Outmigrant Trapping of Juvenile Salmonids in the Lower Tuolumne River, 2007

FINAL REPORT
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Prepared by
Andrea N. Fuller

Submitted to
Turlock and Modesto Irrigation Districts
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INTRODUCTION

Study Area Description

The Tuolumne River is the largest of the three major tributaries (Tuolumne, Merced, and Stanislaus Rivers) to the San Joaquin River, originating in the central Sierra Nevada and flowing 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 generation of power, water supply, and flood control – the largest impoundment is Don Pedro Reservoir.

The lower Tuolumne River corridor extends from its 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 migration since 1871.

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

Purpose and History of Study

Rotary screw traps have been operated at various locations in the Tuolumne River since 1995 within the winter/spring period to meet several objectives including monitoring the abundance and migration characteristics of juvenile salmonids and other fishes, and evaluation of reach-specific survival relative to environmental conditions (Table 1). Rotary screw trap monitoring has been conducted annually near the mouth of the Tuolumne River since 1995 for the purpose of monitoring the abundance and migration characteristics of juvenile salmonids and other fishes. Since 2006 sampling has also been conducted annually near the town of Waterford, about 25 miles upstream, to provide comparative information in size, migration timing, and juvenile fall-run Chinook salmon production at a site downstream from most Chinook spawning activity, along with data on other fishes. An estimated 625 salmon (289 females) spawned in fall 2006.
Table 1. Rotary screw trap monitoring in the Lower Tuolumne River.

<table>
<thead>
<tr>
<th>Year</th>
<th>Site</th>
<th>Period Sampled</th>
<th>Proportion of Outmigration</th>
<th>Total Catch</th>
<th>Total Estimated Passage</th>
<th>Method of Passage Estimation</th>
<th>Results Reported In</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>Shiloh (RM 3.4)</td>
<td>Apr 25- Jun 01</td>
<td>24%</td>
<td>141</td>
<td>15,667</td>
<td>Heyne and Loudermilk 1997</td>
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<tr>
<td>1997</td>
<td>Shiloh</td>
<td>Apr 18 - May 24</td>
<td>24%</td>
<td>57</td>
<td>2,850</td>
<td>Heyne and Loudermilk 1998</td>
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<tr>
<td>1998</td>
<td>Turlock Lake</td>
<td>Feb 11- Apr 13</td>
<td>41%</td>
<td>7,125</td>
<td>259,581</td>
<td>Vick and others 1998</td>
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</tr>
<tr>
<td></td>
<td>State Rec. (RM 42.0)</td>
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<tr>
<td>7/11</td>
<td>(RM 38.5)</td>
<td>Apr 15- May 31</td>
<td>31%</td>
<td>2,413</td>
<td></td>
<td>Vick and others 1998</td>
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<tr>
<td>1999</td>
<td>Charles Road</td>
<td>Mar 27- Jun 01</td>
<td>43%</td>
<td>981</td>
<td>66,848</td>
<td>Vick and others 1998</td>
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<tr>
<td></td>
<td>(RM 25.0)</td>
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<tr>
<td></td>
<td>Shiloh</td>
<td>Feb 15- Jul 01</td>
<td>70%</td>
<td>2,546</td>
<td>1,615,673</td>
<td>Blakeman 2004a</td>
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<tr>
<td>2000</td>
<td>7/11</td>
<td>Jan 19- May 17</td>
<td>79%</td>
<td>80,792</td>
<td>1,737,052</td>
<td>Vick and others 2000</td>
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<tr>
<td></td>
<td>Hughson (RM 23.7)</td>
<td>Apr 08- May 24</td>
<td>31%</td>
<td>449</td>
<td>7,175</td>
<td>Vick and others 2000</td>
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<tr>
<td>2001</td>
<td>Grayson (RM 5.2)</td>
<td>Jan 12- Jun 06</td>
<td>93%</td>
<td>19,327</td>
<td>696,115</td>
<td>Vasques and Kundargi 2001</td>
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<tr>
<td></td>
<td>7/11</td>
<td>Jan 10- Feb 27</td>
<td>32%</td>
<td>61,196</td>
<td>298,755</td>
<td>Hume and others 2001</td>
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<td>Deardorff (RM 35.5)</td>
<td>Apr 09- May 25</td>
<td>31%</td>
<td>634</td>
<td>15,845</td>
<td>Hume and others 2001</td>
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<td></td>
<td>Hughson</td>
<td>Apr 09- May 25</td>
<td>31%</td>
<td>264</td>
<td>2,942</td>
<td>Hume and others 2001</td>
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<tr>
<td></td>
<td>Grayson</td>
<td>Jan 09- Jun 12</td>
<td>95%</td>
<td>2,250</td>
<td>96,195</td>
<td>Vasques and Kundargi 2001</td>
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<tr>
<td></td>
<td>Grayson</td>
<td>Jan 03- May 29</td>
<td>97%</td>
<td>6,478</td>
<td>94,752</td>
<td>Vasques and Kundargi 2002</td>
<td></td>
</tr>
</tbody>
</table>

1 Passage estimate reported in the annual report cited in the last column to the right.
2 Passage estimate derived from multiple regression equation based on data collected from 1999-2006 as described in this report.
### METHODS

**Juvenile Outmigrant Monitoring**

#### Sampling Gear and Trapping Site Locations

Rotary screw traps were installed and operated near Waterford and at Grayson River Ranch (Grayson). The traps, manufactured by E.G. Solutions in Eugene, Oregon, 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 forced 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 opposing banks. Cables fastened to the front of each pontoon were attached to the overhead cable. Warning signs, flashing safety lights, and buoys marked the location of the trap and cables for public safety.

At Grayson (RM 5.2), two traps were held in place by an overhead cable strung between two large trees located on opposing banks. Leader cables descended from the overhead cable and...
were attached to the front of each of four trap pontoons. The downstream force of the water on the traps kept the leader cables taut.

**Trap Monitoring**

Sampling at Waterford began on January 11. The trap was operated intermittently (e.g., 3-7 days per week) until February 19, and then continuously (24 hours per day, 7 days per week) until June 5 when sampling was terminated due to low catch and inadequate depth and water velocity for trap operation. Rotary screw traps with 8-ft. diameter cones generally require water at least 4 feet deep and velocity of at least 1.5 ft/s for the cone to rotate.

Sampling at Grayson began on March 23. The traps were operated continuously (24 hours per day, 7 days per week) until sampling was terminated on May 29 due to low catch and inadequate depth and water velocity for trap operation.

Regardless of location, each trap was checked at least every morning throughout the sampling period, with additional trap checks conducted as conditions required. During each trap check, contents of the liveboxes were removed; all fish were identified and counted; and any marked fish were noted. In addition, random samples of up to 50 salmon and 20 of each non-salmon species during each morning check and up to 20 salmon and 10 of each non-salmon species during each evening check were anesthetized, measured (forklengths in millimeters), and recorded. Salmon were assigned to lifestage category based on a forklength scale, where <50 mm= fry, 50-69 mm= parr, and ≥ 70 mm= smolt. In addition, the smolting appearance of all measured salmon and trout was rated based on a 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 were taken from up to 50 salmon each week (i.e., Monday through Sunday) and from all trout. A weight boat partially filled with stream water was placed on an Ohaus digital balance and the balance was tared. One fish was placed in the weigh boat and after the weight was recorded to the nearest tenth of a gram, the balance was tared again before adding the next fish. Several fish were weighed before the weigh boat was emptied into a recovery bucket.

Salmon daily 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 and unmarked 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 liveboxes was estimated and recorded whenever traps were checked.
 Trap Efficiency Releases

Trap efficiency tests were conducted to estimate the proportion of passing juvenile salmon that were sampled by the Waterford trap. Natural fish captured in the trap were used when catches were sufficient to obtain a group of at least 30 fish over no more than two days. Hatchery fish were not made available for trap efficiency tests during 2007, and catches of natural fish were insufficient for trap efficiency tests to be conducted at Grayson.

Twelve groups of fish (all natural release groups ranging in size from 35 to 238 marked fish) were released at RM 30 (about 0.2 miles upstream of the trap) between February 13 and April 26 to estimate trap efficiencies at the Waterford trap. All marked fish were released after dark.

Holding Facility and Transport Method

Natural fish were transferred from liveboxes into either 5-gallon buckets or 20-gallon insulated coolers depending on the number of fish, temperatures, and distance traveled and transported by boat upstream to the release site.

At release sites, fish were held in live cars constructed of 15” diameter PVC pipe cut into 34” length (Figure 2). A rectangle approximately 6” wide by 23” long was cut longitudinally along the pipe and fitted with aluminum or stainless mesh. Live cars 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.
Marking Procedure

At Waterford, natural fish were marked on the trap or 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. With this method, a marker tip was placed against the caudal fin and orange photonic dye was injected into the fin rays. The photonic dye was chosen because of its known ability to provide a highly visible, long-lasting mark. The photonic dyes were purchased from Day-Glo, Cleveland, OH.

Pre-release Sampling

Prior to release, marked fish were sampled for mean 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; and the remaining fish in each group were enumerated. Mark retention was rated as present or absent. All fish examined during pre-release were found to have marks during 2007.

Release Procedure

Livecars were located several feet away from the specific release point and fish were poured from the livecars 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 so they could swim away. After releasing a "net-full" of fish, about 30 seconds to 3 minutes elapsed before another group of about "net-full" of fish was released. Amount of time between “net-full” releases varied depending on how fast fish swam away after their release. Total release time for marked groups ranged from five minutes to 18 minutes depending on the size of the group.

Monitoring Environmental Factors

Flow Measurements and Trap Speed

Provisional daily average flow for the Tuolumne River at La Grange was obtained from USGS at http://waterdata.usgs.gov/ca/nwis/dv/?site_no=11265000&agency_cd=USGS. Provisional daily average flow for the Tuolumne River at Modesto was obtained from the USGS at http://waterdata.usgs.gov/ca/nwis/dv/?site_no=11290000&agency_cd=USGS. Flow data was also provided by the Turlock Irrigation District for the Hickman spill which affected flows observed at the Waterford trap. Velocity of water entering the traps was measured using two methods. First, the water velocity entering the traps was measured daily with a Global Flow Probe, manufactured by Global Water (Fair Oaks, CA). Second, an average daily trap rotation speed was calculated for each trap by recording the time (in seconds) for three continuous revolutions of the cone both before and after the morning trap cleaning, then averaging the two times per revolution recorded.
**River Temperature, Relative Turbidity and Dissolved Oxygen**

Instantaneous water temperature was measured daily with a mercury thermometer at the trap site. Data was also available from hourly recording thermographs maintained by the Irrigation Districts at Shiloh Road (RM 3.4) near the Grayson traps and by California Department of Fish and Game at Hickman Bridge (RM 32) near the Waterford trap. To measure daily instantaneous turbidity a water sample was collected each morning and later tested at the field station with a LaMotte turbidity meter, model 2020e. Turbidity was recorded in nephelometric turbidity units (NTU). Instantaneous dissolved oxygen was measured during some trap checks with a YSI Model 556 meter at the trap site and recorded in mg/L.

**Estimating Trap Efficiency and Chinook Abundance**

Since sampling did not occur every day at Waterford, catches were first adjusted to account for missing values associated with days not sampled. Catches were not adjusted for temporary trap stoppage which occurred infrequently at both Waterford and Grayson during 2007.

If no sampling occurred on a given day, catch was estimated using the combined daily counts for up to five days prior to and immediately following the period of no sampling days. The estimation procedures involved the following steps:

1. Adding one to the combined counts from the five previous and five subsequent days,
2. Taking the natural logs of the resulting values,
3. Computing the weighted mean of those natural logs, and
4. Re-transforming the resulting mean.

The computation is summarized in the following equation:

\[
\bar{c}(i) = \exp \left( \frac{\sum_{j=1}^{5} w(i+j) \ln[c(i+j)+1] + \sum_{j=1}^{5} w(i-j) \ln[c(i-j)+1]}{\sum_{j=1}^{5} w(i+j) + \sum_{j=1}^{5} w(i-j)} \right) - 1
\]

wherein, \( \ln[ ] \) represents natural log of the function within [ ], \( \exp{ } \) represents the exponential constant raised to the power within{ }, and \( w( ) \) represents a weighting variable. The weights are greater for more proximal days, specifically,

\[
\begin{align*}
  w(i+1) &= w(i-1) = 5, \\
  w(i+2) &= w(i-2) = 4, \\
  w(i+3) &= w(i-3) = 3, \\
  w(i+4) &= w(i-4) = 2, \\
  w(i+5) &= w(i-5) = 1
\end{align*}
\]

unless the count on the day associated with the weight is also missing, the associated weight is 0.
After all missing daily values were calculated, the estimated daily number of fish passing each site was generated by either expanding the catch data by the average estimated trap efficiency for the lifestage captured (Waterford) or by a trap efficiency predictor equation (Grayson).

At Waterford, the trap efficiency dataset is limited because sampling has only been conducted during 2006 and 2007, and the dataset is not yet sufficient to develop meaningful regression relationships between trap efficiency and predictor variables such as river flow, fish size, or turbidity. In the interim, an estimate of salmon relative abundance for the sampling season was calculated by expanding the daily number of fish by the average observed trap efficiency for each lifestage during 2007, or 7.7% (47 recoveries from 612 released) for fry and 5.3% (29 recoveries from 545 released) for parr/smolts.

At Grayson, flow and trap efficiency data collected from 1999 through 2006 were used to develop a multiple regression equation to estimate daily trap efficiencies. Specifically, average daily river flow at Modesto, average fish size at release, and transformed (e.g., natural log) proportions of fish recovered from each release event were used to develop the following trap efficiency predictor equation with an adjusted $R^2$ of 0.64:

$$\text{Daily Predicted Trap Efficiency} = \exp(-0.12171 + (-0.00042 \times \text{Flow at MOD}) + (-0.03631 \times \text{Fish size}))$$

Where Flow at MOD = daily average river flow at Modesto
Fish Size = daily average forklength of fish captured at Grayson

These daily predicted trap efficiencies (DPTE) were then applied to the daily adjusted catch (DAC; actual catch plus missing values) to estimate daily passage as follows:

Estimated Daily Passage = DAC/DPTE

Rough estimates of daily passage were also calculated using the proportion of flow sampled by the trap(s) as a surrogate for trap efficiency. The proportion of flow sampled at each site was estimated by the following equation:

$$N_e = C_d \sqrt{\frac{V_d}{F_d} \left(\frac{3.14 \times r^1}{2}\right)}$$

where, $N_e$ is the expanded daily number of fish; $C_d$ is the daily catch (actual catch and missing values); $V_d$ is the daily velocity; $r$ is the radius of the trap; and $F_d$ is the daily flow measured at La Grange plus flow from the Hickman spill.
RESULTS AND DISCUSSION

Chinook Salmon

*Number of Unmarked Chinook Salmon Captured*

Juvenile salmon outmigration in the San Joaquin Basin typically occurs during the winter and spring, extending from January through May. The winter migration period is dominated by fry migrants that are typically less than 50 mm forklength, and the spring period is dominated by smolts which are typically greater than 70 mm forklength. During 2007 catches of juvenile salmon at Waterford were highest from mid-February through mid-April, and daily catches through mid-March primarily consisted of fry (<50 mm). Daily catches of juvenile salmon at Waterford between January 12 and June 5 ranged from zero to 253 fish and totaled 3,312 fish (Figure 3).

At Grayson, catches of juvenile salmon were highest during the latter half of April and coincident to a ten day pulse flow event of 700-1,000 cfs. Daily catches of juvenile salmon at Grayson during 2007 ranged from zero to six fish and totaled 27 fish between March 24 and May 29 (Figure 4). All salmon captured at Grayson during 2007 were smolts (>70mm); however sampling was not conducted during the winter when fry migration typically occurs.

Total annual catch of juvenile salmon has varied substantially between years at Grayson/Shiloh (Table 1; Figure 5); and this variation is likely due to differences in one or more factors including the duration and timing of the sampling periods, flow conditions, and overall fish abundance (Table 1; Figure 5). Sampling periods have varied between years with sampling initiated as early as January or as late as April and continuing through May/June.

During 1999-2002 and 2006, sampling at Grayson encompassed the majority of the expected winter/spring outmigration season (i.e., January-May/June) and can be described as comprehensive (Table 1; Figure 5). In contrast, sampling was only conducted during the spring smolt outmigration period (i.e., April-May/June) in 1995-1997 at Shiloh and 2003-2005 and 2007 at Grayson, so sampling was incomplete for these years. Sampling during 1998 began in February but was limited to a single trap (note: two traps were operated in all other years); thus, 1998 sampling covered an intermediate proportion of the entire outmigration period relative to all other years of monitoring.

Of the winter/spring sampling years, total trap catch at Grayson ranged from a high of 19,327 during 1999 to a low of 436 during 2002, and averaged 7,123 juvenile salmon (Figure 5). In all years of spring-only sampling, catches ranged from a high of 1,239 during 2001 to a low of 27 during 2007. The proportion of the typical outmigration period monitored each year ranged from 91% to 97% during winter/spring sampling years, from 24% to 45% during spring-only sampling years, and was 70% in the intermediate sampling year (Table 1). These proportions were calculated by taking the total number of sampling days in a given year and dividing by the total number of days for a typical complete outmigration period (i.e., January 1 through May 31). The proportion of the outmigration period sampled may not be representative of the proportion of the juvenile population migrating during the sample period because migration timing can be influenced by environmental factors such as flow.
Figure 3. Daily catch of unmarked Chinook salmon at Waterford and river flow at La Grange (LGN) during 2007.

Figure 4. Daily catch of unmarked Chinook salmon at Grayson and river flow at Modesto (MOD) during 2007.
 Trap Efficiency and Estimated Chinook Salmon Abundance

Trap efficiency estimates for fry at Waterford ranged from 2.9% to 9.2% at flows (e.g., La Grange and Hickman spill combined) of 338 cfs to 350 cfs (Table 2; Figure 6). Trap efficiency estimates for parr and smolt sized fish ranged from 4.0% to 9.5% at flows of 337 cfs to 869 cfs. Average forklength at release of the 12 trap efficiency test groups ranged from 34.9 mm to 84.9 mm (Table 2).

At Grayson, observed trap efficiency estimates during 1999-2006 ranged from zero to 21.2% at flows of 280 cfs to 7,942 cfs (Table 3; Figure 7). Catches of naturally produced salmon in the traps were insufficient to obtain suitable numbers for trap efficiency releases and hatchery fish were not available during 2007; therefore trap efficiency releases were not conducted at Grayson during 2007.

Missing value estimates, daily predicted trap efficiency, and daily estimated passage at Waterford and Grayson in 2007 are provided in Appendices A and B, respectively.
Table 2. Trap efficiency results from Waterford during 2007.

<table>
<thead>
<tr>
<th>Lifestage</th>
<th>Release Date</th>
<th>Origin</th>
<th>Adjusted Number Released</th>
<th>% Recaptured</th>
<th>Length at Release (mm)</th>
<th>Length at Recap. (mm)</th>
<th>Flow (cfs)</th>
<th>Turbidity</th>
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Table 3. Trap efficiency results from 1999-2006 used to derive the regression equation for predicting daily trap efficiencies at Grayson.

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<th>% Recaptured</th>
<th>Length at Release (mm)</th>
<th>Length at Recap. (mm)</th>
<th>Flow (cfs)</th>
<th>Turbidity</th>
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Fish ~ Water ~ Wildlife
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<th>Length at Release (mm)</th>
<th>Length at Recap.ture (mm)</th>
<th>Flow (cfs)</th>
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<td>---------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>09-Feb-06</td>
<td>Wild</td>
<td>Caudal fin pink</td>
<td>37</td>
<td>5</td>
<td>13.5%</td>
<td>34.6</td>
<td>35.2</td>
<td>3393</td>
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<td>Caudal fin pink</td>
<td>26</td>
<td>4</td>
<td>15.4%</td>
<td>34.9</td>
<td>37.3</td>
<td>3437</td>
</tr>
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<td>Caudal fin pink</td>
<td>23</td>
<td>1</td>
<td>4.3%</td>
<td>36.1</td>
<td>37.0</td>
<td>3416</td>
</tr>
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<td>Wild</td>
<td>Caudal fin pink</td>
<td>28</td>
<td>1</td>
<td>3.6%</td>
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<td>03-Mar-06</td>
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<td>34.8</td>
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<td>05-May-06</td>
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<td>Caudal fin yellow</td>
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<td>4</td>
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<td>73.2</td>
<td>74.3</td>
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<td>Caudal fin yellow</td>
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<td>81.8</td>
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<td>Hatchery</td>
<td>Top caudal yellow</td>
<td>1,532</td>
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<td>83.7</td>
<td>69.5</td>
<td>6537</td>
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<td>0.1%</td>
<td>85.4</td>
<td>83.0</td>
<td>4864</td>
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Figure 6. Trap efficiency estimates and river flow at Waterford during 2007.
Based on calculated daily passage estimates, an estimated 57,801 unmarked Chinook salmon passed Waterford during 2007, an average of approximately 200 juveniles per female spawner, and 51% of these were smolts (Table 4). Similar to the pattern observed for catch, it is estimated that a majority of the salmon passing Waterford prior to mid-March were fry and catch was then dominated by smolts from late-March through May (Table 4; Figure 8). Daily estimated passage at Waterford ranged from zero to 4,755 salmon. Peaks in daily passage for fry occurred on February 13 and smolt passage peaked on April 20 (Figure 8; Figure 10).

An estimated 937 smolts passed Grayson during 2007. Daily estimated passage at Grayson ranged from 0 to 217 salmon and peak passage occurred from April 23 to April 26 (Figure 11). Since 1995 total estimated passage at Grayson during winter/spring sampling years ranged from a high of 696,115 during 1999 to a low of 14,315 during 2002 (Table 1; Figure 9). During spring-only sampling years at Grayson/Shiloh, estimated passage ranged from a high of 264,376 in 2005 to a low of 937 during 2007 (Table 1; Figure 9). Estimated passage was highest during 1998 (Table 1; Figure 9) when sampling effort was intermediate (i.e., February-July). However, the 1998 passage estimate may be inflated because no trap efficiency tests were conducted with fry.

For comparison, rough passage estimates were also calculated based on the estimated proportion of flow sampled at each site during 2007. This method produced estimates of 19,404 salmon at Waterford and 270 salmon at Grayson. These estimates are provided for the purpose of comparison only and they are not reflected in the tables and figures presented in this report.

Table 4. Estimated passage by lifestage at Waterford and Grayson during 2007.

<table>
<thead>
<tr>
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<th>Waterford</th>
<th>Grayson</th>
</tr>
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<tbody>
<tr>
<td>Fry</td>
<td>20,633</td>
<td>NS</td>
</tr>
<tr>
<td>Parr</td>
<td>7,614</td>
<td>0</td>
</tr>
<tr>
<td>Smolts</td>
<td>29,554</td>
<td>937</td>
</tr>
<tr>
<td>TOTAL</td>
<td>57,801</td>
<td>937</td>
</tr>
</tbody>
</table>

Figure 7. Trap efficiency observations at Grayson relative to river flow at Modesto, 1999-2006.
Figure 8. Juvenile salmon passage by lifestage at Waterford during 2007.

Figure 9. Total estimated Chinook passage at Shiloh and Grayson during 1995-2007.
Estimated Chinook Salmon Abundance and Environmental Factors

Trends in passage at Waterford and Grayson during 2007 were similar to the trends described for catch, and peaks in juvenile salmon passage coincided with storm events and a late April pulse flow event. River releases during January through mid-April ranged only from 308 cfs to 367 cfs which translated to relatively stable flow conditions in the river at Waterford. Higher pulse flows with two peaks occurred during the spring. River flow was more variable near Grayson as a result of storm run-off, particularly from Dry Creek entering at Modesto, and ranged from 439 cfs to 957 cfs. The Grayson traps were not operated during the winter storm run-off events so salmon passage during these periods was not estimated.

During 2007 monitoring, daily average water temperatures near Waterford ranged from 45.7°F to 70.4°F (Figure 12), and from 55.2°F to 71.4°F near Grayson (Figure 13). Water temperatures generally increased through the outmigration season as ambient air temperatures increased. There were no obvious correlations between trends in passage and water temperature during 2007, but comparisons between years indicate that migration occurs over a more extended timeframe during years when late spring water temperatures in the lower Tuolumne River remain cooler. Relative to earlier migrants, late spring migrants may be exposed to higher water temperatures in the Delta and higher export rates.

Background turbidity was less than 2 NTU at Waterford (Figure 14) and 3 NTU at Grayson (Figure 15) during the 2007 monitoring periods. During several storm events from mid-February through late April spikes in turbidity ranging from 2.9 NTU to 6.8 NTU were observed at Waterford, and from 4.8 NTU to 7.8 NTU were observed at Grayson. Peaks in passage on February 13, March 29-30, and April 20 at Waterford, and April 22-26 at Grayson coincided with periods of elevated turbidity. All turbidity events coincided with changes in flow so it is unclear whether migration was stimulated by changes in flow, elevated turbidity, or a combined influence of the two factors.

The ratio of estimated total passage at Grayson relative to the estimated total passage at Waterford provides an index of survival through the river between the sites (24.6 miles) during years when the majority of the outmigration period is sampled. However, sampling at Grayson began in late March during 2007 and an unknown number of salmon may have moved past the site prior to the initiation of sampling, particularly during run-off events in mid-February and late February/early March. Consequently, an index was not calculated for 2007.
Figure 10. Daily estimated passage of unmarked Chinook salmon at Waterford and river flow at La Grange (LGN) during 2007.

Figure 11. Daily estimated passage of unmarked Chinook salmon at Grayson and river flow at Modesto (MOD) during 2007.
Figure 12. Daily estimated passage of unmarked Chinook salmon at Waterford and daily average water temperature at Hickman Bridge (RM 32) during 2007.

Figure 13. Daily estimated passage of unmarked Chinook salmon at Grayson and daily average water temperature at Shiloh during 2007.
Figure 14. Daily estimated passage of unmarked Chinook salmon and instantaneous turbidity at Waterford during 2007.

Figure 15. Daily estimated passage of unmarked Chinook salmon and instantaneous turbidity at Grayson during 2007.
**Chinook Salmon Length at Migration**

Individual forklengths of unmarked salmon captured at Waterford during 2007 ranged from 29 mm to 166 mm (Figure 16), and average length gradually increased from approximately 34 mm to 89 mm over the course of the sampling period (Figure 17 and Figure 18). Most of the juvenile salmon passing Waterford during 2007 were smolts measuring 70-89 mm or fry measuring 30-39 mm (Figure 21). In total, it is estimated that 20,633 fry (<50 mm), 7,614 parr (50-69 mm), and 29,554 smolts (>70 mm) passed Waterford during 2007.

Individual forklengths of unmarked Chinook salmon captured at Grayson during 2007 ranged from 76 mm to 91 mm (Figure 19), and average length fluctuated between 76 mm and 90 mm during the sampling period (Figure 18 and Figure 20). Nearly 75% of the salmon estimated to have passed Grayson during 2007 measured 80-89 mm, however, the length frequency distribution does not include salmon which may have migrated prior to the initiation of sampling in late March and may not accurately represent the 2007 outmigration.

![Graph](image.png)

Figure 16. Individual forklengths of juvenile salmon captured at Waterford during 2007.
Figure 17. Daily minimum, average, and maximum fork lengths of unmarked Chinook salmon captured at Waterford during 2007.

Figure 18. Average fork length of juvenile Chinook salmon captured at Waterford and Grayson by Julian week during 2007.
Figure 19. Individual forklengths of juvenile salmon captured at Grayson during 2007.

Figure 20. Daily minimum, average, and maximum fork lengths of unmarked Chinook salmon captured at Grayson during 2007.
Figure 21. Estimated Chinook passage by 10 mm fork length intervals at Waterford during 2007.

Figure 22. Estimated Chinook passage by 10 mm fork length intervals at Grayson during 2007.
Chinook Salmon Condition at Migration

Juveniles captured at both Waterford and Grayson during 2007 were generally healthy with no apparent signs of disease or stress. Trends in individual salmon smolt forklength to weight completely overlapped between Waterford and Grayson (Figure 23).

![Individual Weights and Forklengths of Salmon Captured during 2007](image)

Figure 23. Individual forklength and weight of individual juvenile Chinook salmon measured at Waterford and Grayson during 2007.

Oncorhynchus mykiss (Rainbow Trout)

Nine *O. mykiss* were captured at Waterford between February 20 and June 5, 2007 (Table 5). Four *O. mykiss* were classified as young-of-the-year (<100 mm; range: 35 mm to 77 mm), one was classified as Age 1+ (100 mm-299 mm; range: 195 mm) and the remaining four *O. mykiss* were classified as adults (≥300 mm; range: 310 mm to 360 mm).

At Grayson, no *O. mykiss* were captured during 2007.
Table 5. Length, weight, and smolt index of *O. mykiss* captured at Waterford during 2007.

<table>
<thead>
<tr>
<th>Date</th>
<th>Fork Length (mm)</th>
<th>Total Length (mm)</th>
<th>Weight (g)</th>
<th>Smolt Index*</th>
<th>Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-Feb-07</td>
<td>195.0</td>
<td>205.0</td>
<td>74.2</td>
<td>5</td>
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</tr>
<tr>
<td>22-Apr-07</td>
<td>64.0</td>
<td>67.0</td>
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</tr>
<tr>
<td>27-Apr-07</td>
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<td>315.0</td>
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</tr>
<tr>
<td>2-May-07</td>
<td>35.0</td>
<td>36.0</td>
<td>0.3</td>
<td>2</td>
<td>No</td>
</tr>
<tr>
<td>3-May-07</td>
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<td>334.0</td>
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<td>No</td>
</tr>
<tr>
<td>15-May-07</td>
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<td>375.0</td>
<td>621.7</td>
<td>IAD</td>
<td>No</td>
</tr>
<tr>
<td>18-May-07</td>
<td>77.0</td>
<td>80.0</td>
<td>5.4</td>
<td>3</td>
<td>No</td>
</tr>
<tr>
<td>5-Jun-07</td>
<td>325.0</td>
<td>345.0</td>
<td>439.0</td>
<td>IAD</td>
<td>No</td>
</tr>
</tbody>
</table>

*Smolt index 1=yolk-sac fry; 2=fry; 3=parr; 4=silvery parr; 5=smolt; 6=mature adult; IAD= immature adult

Other Fish Species Captured

A total of 4,944 non-salmonids representing at least 18 species (6 native, 12 introduced) were captured during operation of the Waterford and Grayson traps in 2007 (Table 6; Appendices C and D). Native species comprised 94% of the total non-salmonid catch, consisting primarily of Sacramento sucker (n= 3,784). Species captured only at Waterford were brown bullhead, prickly sculpin, riffle sculpin, and lamprey; and those recorded only at Grayson were channel catfish, carp, smallmouth bass, and warmouth. Lamprey captured in the traps were primarily ammocoetes and were not identified to species or measured.
Table 6. Non-salmonid species captured at Waterford and Grayson during 2007. Native species are indicated in bold.

| Common Name | Scientific Name | Waterford | | | Grayson | | | | |
| | | Total Catch | Minimum Length (mm) | Average Length (mm) | Maximum Length (mm) | Total Catch | Minimum Length (mm) | Average Length (mm) | Maximum Length (mm) |
| Catfish Family | Ictalurus nebulosus | 1 | 190 | 190 | 190 | 0 | - | - | - |
| Brown Bullhead | Ictalurus punctatus | 0 | - | - | - | 9 | 49 | 286 | 550 |
| White catfish | Ictalurus catus | 7 | 172 | 216 | 270 | 78 | 30 | 84 | 278 |
| Herring Family | Dorosoma petenense | 1 | 109 | 109 | 109 | 1 | 98 | 98 | 98 |
| Threadfin shad | Not applicable | 26 | - | - | - | 0 | - | - | - |
| Lamprey Family | Not applicable | 0 | - | - | - | 0 | - | - | - |
| Lamprey - unidentified species | Not applicable | 0 | - | - | - | 0 | - | - | - |
| Livebearer Family | Gambusia affinis | 1 | 28 | 28 | 28 | 2 | 29 | 34 | 38 |
| Mosquitofish | Cyprinus carpio | 0 | - | - | - | 2 | 24 | 272 | 520 |
| Minnow Family | Mylopharodon conopephalus | 557 | 28 | 41 | 145 | 41 | 30 | 44 | 60 |
| Hardhead | Notemigonus crysoleucas | 3 | 44 | 63 | 100 | 3 | 66 | 77 | 83 |
| Golden shiner | Cyprinella lutrensis | 7 | 36 | 47 | 60 | 18 | 30 | 48 | 115 |
| Red shiner | Ptychocheilus grandis | 150 | 30 | 50 | 137 | 25 | 28 | 52 | 78 |
| Sacramento pike minnow | Cottus asper | 87 | 53 | 72 | 100 | 0 | - | - | - |
| Sculpin Family | Cottus gulosus | 6 | 69 | 80 | 87 | 0 | - | - | - |
| Prickly Sculpin | Catostomus occidentalis | 128 | 24 | 48 | 427 | 3,656 | 13 | 27 | 46 |
| Riffle sculpin | Lepomis macrochirus | 9 | 47 | 66 | 134 | 3 | 116 | 139 | 160 |
| Sunfish Family | Micropterus salmoides | 4 | 23 | 25 | 25 | 54 | 18 | 28 | 85 |
| Bluegill | Micropterus dolomieu | 0 | - | - | - | 49 | 18 | 35 | 142 |
| Large mouth bass | Lepomis gulosus | 0 | - | - | - | 2 | 67 | 74 | 80 |
| Smallmouth bass | Not applicable | 0 | - | - | - | 6 | 18 | 22 | 27 |
| Warmouth | Not applicable | 0 | - | - | - | 8 | 10 | 22 | 26 |
REFERENCES CITED


### Appendix A. Daily Chinook catch, length, and passage at Waterford and environmental data from 2007.

<table>
<thead>
<tr>
<th>Date</th>
<th>Catch</th>
<th>Unmarked Salmon</th>
<th>Estimated Passage</th>
<th>Flow</th>
<th>Environmental Conditions</th>
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<tr>
<td></td>
<td>Observed</td>
<td>Missing</td>
<td>Adjusted</td>
<td>Forklength (mm)</td>
<td>Est. Efficiency</td>
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<td>-</td>
</tr>
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| Total    | 6   | 3   | 2   | 9   | 3   | 41  | 54  | 2   | 18  | 25   | 3,656 | 49  | 1   | 8    | 2 | 78  |

D-2
Key to species codes

BGS  Bluegill
CHC  Channel catfish
CHNF  Chinook
FHM  Fathead minnow
GF  Goldfish
GSF  Green sunfish
GSN  Golden shiner
HH  Hardhead
HCH  Hitch
LAM  Lamprey, unidentified species
LMB  Largemouth bass
MQK  Mosquitofish
MSS  Inland silverside
RBT  Rainbow trout
RES  Redear sunfish
RSN  Red shiner
SASQ  Sacramento pikeminnow
SASU  Sacramento sucker
SMB  Smallmouth bass
TP  Tule perch
UNID  Unidentified species
W  Warmouth
WHC  White catfish