67
1/6/13	0	-	-	-	13.6%	0	0	0	0	177	1.6	48.5	4.45
1/7/13	2	34	35	35	15.4%	13	0	0	13	176	1.8	48.7	3.29
1/8/13	3	33	34	34	13.6%	22	0	0	22	176	1.6	48.6	6.84
1/9/13	15	32	35	36	9.4%	160	0	0	160	176	1.1	48.8	3.43
1/10/13	23	29	34	36	9.5%	242	0	0	242	174	1.1	48.4	2.00
1/11/13	29	27	34	37	9.4%	307	0	0	307	175	1.1	47.5	1.87
1/12/13	155	29	35	36	12.8%	1211	0	0	1211	176	1.5	46.4	3.02
1/13/13	69	33	35	37	9.4%	737	0	0	737	nd	1.1	45.4	1.94
1/14/13	84	32	35	36	12.7%	660	0	0	660	177	1.5	44.5	1.45
1/15/13	74	32	35	39	11.2%	660	0	0	660	174	1.3	44.8	2.34
1/16/13	31	34	35	36	1.7%	1796	0	0	1796	174	0.2	45.2	0.84
1/17/13	32	34	35	37	6.0%	533	0	0	533	175	0.7	45.9	0.63
1/18/13	64	35	36	39	9.5%	674	0	0	674	174	1.1	46.6	3.55
1/19/13	44	29	35	39	7.8%	567	0	0	567	174	0.9	47.2	1.97
1/20/13	65	30	35	38	12.1%	538	0	0	538	174	1.4	47.6	1.06
1/21/13	81	32	37	39	7.8%	1043	0	0	1043	174	0.9	47.8	1.28
1/22/13	80	32	36	40	11.2%	717	0	0	717	175	1.3	48.2	1.86
1/23/13	23	32	36	39	7.7%	300	0	0	300	176	0.9	49.1	0.96
1/24/13	1	35	35	35	12.0%	8	0	0	8	175	1.4	49.7	2.10
1/25/13	1	37	37	37	13.7%	7	0	0	7	175	1.6	52.2	1.89
1/26/13	0	-	-	-	9.5%	0	0	0	0	174	1.1	54.1	2.60
1/27/13	14	35	36	39	12.9%	108	0	0	108	174	1.5	53.2	1.28
1/28/13	47	35	37	40	13.0%	361	0	0	361	173	1.5	51.5	1.99
1/29/13	25	31	37	39	11.2%	224	0	0	224	175	1.3	50.4	1.05
1/30/13	20	33	36	38	12.9%	155	0	0	155	175	1.5	50.1	2.58
1/31/13	27	32	36	39	12.8%	211	0	0	211	176	1.5	50.5	0.80
2/1/13	84	32	36	44	10.4%	811	0	0	811	174	1.2	51.1	0.77
2/2/13	21	32	35	47	10.5%	200	0	0	200	172	1.2	51.5	1.20
2/3/13	26	32	34	39	12.2%	214	0	0	214	173	1.4	51.4	1.90
2/4/13	10	33	38	47	7.8%	129	0	0	129	174	0.9	52.2	0.78
2/5/13	3	33	37	45	12.9%	23	1	0	23	174	1.5	52.5	0.69
2/6/13	14	31	37	46	11.2%	122	3	0	125	173	1.3	52.2	1.13
2/7/13	18	37	38	38	13.3%	133	3	0	136	180	1.6	51.6	0.71
2/8/13	25	32	36	38	11.5%	212	5	0	217	181	1.4	50.9	2.15
2/9/13	35	32	38	52	12.3%	278	6	0	285	182	1.5	50.0	2.03
2/10/13	52	33	38	50	13.3%	383	9	0	392	180	1.6	49.7	0.58
2/11/13	39	32	37	41	12.1%	316	7	0	323	173	1.4	50.1	0.54
2/12/13	25	32	37	49	10.3%	233	10	0	243	173	1.2	50.6	0.40
2/13/13	11	35	37	41	13.0%	81	3	0	85	172	1.5	51.3	0.99
2/14/13	11	33	37	39	13.1%	81	3	0	84	170	1.5	52.1	0.94
2/15/13	10	36	38	45	13.3%	72	3	0	75	167	1.5	53.1	1.69
2/16/13	46	33	37	52	13.0%	341	15	0	355	172	1.5	53.7	0.70
2/17/13	60	34	38	57	12.9%	447	19	0	466	173	1.5	53.9	0.77
2/18/13	21	33	37	57	13.2%	153	7	0	159	169	1.5	54.1	0.48
2/19/13	16	35	38	52	10.6%	117	18	15	151	168	1.3	53.2	2.02
2/20/13	78	33	37	61	9.8%	618	97	81	796	168	1.2	51.6	1.16
2/21/13	72	32	38	61	14.0%	401	63	52	516	167	1.7	52.0	0.70
2/22/13	17	32	42	60	11.5%	115	18	15	148	167	1.4	52.1	1.12

	Unmarked Chinook Salmon									*Environmental Conditions*			
		Fork Length (mm)			-	Estimated Passage				Flow (cfs)			
Date	Catch	Min	Avg	Max	Average Catchability	Fry	Parr	Smolt	Total	La Grange	Velocity (ft/s)	Temp at Trap (F)	Turbidity
2/23/13	29	35	37	54	12.3%	183	29	24	235	167	1.5	53.4	1.20
2/24/13	131	35	42	61	9.0%	1133	178	148	1459	168	1.1	52.6	1.23
2/25/13	158	35	40	61	11.5%	1067	168	139	1374	167	1.4	53.1	0.44
2/26/13	87	35	45	63	9.6%	497	187	226	910	166	1.3	53.5	1.06
2/27/13	72	33	40	61	8.8%	448	169	204	821	167	1.2	53.7	0.43
2/28/13	13	35	41	60	8.8%	81	31	37	148	167	1.2	53.6	0.64
3/1/13	24	35	48	69	8.8%	149	56	68	274	167	1.4	56.4	1.68
3/2/13	15	35	47	70	10.2%	80	30	37	148	168	1.3	57.6	1.75
3/3/13	43	35	41	70	9.5%	247	93	112	453	167	1.3	58.7	1.66
3/4/13	23	35	53	72	9.4%	133	50	61	244	168	nd	58.6	0.39
3/5/13	56	35	49	70	7.3%	173	142	450	765	170	1.1	58.8	1.48
3/6/13	2	66	66	66	6.2%	7	6	19	32	170	1.2	57.8	1.89
3/7/13	5	40	58	76	6.8%	17	14	43	73	168	1.4	56.5	2.38
3/8/13	12	40	60	74	8.0%	34	28	89	151	168	1.3	56.6	1.10
3/9/13	9	36	56	65	7.4%	27	22	71	121	167	nd	56.7	1.29
3/10/13	35	34	55	84	7.4%	107	88	278	473	168	1.3	57.3	1.43
3/11/13	16	36	58	72	7.4%	49	40	127	216	168	0.9	58.0	2.81
3/12/13	14	42	58	71	4.5%	19	73	217	308	167	1.5	59.2	3.14
3/13/13	21	47	63	75	7.3%	17	68	203	289	174	1.3	60.6	2.62
3/14/13	4	46	65	74	6.5%	4	15	44	62	170	1.6	61.5	1.92
3/15/13	5	53	61	72	8.1%	4	15	44	62	167	1.6	61.4	1.93
3/16/13	11	51	63	75	7.9%	8	33	97	138	170	1.3	61.2	0.92
3/17/13	4	44	54	66	6.6%	4	14	43	61	167	nd	61.3	1.25
3/18/13	6	50	64	82	6.6%	6	22	64	91	167	1.5	60.5	2.58
3/19/13	4	52	58	65	6.4%	0	5	58	63	172	1.3	60.7	0.56
3/20/13	2	60	71	82	5.7%	0	3	33	35	167	1.7	61.2	0.74
3/21/13	5	52	61	66	7.5%	0	5	62	67	166	1.5	60.9	2.10
3/22/13	11	55	74	87	6.6%	0	12	155	168	167	1.3	59.4	0.97
3/23/13	10	70	75	85	5.7%	0	13	164	177	168	1.3	58.2	3.18
3/24/13	12	58	71	80	5.7%	0	16	195	211	167	1.1	59.0	0.76
3/25/13	10	64	73	84	4.8%	0	15	192	208	167	1.7	60.2	0.84
3/26/13	6	70	76	85	7.2%	0	2	82	84	168	1.5	60.8	3.04
3/27/13	8	60	60	60	6.3%	0	2	125	127	169	1.4	61.4	3.19
3/28/13	3	64	70	80	5.9%	0	1	50	51	169	1.4	63.2	1.12
3/29/13	2	61	62	63	5.9%	0	1	33	34	169	1.4	64.4	2.30
3/30/13	7	70	76	82	5.9%	0	2	117	119	169	1.4	65.5	3.42
3/31/13	6	57	66	71	5.9%	0	2	100	102	169	1.6	65.6	1.41
4/1/13	1	75	75	75	6.7%	0	0	15	15	169	1.5	65.6	2.84
4/2/13	14	68	77	85	6.2%	0	0	225	225	169	1.6	65.4	0.8
4/3/13	6	64	78	89	6.6%	0	0	90	90	169	1.4	65.4	1.21
4/4/13	4	66	82	88	5.8%	0	0	69	69	169	1.8	65.5	1.24
4/5/13	5	70	73	75	7.4%	0	0	67	67	170	1.8	64.6	1.95
4/6/13	5	72	79	94	7.4%	0	0	67	67	170	1.4	64.4	0.78
4/7/13	3	67	77	82	5.8%	0	0	52	52	170	1.3	64.5	4.07
4/8/13	5	79	84	91	5.4%	0	0	93	93	169	1.4	63.4	1.07
4/9/13	10	68	74	80	5.8%	0	0	172	172	169	1.2	62.0	1.19
4/10/13	0	-	-	-	5.0%	0	0	0	0	170	1.2	63.0	0.56
4/11/13	24	65	80	98	5.0%	0	0	482	482	169	1.4	64.0	1.44
4/12/13	1	87	87	87	5.8%	0	0	17	17	168	1.6	66.4	1.54
4/13/13	3	80	82	85	6.5%	0	0	46	46	172	1.3	66.7	0.25
4/14/13	6	63	77	101	3.8%	0	0	157	157	238	2.1	65.7	1.06
4/15/13	5	73	81	88	2.5%	0	0	200	200	588	2.5	62.9	4.25
4/16/13	147	60	81	95	3.7%	0	7	4013	4020	480	3.1	56.9	0.8
4/17/13	45	65	76	89	5.6%	0	1	803	804	389	2.8	56.7	1.66
4/18/13	25	64	78	87	5.1%	0	1	491	492	387	2.4	58.1	1.59

	Unmarked Chinook Salmon									Environmental Conditions			
		Fork Length (mm)			-	Estimated Passage				Flow (cfs)			
Date	Catch	Min	Avg	Max	Average Catchability	Fry	Parr	Smolt	Total	La Grange	Velocity (ft/s)	Temp at Trap (F)	Turbidity
4/19/13	31	67	77	92	4.3%	0	1	714	716	389	2.1	59.8	0.90
4/20/13	6	59	76	81	3.2%	0	0	186	186	457	2.5	61.1	2.74
4/21/13	3	80	80	80	2.3%	0	0	132	133	776	3.3	60.4	3.63
4/22/13	87	70	81	92	3.4%	0	5	2552	2557	681	3.7	58.6	0.85
4/23/13	17	35	73	109	4.8%	24	7	321	351	584	2.7	58.9	0.98
4/24/13	6	35	77	95	3.6%	11	3	152	167	574	2.9	59.1	0.66
4/25/13	8	35	77	90	3.8%	14	4	190	208	576	2.6	59.5	0.99
4/26/13	2	74	81	88	3.2%	4	1	57	63	622	2.9	59.6	1.50
4/27/13	3	84	87	89	2.3%	9	2	120	132	974	3.5	59.0	2.16
4/28/13	1	95	95	95	3.0%	2	1	30	33	886	3.5	58.4	0.39
4/29/13	0	-	-	-	3.4%	0	0	0	0	784	2.8	59.4	0.40
4/30/13	7	76	83	86	2.6%	5	0	264	269	768	3.4	59.4	0.51
5/1/13	3	82	87	93	2.9%	2	0	103	105	847	3.5	58.5	0.35
5/2/13	3	88	90	92	2.1%	2	0	140	143	1190	4.1	57.8	1.5
5/3/13	7	36	79	95	2.8%	4	0	242	246	1030	4.6	57.4	0.88
5/4/13	7	82	86	97	4.2%	3	0	162	165	776	3.6	58.4	0.99
5/5/13	1	100	100	100	4.3%	0	0	23	23	603	3.2	58.3	1.13
5/6/13	0	-	-	-	6.0%	0	0	0	0	384	3.1	59.0	2.18
5/7/13	0	-	-	-	7.6%	0	0	0	0	286	2.1	60.6	0.47
5/8/13	2	88	94	100	5.4%	0	0	37	37	274	2.0	62.3	1.72
5/9/13	12	80	89	104	6.6%	0	0	182	182	213	1.4	64.2	1.24
5/10/13	0	-	-	-	6.0%	0	0	0	0	163	1.5	64.8	0.13
5/11/13	3	80	88	99	6.4%	0	0	47	47	164	1.4	70.6	1.21
5/12/13	1	90	90	90	6.0%	0	0	17	17	164	1.0	73.5	0.65
5/13/13	0	-	-	-	4.3%	0	0	0	0	162	2.1	74.0	1.46
5/14/13	0	-	-	-	0.0%	0	0	0	0	165	1.3	74.0	1.45
5/15/13	0	-	-	-	0.0%	0	0	0	0	165	1.2	72.8	1.14
5/16/13	0	-	-	-	0.0%	0	0	0	0	164	0.8	69.8	nd
5/17/13	0	-	-	-	0.0%	0	0	0	0	165	1.2	67.9	1.08
5/18/13	0	-	-	-	0.0%	0	0	0	0	164	1.3	68.4	0.93
5/19/13	0	-	-	-	0.0%	0	0	0	0	165	1.3	69.6	1.2
5/20/13	0	-	-	-	0.0%	0	0	0	0	163	0.8	71.1	1.19
5/21/13	0	-	-	-	0.0%	0	0	0	0	162	1.5	71.8	1.29
5/22/13	0	-	-	-	0.0%	0	0	0	0	164	1.2	69.2	1.37
5/23/13	0	-	-	-	0.0%	0	0	0	0	165	1.3	67.6	0.86
5/24/13	0	-	-	-	0.0%	0	0	0	0	164	1.5	68.4	0.95
5/25/13	0	-	-	-	0.0%	0	0	0	0	164	1.1	69.0	2.47
5/26/13	0	-	-	-	0.0%	0	0	0	0	164	1.1	69.4	1.3
5/27/13	0	-	-	-	0.0%	0	0	0	0	164	1.1	68.8	1.22
5/28/13	0	-	-	-	0.0%	0	0	0	0	164	0.3	69.1	1.27
5/29/13	0	-	-	-	0.0%	0	0	0	0	164	1.1	71.0	1.63
5/30/13	0	-	-	-	0.0%	0	0	0	0	163	1.3	71.7	1.43
5/31/13	0	-	-	-	0.0%	0	0	0	0	164	1.1	72.5	1.34

Appendix B. Daily Chinook catch, length, average catchability, and estimated passage at Grayson and associated environmental data from 2013.

	Unmarked Chinook Salmon									*Environmental Conditions*				
Date	Catch	Fork Length (mm)			Average Catchability	Estimated Passage				Flow (cfs)	Velocity (ft/s)		Temp at the traps (F)	Turbidity (NTU)
		Min	Avg	Max		Fry	Parr	Smolt	Total	Modesto Flow	North	South		
1/3/13	0	-	-	-	0.0%	0	0	0	0	239	1.3	1.5	46.35	8.95
1/4/13	0	-	-	-	0.0%	0	0	0	0	233	1.5	1.5	46.65	4.38
1/5/13	0	-	-	-	0.0%	0	0	0	0	232	1.6	1.3	46.85	3.12
1/6/13	0	-	-	-	0.0%	0	0	0	0	348	1.6	1.5	48.11	8.99
1/7/13	0	-	-	-	0.0%	0	0	0	0	510	1.6	1.5	47.18	8.26
1/8/13	0	-	-	-	0.0%	0	0	0	0	493	2.1	2.1	46.27	33.70
1/9/13	0	-	-	-	0.0%	0	0	0	0	346	1.5	0.9	47.10	21.50
1/10/13	0	-	-	-	0.0%	0	0	0	0	299	1.0	1.2	47.63	10.72
1/11/13	0	-	-	-	0.0%	0	0	0	0	269	1.2	1.1	46.79	7.33
1/12/13	0	-	-	-	0.0%	0	0	0	0	253	1.6	1.5	46.31	8.85
1/13/13	0	-	-	-	0.0%	0	0	0	0	242	1.5	1.1	45.20	3.68
1/14/13	0	-	-	-	0.0%	0	0	0	0	235	1.3	1.6	44.30	3.60
1/15/13	1	30	30	30	16.1%	6	0	0	6	229	1.5	1.3	44.87	4.52
1/16/13	0	-	-	-	16.1%	0	0	0	0	223	1.3	1.5	45.43	3.81
1/17/13	0	-	-	-	16.1%	0	0	0	0	219	1.1	0.7	45.80	2.25
1/18/13	0	-	-	-	16.1%	0	0	0	0	216	1.3	1.3	46.33	2.61
1/19/13	0	-	-	-	16.1%	0	0	0	0	213	1.5	1.5	46.82	0.54
1/20/13	0	-	-	-	16.1%	0	0	0	0	210	1.5	1.4	47.41	1.72
1/21/13	0	-	-	-	16.1%	0	0	0	0	210	1.2	0.8	47.71	1.82
1/22/13	0	-	-	-	16.1%	0	0	0	0	204	1.5	1.7	48.12	2.35
1/23/13	0	-	-	-	16.1%	0	0	0	0	201	nd	nd	49.40	1.65
1/24/13	0	-	-	-	16.1%	0	0	0	0	204	1.3	1.5	49.99	1.92
1/25/13	0	-	-	-	16.1%	0	0	0	0	204	1.5	1.7	52.97	2.08
1/26/13	0	-	-	-	16.1%	0	0	0	0	200	1.3	1.6	54.63	3.26
1/27/13	0	-	-	-	16.1%	0	0	0	0	198	1.6	1.6	52.69	2.42
1/28/13	0	-	-	-	16.1%	0	0	0	0	196	1.3	1.7	51.48	0.98
1/29/13	0	-	-	-	16.1%	0	0	0	0	196	1.5	1.9	52.12	1.58
1/30/13	0	-	-	-	16.1%	0	0	0	0	197	1.6	1.7	52.66	2.03
1/31/13	0	-	-	-	16.1%	0	0	0	0	194	1.4	1.4	53.03	1.00
2/1/13	0	-	-	-	16.1%	0	0	0	0	196	1.5	1.6	53.30	0.76
2/2/13	0	-	-	-	16.1%	0	0	0	0	193	1.2	1.0	53.29	0.88
2/3/13	0	-	-	-	16.1%	0	0	0	0	191	1.4	1.6	53.09	3.12
2/4/13	0	-	-	-	16.1%	0	0	0	0	192	1.6	1.0	53.42	2.18
2/5/13	0	-	-	-	16.1%	0	0	0	0	191	1.3	1.5	54.23	0.98
2/6/13	0	-	-	-	16.1%	0	0	0	0	191	1.3	1.7	53.89	1.02
2/7/13	0	-	-	-	16.1%	0	0	0	0	195	1.6	1.7	54.31	0.91
2/8/13	0	-	-	-	16.1%	0	0	0	0	196	1.7	1.8	52.47	4.45
2/9/13	0	-	-	-	16.1%	0	0	0	0	198	1.3	1.3	51.35	1.20
2/10/13	0	-	-	-	16.1%	0	0	0	0	197	1.5	1.7	51.47	0.70
2/11/13	0	-	-	-	16.1%	0	0	0	0	196	1.7	2.1	51.86	0.55
2/12/13	0	-	-	-	16.1%	0	0	0	0	189	1.4	1.8	52.36	1.99
2/13/13	0	-	-	-	16.1%	0	0	0	0	187	1.8	1.7	53.05	0.68
2/14/13	0	-	-	-	16.1%	0	0	0	0	186	1.8	1.3	53.92	1.21
2/15/13	0	-	-	-	16.1%	0	0	0	0	184	1.5	1.2	54.94	5.99
2/16/13	0	-	-	-	16.1%	0	0	0	0	181	1.2	1.5	55.22	1.17
2/17/13	0	-	-	-	16.1%	0	0	0	0	194	1.7	1.7	55.50	1.66
2/18/13	0	-	-	-	16.1%	0	0	0	0	200	1.6	1.7	55.37	0.59
2/19/13	0	-	-	-	16.1%	0	0	0	0	220	1.3	1.2	53.92	1.34
2/20/13	0	-	-	-	16.1%	0	0	0	0	210	1.3	1.4	52.20	2.92
2/21/13	0	-	-	-	16.1%	0	0	0	0	195	1.7	1.6	53.73	1.09
2/22/13	0	-	-	-	16.1%	0	0	0	0	194	1.7	1.5	54.48	1.82
2/23/13	0	-	-	-	16.1%	0	0	0	0	192	1.8	1.5	55.85	1.79

Date	Unmarked Chinook Salmon									Environmental Conditions				
	Catch	Fork Length (mm)			Average Catchability	Estimated Passage				Flow (cfs) Modesto Flow	Velocity (ft/s)		Temp at the traps (F)	Turbidity (NTU)
		Min	Avg	Max		Fry	Parr	Smolt	Total		North	South		
2/24/13	0	-	-	-	16.1%	0	0	0	0	192	nd	1.4	53.67	2.12
2/25/13	0	-	-	-	16.1%	0	0	0	0	194	1.5	1.4	54.56	0.62
2/26/13	0	-	-	-	16.1%	0	0	0	0	191	1.7	1.3	55.23	1.17
2/27/13	1	55	55	55	14.9%	0	7	0	7	190	1.5	1.3	55.64	0.54
2/28/13	0	-	-	-	14.9%	0	0	0	0	190	1.2	1.5	55.43	0.78
3/1/13	0	-	-	-	14.9%	0	0	0	0	189	1.3	1.7	59.58	0.76
3/2/13	0	-	-	-	14.9%	0	0	0	0	190	nd	nd	60.76	0.79
3/3/13	0	-	-	-	14.9%	0	0	0	0	196	1.7	1.9	61.63	1.82
3/4/13	0	-	-	-	14.9%	0	0	0	0	197	nd	1.6	60.82	1.02
3/5/13	0	-	-	-	14.9%	0	0	0	0	202	1.3	1.4	61.08	1.46
3/6/13	0	-	-	-	14.9%	0	0	0	0	213	1.3	1.3	59.84	2.73
3/7/13	0	-	-	-	14.9%	0	0	0	0	213	1.5	1.3	59.05	1.80
3/8/13	0	-	-	-	14.9%	0	0	0	0	224	1.3	1.2	60.29	1.96
3/9/13	0	-	-	-	14.9%	0	0	0	0	236	2.1	1.8	59.61	3.84
3/10/13	0	-	-	-	14.9%	0	0	0	0	228	1.5	1.7	59.84	7.87
3/11/13	0	-	-	-	14.9%	0	0	0	0	220	1.2	1.3	60.70	1.77
3/12/13	0	-	-	-	14.9%	0	0	0	0	225	1.3	1.0	62.36	2.95
3/13/13	0	-	-	-	14.9%	0	0	0	0	224	0.9	0.4	63.89	6.22
3/14/13	0	-	-	-	14.9%	0	0	0	0	225	1.6	1.8	64.86	12.62
3/15/13	0	-	-	-	14.9%	0	0	0	0	238	1.3	1.5	64.33	3.35
3/16/13	0	-	-	-	14.9%	0	0	0	0	239	1.1	1.5	64.37	6.12
3/17/13	0	-	-	-	14.9%	0	0	0	0	253	1.5	1.3	64.26	3.22
3/18/13	0	-	-	-	14.9%	0	0	0	0	248	1.5	1.5	63.26	6.09
3/19/13	0	-	-	-	14.9%	0	0	0	0	251	1.7	1.5	63.81	3.88
3/20/13	0	-	-	-	14.9%	0	0	0	0	261	1.9	1.6	64.40	9.88
3/21/13	0	-	-	-	14.9%	0	0	0	0	269	1.3	1.5	63.61	7.57
3/22/13	0	-	-	-	14.9%	0	0	0	0	258	1.7	1.6	60.73	5.91
3/23/13	0	-	-	-	14.9%	0	0	0	0	247	1.7	1.4	60.00	9.33
3/24/13	0	-	-	-	14.9%	0	0	0	0	245	1.5	1.5	62.09	3.61
3/25/13	0	-	-	-	14.9%	0	0	0	0	250	1.7	1.3	63.55	7.55
3/26/13	0	-	-	-	14.9%	0	0	0	0	245	1.6	1.3	63.72	7.19
3/27/13	0	-	-	-	14.9%	0	0	0	0	246	1.7	1.7	65.22	14.87
3/28/13	0	-	-	-	14.9%	0	0	0	0	260	1.6	1.4	66.62	4.66
3/29/13	0	-	-	-	14.9%	0	0	0	0	261	1.4	1.6	67.39	9.73
3/30/13	1	85	85	85	9.4%	0	0	11	11	266	1.8	1.8	68.30	5.84
3/31/13	0	-	-	-	9.4%	0	0	0	0	336	1.7	1.8	68.42	8.80
4/1/13	0	-	-	-	9.4%	0	0	0	0	323	2.2	2.0	67.59	6.38
4/2/13	0	-	-	-	9.4%	0	0	0	0	264	1.8	2.0	67.34	3.67
4/3/13	0	-	-	-	9.4%	0	0	0	0	253	1.3	1.7	69.0	2.8
4/4/13	0	-	-	-	9.4%	0	0	0	0	275	1.8	1.6	69.42	5.73
4/5/13	1	85	85	85	9.9%	0	0	10	10	253	1.8	1.8	68.60	3.90
4/6/13	0	-	-	-	9.9%	0	0	0	0	254	1.6	1.5	67.93	4.41
4/7/13	0	-	-	-	9.9%	0	0	0	0	231	1.6	1.4	68.59	4.05
4/8/13	0	-	-	-	9.9%	0	0	0	0	223	0.4	1.3	65.73	3.20
4/9/13	0	-	-	-	9.9%	0	0	0	0	221	1.7	1.5	63.83	3.45
4/10/13	0	-	-	-	9.9%	0	0	0	0	221	1.4	1.0	66.43	2.48
4/11/13	0	-	-	-	9.9%	0	0	0	0	220	1.8	1.7	67.68	2.62
4/12/13	0	-	-	-	9.9%	0	0	0	0	226	2.2	1.6	68.93	1.85
4/13/13	0	-	-	-	9.9%	0	0	0	0	219	1.6	1.2	69.52	2.00
4/14/13	0	-	-	-	9.9%	0	0	0	0	267	1.9	1.0	68.50	3.07
4/15/13	0	-	-	-	9.9%	0	0	0	0	307	1.8	2.0	66.38	10.61
4/16/13	0	-	-	-	9.9%	0	0	0	0	593	1.6	2.0	63.84	2.73
4/17/13	1	91	91	91	5.5%	0	0	18	18	573	2.3	2.2	63.2	5.1
4/18/13	6	74	83	97	5.5%	0	0	109	109	493	2.2	1.7	62.26	2.65
4/19/13	9	79	87	95	6.3%	0	0	144	144	480	2.1	2.2	64.00	3.47
4/20/13	0	-	-	-	6.3%	0	0	0	0	470	1.6	1.2	65.93	9.61

Date	Catch	Unmarked Chinook Salmon								Environmental Conditions				
		Fork Length (mm)			Average Catchability	Estimated Passage				Flow (cfs) Modesto Flow	Velocity (ft/s)		Temp at the traps (F)	Turbidity (NTU)
		Min	Avg	Max		Fry	Parr	Smolt	Total		North	South		
4/21/13	5	80	85	95	5.4%	0	0	92	92	538	2.0	2.2	67.13	7.63
4/22/13	1	91	91	91	2.7%	0	0	37	37	804	1.7	1.4	67.45	9.03
4/23/13	2	78	79	79	4.2%	0	0	48	48	763	2.2	2.4	65.29	3.27
4/24/13	2	79	82	84	4.2%	0	0	48	48	687	2.1	2.0	64.94	1.80
4/25/13	1	83	83	83	3.3%	0	0	30	30	668	1.7	1.5	65.55	1.69
4/26/13	1	81	81	81	3.7%	0	0	27	27	688	2.0	1.6	65.84	2.28
4/27/13	0	-	-	-	3.7%	0	0	0	0	744	2.5	2.3	66.76	2.04
4/28/13	0	-	-	-	3.7%	0	0	0	0	992	2.5	2.4	66.14	2.36
4/29/13	0	-	-	-	3.7%	0	0	0	0	961	2.1	2.4	65.61	4.16
4/30/13	0	-	-	-	3.7%	0	0	0	0	878	2.4	nd	65.36	2.86
5/1/13	1	75	75	75	3.9%	0	0	26	26	878	2.3	2.6	64.47	2.39
5/2/13	0	-	-	-	3.9%	0	0	0	0	950	2.4	2.2	65.27	2.07
5/3/13	0	-	-	-	3.9%	0	0	0	0	1140	2.1	2.2	64.3	3.2
5/4/13	0	-	-	-	3.9%	0	0	0	0	1050	2.5	2.2	63.60	3.03
5/5/13	0	-	-	-	3.9%	0	0	0	0	899	2.4	2.6	63.91	4.15
5/6/13	0	-	-	-	3.9%	0	0	0	0	748	2.1	2.2	64.70	2.19
5/7/13	1	91	91	91	5.1%	0	0	19	19	556	1.8	2.3	64.64	1.53
5/8/13	0	-	-	-	5.1%	0	0	0	0	410	2.2	1.8	65.77	5.28
5/9/13	0	-	-	-	5.1%	0	0	0	0	375	1.6	1.8	68.09	3.23
5/10/13	0	-	-	-	5.1%	0	0	0	0	322	1.5	1.5	68.24	1.83
5/11/13	1	99	99	99	9.4%	0	0	11	11	246	1.6	1.7	73.74	2.57
5/12/13	0	-	-	-	9.4%	0	0	0	0	258	1.7	1.7	75.87	2.98
5/13/13	0	-	-	-	9.4%	0	0	0	0	236	1.2	1.5	76.10	7.00
5/14/13	0	-	-	-	9.4%	0	0	0	0	210	1.3	1.1	76.56	4.74
5/15/13	0	-	-	-	9.4%	0	0	0	0	207	1.1	1.0	75.10	4.51
5/16/13	0	-	-	-	9.4%	0	0	0	0	245	1.4	1.2	72.17	4.94
5/17/13	0	-	-	-	9.4%	0	0	0	0	241	0.9	1.3	71.16	3.66
5/18/13	0	-	-	-	9.4%	0	0	0	0	232	0.8	0.7	71.70	2.64
5/19/13	0	-	-	-	9.4%	0	0	0	0	248	0.8	1.3	72.79	2.94
5/20/13	0	-	-	-	9.4%	0	0	0	0	256	1.5	0.4	73.7	2.3
5/21/13	0	-	-	-	9.4%	0	0	0	0	235	0.4	0.6	73.98	3.48
5/22/13	0	-	-	-	9.4%	0	0	0	0	224	1.3	1.3	69.75	2.77
5/23/13	0	-	-	-	9.4%	0	0	0	0	210	1.1	1.3	69.69	2.80

Appendix C. Daily counts of non-salmonids captured at Waterford during 2013. See key below for species codes.

Batch Date	BAS	BGS	BKS	CHC	GF	GSF	GSN	HH	LAM	LMB	MQK	PKS	PRS	RES	RSN	SASQ	SASU	SMB	SNF	UNID	W	WHC
1/2/13																						
1/3/13																						
1/4/13																						
1/5/13								1														
1/6/13								4														
1/7/13								2			1											
1/8/13																						
1/9/13									1													1
1/10/13								1					1									
1/11/13																						
1/12/13																						
1/13/13													1									
1/14/13		2																				
1/15/13																						
1/16/13																						
1/17/13																1						
1/18/13																						
1/19/13								1														
1/20/13																						
1/21/13													1									
1/22/13													1									
1/23/13										1			2									
1/24/13		1											2									
1/25/13																						
1/26/13																						
1/27/13													6									
1/28/13		2											3									

Batch Date	BAS	BGS	BKS	CHC	GF	GSF	GSN	HH	LAM	LMB	MQK	PKS	PRS	RES	RSN	SASQ	SASU	SMB	SNF	UNID	W	WHC
1/29/13													1									
1/30/13		1											3			1						
1/31/13																						
2/1/13		1											2									1
2/2/13																						
2/3/13																						
2/4/13													1									
2/5/13																						
2/6/13																						
2/7/13	1																					
2/8/13																						
2/9/13																						
2/10/13													1									
2/11/13													1									
2/12/13										1			2									1
2/13/13													1									
2/14/13											1											
2/15/13																						
2/16/13																						
2/17/13													1				1					
2/18/13																						1
2/19/13																						
2/20/13		1																				
2/21/13		1																				
2/22/13		1											1									
2/23/13																						
2/24/13		1																				
2/25/13		3														1						
2/26/13		1														1						

Batch Date	BAS	BGS	BKS	CHC	GF	GSF	GSN	HH	LAM	LMB	MQK	PKS	PRS	RES	RSN	SASQ	SASU	SMB	SNF	UNID	W	WHC
2/27/13		1											1									
2/28/13		1																				
3/1/13																						
3/2/13																	1		1			
3/3/13																						
3/4/13		1																				
3/5/13		10							1				6								1	
3/6/13																2			1			
3/7/13		2																				
3/8/13		2																			1	
3/9/13																						
3/10/13																2						
3/11/13		4						1														2
3/12/13		2																				
3/13/13		1												2								
3/14/13				1												2						
3/15/13																						1
3/16/13		1																				
3/17/13		1																				
3/18/13		1											1				1					
3/19/13		1														1					1	2
3/20/13						1																
3/21/13		1								1			1			1						
3/22/13		1																				
3/23/13		3									1		1			1						
3/24/13																						
3/25/13													1					1				
3/26/13																						
3/27/13																	1				1	

Batch Date	BAS	BGS	BKS	CHC	GF	GSF	GSN	HH	LAM	LMB	MQK	PKS	PRS	RES	RSN	SASQ	SASU	SMB	SNF	UNID	W	WHC
3/28/13	1															1						
3/29/13											1											
3/30/13		1																				
3/31/13																		1				
4/1/13																						
4/2/13																						
4/3/13		1		1																		1
4/4/13																		1				
4/5/13								1														
4/6/13																		1				1
4/7/13													1									1
4/8/13																						1
4/9/13																						
4/10/13																						
4/11/13		1								1								1				1
4/12/13													1					2				1
4/13/13																						
4/14/13	1																					
4/15/13																		1				1
4/16/13		1										1									1	
4/17/13		1												2				1				
4/18/13									1													
4/19/13		1									1					1						1
4/20/13																1						1
4/21/13																						
4/22/13	1	1	1	1							1										1	
4/23/13							2	1			1					2					1	2
4/24/13							1				1										2	1
4/25/13		3																			1	

Batch Date	BAS	BGS	BKS	CHC	GF	GSF	GSN	HH	LAM	LMB	MQK	PKS	PRS	RES	RSN	SASQ	SASU	SMB	SNF	UNID	W	WHC
4/26/13		1												1			1					
4/27/13		2													1							1
4/28/13	1																					2
4/29/13		1														1	6					
4/30/13																						2
5/1/13							1				1						3					
5/2/13																					2	
5/3/13								3									1					3
5/4/13		1					2				1			1								2
5/5/13		1																				2
5/6/13							1							1		1	2					
5/7/13																	2					1
5/8/13		1																				1
5/9/13		2			1												1	1			1	
5/10/13																						2
5/11/13	1																					2
5/12/13																						1
5/13/13	2																					2
5/14/13																						
5/15/13	1																					1
5/16/13																						4
5/17/13																						
5/18/13	2																					1
5/19/13	1															1						2
5/20/13																						
5/21/13	1																					1
5/22/13	1																					1
5/23/13																						
5/24/13																						

Batch Date	BAS	BGS	BKS	CHC	GF	GSF	GSN	HH	LAM	LMB	MQK	PKS	PRS	RES	RSN	SASQ	SASU	SMB	SNF	UNID	W	WHC
5/25/13	1																					1
5/26/13	2			1																		
5/27/13	9																					
5/28/13																						
5/29/13	46																			2		
5/30/13																						
5/31/13	15																					

Appendix D. Daily counts of non-salmonids captured at Grayson during 2013. See key below for species codes.

Date	BAS	BGS	BKB	BKS	BRB	C	CAT	CHC	GSF	GSN	HCH	HH	LAM	LMB	MQK	MSS	PKS	PRS	RES	RSN	SASQ	SASU	SMB	STB	TP	UNID	W	WHC
1/3/13	2					1																				1		
1/4/13	2	2						2					1								15							
1/5/13		1								1					1			1		8								
1/6/13		2								2		1								1								
1/7/13					1					7			3		2													
1/8/13		1											2															
1/9/13										1			2															
1/10/13		2								1						1												1
1/11/13								1		3			2					1										
1/12/13										1					3					2								
1/13/13				1						1											1	1						
1/14/13																												1
1/15/13																					1							
1/16/13																												
1/17/13								1		2						1												1
1/18/13		1																										1
1/19/13										3									1									
1/20/13										1										1								
1/21/13										1																		
1/22/13																2		1										
1/23/13																				1								
1/24/13						1									1													1
1/25/13																												
1/26/13		1																		1								
1/27/13																				1								
1/28/13																												
1/29/13											1					1												

Date	BAS	BGS	BKB	BKS	BRB	C	CAT	CHC	GSF	GSN	HCH	HH	LAM	LMB	MQK	MSS	PKS	PRS	RES	RSN	SASQ	SASU	SMB	STB	TP	UNID	W	WHC
1/30/13																												
1/31/13										1																		
2/1/13																1												
2/2/13																												
2/3/13																												
2/4/13																												
2/5/13																												
2/6/13																		1					1					
2/7/13																		1										
2/8/13																												
2/9/13																												
2/10/13																												
2/11/13																1												1
2/12/13																												
2/13/13																							1					
2/14/13																												
2/15/13																												
2/16/13																												
2/17/13																												
2/18/13																							1					
2/19/13														1														
2/20/13								1					3															
2/21/13										3																		
2/22/13																												
2/23/13																												
2/24/13																												
2/25/13																												
2/26/13													1					1										
2/27/13										1																		

Date	BAS	BGS	BKB	BKS	BRB	C	CAT	CHC	GSF	GSN	HCH	HH	LAM	LMB	MQK	MSS	PKS	PRS	RES	RSN	SASQ	SASU	SMB	STB	TP	UNID	W	WHC
2/28/13																												
3/1/13																												
3/2/13																												
3/3/13																												
3/4/13																												1
3/5/13										1			1															2
3/6/13																												
3/7/13																												
3/8/13																												1
3/9/13																												
3/10/13																												
3/11/13																												
3/12/13																												
3/13/13																												2
3/14/13		1								1			2															1
3/15/13													2					1		1								3
3/16/13													3															3
3/17/13																												1
3/18/13		1								1			1															9
3/19/13								1		1																		7
3/20/13										1																		
3/21/13										1			12	1									2					8
3/22/13		1								2			10			1							4					4
3/23/13													3		2	1							1					2
3/24/13	1									1			1												1			2
3/25/13	1									2					1								1					3
3/26/13										1																		
3/27/13									1	2					2													6
3/28/13		1																										

Date	BAS	BGS	BKB	BKS	BRB	C	CAT	CHC	GSF	GSN	HCH	HH	LAM	LMB	MQK	MSS	PKS	PRS	RES	RSN	SASQ	SASU	SMB	STB	TP	UNID	W	WHC
3/29/13																							1					17
3/30/13	1				2			1					6		1					3								21
3/31/13															1								1					8
4/1/13			1	1			1	3		1			22			1							15					28
4/2/13	1							7		5													9					15
4/3/13		1	4							8	1												2					21
4/4/13										9					2													11
4/5/13										3													5					18
4/6/13	1														1								1					9
4/7/13								4		1																		7
4/8/13																							2					3
4/9/13																				1								6
4/10/13															1	1												10
4/11/13																							2					7
4/12/13									1	2																		12
4/13/13																												4
4/14/13	1												1															4
4/15/13										1												1						10
4/16/13			1																				1			3		6
4/17/13										3				10	4								7					13
4/18/13										3						3							21				1	7
4/19/13	1			1						6													9					6
4/20/13	3																			2								3
4/21/13	3	1				1				2										2			1					2
4/22/13	4														3					4								4
4/23/13										3					4		1						6					19
4/24/13	1			1					1	9					2	1						1	5					4
4/25/13	2									3					4								3					2
4/26/13	2	2								3					1								1					6

Date	BAS	BGS	BKB	BKS	BRB	C	CAT	CHC	GSF	GSN	HCH	HH	LAM	LMB	MQK	MSS	PKS	PRS	RES	RSN	SASQ	SASU	SMB	STB	TP	UNID	W	WHC
4/27/13										1	1									3				1				5
4/28/13	1														1								3					4
4/29/13	4									3										1			1					3
4/30/13	1														2													2
5/1/13											2												1					3
5/2/13	5									1					1								1					5
5/3/13																												
5/4/13	1									1					1													1
5/5/13																												
5/6/13	5									5					1								1					1
5/7/13	13	1						1		4					1													2
5/8/13																												
5/9/13	13									1										1			2					5
5/10/13	8														1													1
5/11/13	20																											6
5/12/13	17																											1
5/13/13	18												1															3
5/14/13	7																						5					9
5/15/13	20																											1
5/16/13	117	1																					1					3
5/17/13	104														1						6		4					3
5/18/13	70	1																					2					
5/19/13	53	4																										5
5/20/13	195														1													3
5/21/13	115	2																					2					
5/22/13	57	1																										1
5/23/13	131	1						1	1				1										3					3

Appendix E. Key to species codes.

BAS	Unidentified bass
BGS	Bluegill
BKB	Black bullhead
BKS	Black crappie
BRB	Brown bullhead
C	Carp
CAT	Unidentified catfish
CHC	Channel catfish
CHN	Chinook
GF	Goldfish
GSF	Green sunfish
GSN	Golden shiner
HCH	Hitch
HH	Hardhead
LAM	Lamprey, unidentified species
LMB	Largemouth bass
MQK	Mosquitofish
MSS	Inland silverside
PKS	Pumpkinseed
PRS	Prickly sculpin
RES	Redear sunfish
RSN	Red shiner
SASQ	Sacramento pikeminnow
SASU	Sacramento sucker
SMB	Smallmouth bass
SNF	Unidentified sunfish
STB	Striped bass
TP	Tule perch
UNID	Unidentified species
W	Warmouth
WHC	White catfish