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	)	
and	)	Project No. 2299
	)	
Modesto Irrigation District	)	

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Large CWT Smolt Survival Analysis Update (1987–2002)

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INTRODUCTION AND OVERVIEW OF THE CWT EVALUATION

Pursuant to an agreement by TRTAC representatives at a meeting on 16 December 1999, a TAC Subcommittee ("Subgroup") was assigned the task of reviewing and evaluating the smolt-survival studies that have been conducted by the California Department of Fish Game (CDFG) in the Tuolumne River since the mid-1980s. Those CDFG studies entail the marking with coded-wire tags (CWTs) and release of large numbers of hatchery-reared juvenile salmon at specified locations, followed by attempted recaptures of the marked fish by intensive sampling at localities downstream of the release sites. The purpose of the CWT-based studies (henceforth, "CWT studies") is to estimate smolt survival rates as the fish travel downstream and to relate those survival rates to conditions that were experienced by the migrating fish.

After initial discussion, the Subgroup decided that the objectives of its evaluation would be to address the following questions.

(1) Does the implementation of the experimental design meet the critical underlying assumptions of the mark-and-release procedure in each year of the studies?
(2) Can the survival estimate obtained for each year be related to a specific flow or range of flows in the Tuolumne River?

The need for an evaluation of the CWT studies and the general philosophy in conducting it was described in an earlier document within the 2001 Annual FERC Report (Report 2001-5, "Rationale for Conducting the CWT Evaluation in Progress by the TRTAC Subgroup"). That document noted the exploratory nature of the evaluation, the progress and justification of which was subject to periodic assessment by the Subgroup.

Conducting the CWT Evaluation. The strategy adopted by the Subgroup in conducting the evaluation consisted of two steps: (a) delegate to CDFG the responsibility of checking the completeness and accuracy of its databases and consolidating all relevant data from its CWT program into electronic format: (b) contract Stillwater Sciences of Berkeley California to perform data organization and analysis, subject to ongoing review by the Subgroup as phases of the evaluation are completed.

As described in detail in the 2001 Annual FERC Report (Report 2001-5, "Rationale for Conducting the CWT Evaluation in Progress by the TRTAC Subgroup"), the evaluation of the CWT data was conducted in segments. The evaluation of the first set of data (for years 1994-1998) was largely completed by November 2001 and followed by evaluation of the second data set comprising years 1987, 1990, 1999-2001 and of the third data set for year 2002. Results from the latest evaluation encompassing all data-set years are given in the present report

Present Status of the CWT Evaluation. One significant accomplishment of the CWT evaluation to date has been the completion of data-quality checking and consolidation of data sets relevant to the CWT field studies. That effort was largely conducted by CDFG staff and provides at least two benefits. (1) There is now a better understanding of how much data, and of what quality, are available from all the years of CWT studies. (2) The data are better organized and more accessible for future analyses, whether for smolt-survival estimates or other issues.

As described in detail in this report, smolt-survival estimates have been computed and an assessment of the reliability, or validity, of the underlying data has been made. Also, consonant with the original goal of the CWT studies, the relationship between the estimated survival values

and corresponding river flows has been tentatively explored. The task that must now be confronted is for the TRTAC biologists and stakeholders to discuss and interpret the putative relationship between smolt survival and flows.

BACKGROUND

Since 1986, the California Department of Fish and Game (CDFG) has conducted a series of paired release experiments of coded wire tagged (CWT) chinook salmon smolts to estimate survival rates and to quantify the relationship between smolt survival and flow in the Tuolumne River as part of the Don Pedro Project study plan. At the request of the TRTAC, the Monitoring Subcommittee has conducted a multi-year review of the CDFG coded wire tag (CWT) smolt release experiments. Its purpose is to provide a critical review of the underlying data quality of each year's smolt survival index so that these indices might be used in the development of a smolt survival relationship with flow.

The Monitoring Subcommittee initially defined several data analysis tasks that were completed by Stillwater Sciences on a sub-set of the data set between the years 1987, 1990, 1994–2001 (TID/MID 2002, 2003, and 2004). This report includes an expanded analysis of one additional year of data collected in 2002 (Appendix A) and constitutes an addendum to the previous reports on the CWT study review.

METHODS

Update for 2002 Data. Test flows at La Grange were near 1,300 cfs in 2002, with 74,924 smolts released at Old La Grange Bridge on April 24–25. The two lower release groups of 23,871 and 25,701 were released at the Old Fisherman's Club in the San Joaquin River on April 26 and April 29. Preliminary review of the daily recaptures at Mossdale indicated a large discrepancy in recaptures totals for first and second lower release groups (Tag Codes 06-44-61 and 06-44-69). The three days difference in release timing and a missed day of sampling at the Mossdale trawl on April 30 were sufficient to cause a large difference in recovery totals (116 total vs. 25 for first and second groups, respectively). Based upon discussions within the Monitoring Subcommittee, it was suggested that the peak recapture period for the second lower release group may have been on the missed trawl day, whereas the peak recapture period had already occurred for the other release codes (Appendix A). A decision was made to exclude the recovery data from the second lower release group, changing the calculated smolt survival index from over 80% to 53%.

Overall Data Quality Review. The prior reviews of the CDFG CWT experiments (TID/MID 2002) assessed fifteen factors that may have affected the paired release assumptions (*e.g.*, fish size, exposure to similar conditions, equality of capture effort, etc.). Table 1 shows the relative importance of each study factor, where each matrix cell (i,j) represents the outcome of comparing factor i and factor j with regard to the relative importance of the two factors, as judged by the CWT-evaluation Subgroup members (TID/MID 2003). Table 2 presents an evaluation of the fifteen experimental factors the CWT Subgroup used to assess the data quality underlying each year's survival index. The scores in Table 2 reflect a zero for circumstances in which study assumptions were clearly not met, 1 when study assumptions may not have been met, and 2 when study assumptions were satisfied. Table 3 shows the relative importance of each study factor and data quality in each year combined as a product. These products are then summed in the bottom row of the Table 3 to give a confidence weight for each year (column) that represents an index of

confidence in the data validity for that year. Higher weights indicated greater confidence in data validity.

Smolt Survival Estimates. Table 4 shows the total numbers of tagged smolts released and recaptured both as raw and expanded numbers for capture effort at Mossdale, along with the relevant flows for each smolt survival experiment as presented in prior year CWT evaluation reports (TID/MID 2002, 2003). To calculate the smolt survival index, the CWT experiments conducted by CDFG use a paired release-recapture design (Burnham et. al. 1987) of upstream (treatment) and downstream (control) fish. The in-river survival is estimated by comparing the rates at which the two groups are recovered further downstream (*e.g.*, Mossdale, CVP and SWP Fish Protection Facilities, Chipps Island Trawl, etc.). Given the known release numbers n_c and n_t for the control and treatment groups, respectively, and corresponding recovery numbers m_c and m_t at some downstream location, the usual estimate of in-river survival is:

$$\hat{S} = \frac{m_t / n_t}{m_c / n_c}, \qquad \hat{\text{var}}\left(\hat{S}\right) = \hat{S}^2 \left(\hat{\sigma}_t^2 / m_t^2 + \hat{\sigma}_c^2 / m_c^2\right)$$

Where $\hat{\sigma}_t^2$ and $\hat{\sigma}_c^2$ are the estimates of the variances of m_c and m_t, respectively. Table 4 shows the smolt survival indices for each year calculated on both actual recaptures as well as those calculated on a capture effort expansion basis.

Flow vs. Survival Regressions. To arrive at flow vs. survival regressions, survival indices from Table 4 were paired with various estimates of the flows best representing test conditions. In addition to the flows at La Grange on the day of release, average flows during the experiments at La Grange were combined as a single average calculated by multiplying flow by the daily smolt recovery at Mossdale, making a summation of these products for all days between first and last recapture, and then dividing by the total smolt recovery. Adjustment for water travel time from La Grange to Mossdale was also included by "lagging" the flow at La Grange by three days preceding the recapture dates at Mossdale.

RESULTS

Linear Flow vs. Survival Regressions. Figure 1 shows a linear model between flow and survival along with its associated uncertainty (shaded confidence band), representing actual smolt recoveries and the recovery-weighted mean flow (cfs) at La Grange from the day of release to the last recapture. Because survival estimates in the annual FERC reports do not reflect adjustments for capture effort, daily recaptures and trawl effort at Mossdale (Appendix A) were used to calculate a capture effort expansion of the apparent survival estimates (Table 4). Figure 2 shows a modified linear relationship between recovery weighted mean flow at La Grange and capture effort adjusted survival with only validated points from Table 3 included (*i.e.*, excluding 1990, 1994 and 1997).

The confidence band of Figures 1 and 2 are large enough that it is clear that the linear regression model cannot be used in any meaningful way as a management tool without the inclusion of more data points to narrow the associated uncertainty. For example, Equation 1 shows that the relationship between the raw survival data and release flows shown in Figure 1 is not statistically significant (p=0.49). Although the capture effort and flow adjusted smolt survival relationship shown in Figure 2 is marginally significant (p=0.1) after removing the excluded survival estimates (*i.e.*, 1990, 1994 and 1997), the two linear regression models fall within each of their

associated confidence intervals and thus Equations 1 and 2 cannot be treated as significantly different from one another.

$$SI = 0.453 + 4.86\text{x}10^{-5}*\text{Flow}, p = 0.49 \text{ (all years)} \qquad \text{Equation 1}$$
$$SI = 0.257 + 8.30\text{x}10^{-5}*\text{Flow}, p = 0.10 \text{ (validated points)} \qquad \text{Equation 2}$$

Logistic Flow vs. Survival Model. In addition to the marginal significance of the linear flow vs. survival relationship shown in Figure 2, the use of linear regression conceals a number of hidden assumptions in developing an acceptable relationship. Use of a linear regression model assumes:

1. For each experiment, the capture effort adjusted survival estimate is a sample from a Gaussian distribution.
2. The expected value of each of these distributions is a linear function of the recapture-weighted flow at LaGrange for the experiment.
3. All of these distributions have the same standard deviation.

Whether or not the first and third assumptions are met, one may still employ the tool of linear regression analysis to determine model parameters. However, the second assumption above is biologically unsound, since it violates the clear requirement that true smolt survival must be between zero and one.

To clarify the effect of these assumptions, an alternate analysis was conducted, using a relationship between flow and survival which respects the limits on survival and considers the underlying statistical assumptions more carefully. In this model:

1. All fish from the upper release group of a given experiment have the same probability of surviving to the downstream release location. This probability is a logistic function of the recapture-weighted flow at LaGrange for the experiment.
2. The expanded recoveries at the Mossdale trap from each group are samples from a gamma distribution (interpreted as an overdispersed Poisson distribution). The expected value of this distribution is proportional to the number of fish from the group which is present at the downstream release location. The constant of proportionality is assumed to be the same for both the treatment and control groups in any given experiment.

This model was fitted using the validated experiments only (i.e., omitting the 1990, 1994, and 1997 data). A highly significant ($p < 0.01$) relationship was found between flow and survival. The fitted flow-survival relationship is given in Equation 3. Figure 3 displays this relationship with 95% prediction confidence intervals, and with the simple "point" estimates of survival from each experiment for reference.

$$SI = 1/(1 + \exp(1.271 - 3.819\text{x}10^{-4}*\text{Flow})), p < 0.01 \text{ (validated points)} \qquad \text{Equation 3}$$

DISCUSSION

A number of factors have been discussed during the CWT evaluation and it is recognized that the analysis conducted to date using flow as the primary factor in determining smolt survival may not completely address other study factors or environmental conditions, ranging from changing release locations to flow and temperature variations. Below we summarize the major points of discussion for the purposes of improving the CWT evaluation to date.

Test Flows. The primary goal of the CWT studies was to attempt to gain an understanding of the flows required to ensure adequate smolt survival during spring outmigration. However, a number of conditions have called into question how well the test flows represent flows experienced by the CWT fish while in the study reach of the lower Tuolumne River. For example, test flows did not arrive at the lower release site in 1990 before the control group fish were released. In most years, the combination of extended CWT recovery periods of up to 30 days with varying flows after the few days following release means that using the initial release flow may misrepresent study conditions.

Although the Subgroup's decision to use recovery weighted average flow conditions produced large changes in the flow estimates for 1997 and 1998, the advantage of the selected method is that it weights the study flow towards the highest recovery period, typically the first few days after release of the CWT-marked fish. The primary disadvantage is that like the 70% and 90% recapture averaging periods used previously (TID/MID 2002, 2003); using recovery weighting instead of a fixed period after release may bias the flow towards conditions representing higher CWT recovery (i.e. either high survival or high capture probability). In the end, this decision recognizes a trade-off between determining appropriate release flows at La Grange and accurately representing flows experienced by outmigrating smolts.

Annual Variations in Meteorology and Temperature. While flow is widely accepted as a surrogate for many other environmental factors, it was noted that during low flow conditions the juvenile and smolt survival rates may be affected by high or variable water temperatures. It was noted by the Subgroup that although water temperatures would be fairly constant during high flows, it is possible that variable and stressful temperatures occur during low flow conditions and hot weather. Further, in some years excessively cold water temperatures in the study reach may affect smoltification and outmigration cues sufficiently to cause "residualization" or hold up of the test group relative to the controls. In addition to photo-period and other environmental causes, there is evidence to support this temperature hypothesis (McCormick and Saunders 1987 as cited in Hogasen 1998). In addition, Appendix A Tables show that with the exception of 1995, low water temperatures were associated with extended recovery periods in most years (e.g., 1996, 1998, 2000).

Although differential exposure to higher or lower temperatures was implicit in the data quality review (Tables 2 and 3), as an interim data analysis, the survival estimates and test flows were fit to a two parameter model by adding temperature as an effect. In general, adding temperature to the linear smolt survival model did not improve the significance over the logistic model. It is possible that a much larger data set may improve the significance of a combined flow and temperature model, given the small data set collected to date; these results do not warrant the inclusion of temperature in the model.

Use of survival estimates calculated from other recovery locations. To address the broad confidence interval developed to date, the Subgroup has discussed calculating additional survival estimates based upon recaptures at other location (*e.g.*, Chipps Island, Ocean Harvest estimates, etc.). The increased replication of independent estimates of smolt survival from other recovery locations may improve (i.e., reduce) the confidence intervals of the models developed to date. However, additional data quality verification and evaluation procedures would have to precede this analysis. In addition to factors related to export and barrier operations, the low recovery numbers of CWT fish at distant sites will increase the uncertainty of the individual survival estimates.

CONCLUSIONS

- Based upon the analyses to date, the CDFG CWT smolt survival experiments meet the majority of paired release study assumptions set forth by the TRTAC Monitoring Subcommittee.

- The resulting logistic relationship between Chinook salmon smolt survival and flow in the Tuolumne River is sufficient to provide a broad estimate of survival specific flows.

- More smolt survival estimates from other recovery locations or future experiments are needed to narrow the confidence intervals shown to date. The breadth of the confidence interval suggests that an attempt to reduce the existing confidence interval by one half would require four times the current number of smolt survival estimates used (i.e., 4 x 7 or 28 additional survival/flow estimates)

- Although the Subgroup has expressed a desire to gain an understanding at flows below those tested to date (*i.e.*, below 500 cfs), the uncertainty in the survival prediction interval increases markedly at flows above 4,000 cfs. For this reason, the greatest leverage in improving the existing flow vs. survival relationship would be realized at test conditions above these flows.

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Table 1: Assignment of Relative Importance of Experimental Factors of Tuolumne River CWT Studies as determined by TRTAC Monitoring SubCommittee on October 17, 2001

Note: Matrix values in each cell (i,j) indicate importance of each factor in comparison with all others.

Factor	i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	$\Sigma_{j=1-15}$
Control and treatment group fish > 75 mm FL at release	1	x															0
Control and treatment group fish were the same size (<5% Diff.) at release	2	2	x														1
Control and treatment group fish were of the same origin?	3	1	3	x													1
Control and treatment group fish were of the same egg lot?	4	1	2	3	x												0
Below 3°C Difference in hatchery water temperatures.	5	1	2	5	5	x											2
Below 3°C Difference in transport water temperatures.	6	1	2	3	6	5	x										1
Same potential for thermal shock at release site.	7	7	7	7	7	7	7	x									6
Control and treatment group fish exposed to temperatures >20°C at different times?	8	8	8	8	8	8	8	8	x								7
Control and treatment group fish traveled together out of lower Tuolumne river?	9	1	2	3	9	5	9	7	8	x							2
Low Temp. variation at Modesto (Range/Target < 20%) during 70% Shiloh recapture period	10	1	2	10	10	5	10	7	8	10	x						4
Low flow variation (Range/Target < 20%) at Modesto during 70% Shiloh recapture period	11	1	2	11	11	5	11	7	8	11	11	x					5
Control and treatment group fish traveled together through San Joaquin river?	12	1	2	12	12	5	12	7	8	12	12	11	x				5
Control and treatment group fish experienced similar Temp variations at Vernalis during 70% Mossdale recapture period.	13	1	2	13	13	5	13	7	8	13	10	11	12	x			4
Control and treatment group fish experienced similar Flow variations at Vernalis during 70% Mossdale recapture period.	14	1	2	14	14	5	14	7	8	14	10	11	12	14	x		5
Control and treatment group fish were subjected to similar capture effort at Mossdale	15	1	2	15	15	5	15	7	8	15	10	11	12	15	14	x	5
	$\Sigma_{i=1-15}$	11	10	3	0	8	0	7	7	0	3	4	3	0	1	0	
	$\Sigma_{(i,j)}$	11	11	4	0	10	1	13	14	2	7	9	8	4	6	5	
	Overall Importance (0 -15):	***12***	***13***	***4***	***1***	***11***	***2***	***14***	***15***	***3***	***8***	***10***	***9***	***5***	***7***	***6***	

Table 2: Evaluation of Data Quality of Experimental Factors of Tuolumne River CWT Studies between 1987-2002

ID	Factors Necessary to Meet CWT Study Assumptions	Assumptions Met in Year?										
		1987	1990	1994	1995	1996	1997	1998	1999	2000	2001	2002
Fish in the control and treatment groups were biologically similar and experienced similar handling, especially with regard to water temperatures at the hatchery, in the trailer, and at the release site.												
1	Control and treatment group fish were larger than 75 mm FL (Table 2).	2	0	2	2	2	0	2	2	1	2	2
2	Control and treatment group fish were the same size (<5% Diff.) at release (Table 2).	2	0	2	2	2	1	2	2	2	2	2
3	Control and treatment group fish were of the same origin?	2	2	2	2	2	2	2	2	2	2	2
4	Control and treatment group fish were of the same egg lot? (Table 2).	1	0	2	2	2	2	2	2	2	2	2
5	Below 3°C Difference in hatchery water temperatures (Table 2).	2	1	2	2	2	2	2	2	2	2	2
6	Below 3°C Difference in transport water temperatures (Table 2).	0	2	2	1	2	2	0	2	2	0	2
7	Same potential for thermal shock at release site (Table 2)	0	0	0	0	0	0	2	2	2	0	0
8	Were either treatment or control fish exposed to temperatures >20°C at different times (Table 5)	2	0	1	2	2	0	1	2	2	2	2
Did treatment and control fish experience similar conditions in Tuolumne River reach?												
9	70% recovery timing at lower Tuolumne site (Table 3) indicates treatment and control fish migrated out of the Tuolumne River under uniform conditions	0	0	0	0	0	0	0	1	0	1	0
10	Low Temperature variation at Modesto (Range/Target < 20%) during 70% Lower Tuolumne capture period (Table 5).	0	0	0	2	2	2	2	0	0	0	0
11	Low flow variation (Range/Target < 20%) at Modesto during 70% Lower Tuolumne capture period (Table 4).	2	0	0	2	2	0	2	0	0	2	0
Did treatment and control fish experience similar conditions in the San Joaquin River reach?												
12	70% Mossdale recovery timing (Table 3) indicates treatment and controls migrated together through the San Joaquin River.	0	0	2	1	0	0	0	0	1	2	2
13	Temperature variations at Vernalis during 70% Mossdale recapture period (Table 5) were similar for treatment and control fish.	2	2	2	1	2	1	2	2	2	2	2
14	Flow variations at Vernalis during 70% Mossdale recapture period (Table 4) were similar for treatment and control fish..	2	1	2	2	2	2	2	1	2	2	2
15	Control and treatment group fish were subjected to similar capture effort at Mossdale (Task 2).	1	2	1	1	0	0	0	1	1	2	2

2 Study Assumption Met
1 Study Assumption May Not Have Been Met
0 Factor Caused Violation in Study Assumption
Inferred assumption based on entry with no data.

Table 3: Relative Weights of Tuolumne River CWT Studies Survival Indices between 1987-2002

Note: Survival weights are calculated as the product of Study Factor Importance and Quality for each year.

ID	Importance	Factors Necessary to Meet CWT Study Assumptions	Assumptions Met in Year?										
			1987	1990	1994	1995	1996	1997	1998	1999	2000	2001	2002
Fish in the control and treatment groups were biologically similar and experienced similar handling, especially with regard to water temperatures at the hatchery, in the trailer, and at the release site.													
1	12	Control and treatment group fish were larger than 75 mm FL (Table 2).	24	0	24	24	24	0	24	24	12	12	24
2	13	Control and treatment group fish were the same size (<5% Diff.) at release (Table 2).	26	0	26	26	26	13	26	26	26	26	26
3	4	Control and treatment group fish were of the same origin?	8	8	8	8	8	8	8	8	8	8	8
4	1	Control and treatment group fish were of the same egg lot? (Table 2).	1	0	2	2	2	2	2	2	2	2	2
5	11	Below 3°C Difference in hatchery water temperatures (Table 2).	22	11	22	22	22	22	22	22	22	22	22
6	2	Below 3°C Difference in transport water temperatures (Table 2).	0	4	4	2	4	4	0	4	4	4	4
7	14	Same potential for thermal shock at release site (Table 2)	0	0	0	0	0	0	28	28	28	28	0
8	15	Were either treatment or control fish exposed to temperatures >20°C at different times (Table 5)	30	0	15	30	30	0	15	30	30	30	30
Did treatment and control fish experience similar conditions in Tuolumne River reach?													
9	3	70% Shiloh recovery timing (Table 3) indicates treatment and control fish migrated out of the Tuolumne River under Uniform conditions	0	0	0	0	0	0	0	3	0	0	0
10	8	Low Temperature variation at Modesto (Range/Target < 20%) during 70% Lower Tuolumne capture period (Table 5).	0	0	0	16	16	16	16	0	0	0	0
11	10	Low flow variation (Range/Target < 20%) at Modesto during 70% Lower Tuolumne capture period (Table 4).	20	0	0	20	20	0	20	0	0	0	0
Did treatment and control fish experience similar conditions in the San Joaquin River reach?													
12	9	70% Mossdale recovery timing (Table 3) indicates treatment and controls migrated together through the San Joaquin River.	0	0	18	9	0	0	0	0	9	9	18
13	5	Temperature variations at Vernalis during 70% Mossdale recapture period (Table 5) were similar for treatment and control fish.	10	10	10	5	10	5	10	10	10	10	10
14	7	Control and treatment group fish experienced similar Flow variations at Vernalis during 70% Mossdale recapture period.	14	7	14	14	14	14	14	7	14	14	14
15	6	Control and treatment group fish were subjected to similar capture effort at Mossdale (Task 2).	6	12	6	6	0	0	0	6	6	6	12
Relative weight of survival estimate for each year to be used in developing a La Grange flow vs. river-wide survival regression.													
Overall Weighting of Confidence in Survival Estimate for each Year (0 = None, 225 = Moderate, 450 = High)			***161***	***52***	***149***	***184***	***176***	***84***	***185***	***170***	***171***	***171***	***170***

Table 4: Comparison of Tuolumne River smolt survival between 1987 and 200 using actual and capture-effort-expanded CWT smolt recoverie

Year and CWT Release Group Number	Flow (cfs) at Release Measured at La Grange (Modesto)	Mean Flow (cfs) at La Grange weighted by daily recaptures at Mossdale	Mean Water Temperature (^{o}C) at Modesto weighted by daily recaptures at Mossdale	Actual Recovery Results		Capture Effort Expanded Results	
				Recaptures	Survival (%)	Recaptures	Survival (%)
1987 Upper 89,599	563	563	17.6	128	42 ± 9	2,494	35 ± 8
1987 Lower 93,509	(741)			317		7,174	
1990 Upper 93,653	599	241	19.4	63	30 ± 9	698	30 ± 9
1990 Lower 77,425	(556)			173		2,357	
1994 Upper 83,408	1,160	889	15.8	207	173 ± 46	NA	NA
1994 Lower 50,058	(862)			72		NA	
1995 Upper 83,549	7,730	8,217	11.3	58	79 ± 30	827	82 ± 16
1995 Lower 53,298	(7,740)			47		655	
1996 Upper 67,155	2,580	2,664	13.4	66	32 ± 9	525	35 ± 5.3
1996 Lower 50,460	(2,810)			156		1143	
1997 Upper 93,501	2,860	1,436	14.7	32	44 ± 19	273	33 ± 7.4
1997 Lower 72,464	(2,970)			56		663	
1998 Upper 94,058	6,400	4,050	12.1	130	103 ± 31	816	117 ± 18
1998 Lower 47,760	(7,100)			64		361	
1999 Upper 76,221	1,953	1,960	14.2	45	19 ± 6	248	34 ± 12
1999 Lower 50,957	(1,965)			158		728	
2000 Upper 72,674	3,793	2,982	13.1	37	28 ± 11	210	50 ± 20
2000 Lower 44,769	(3,750)			81		422	
2001 Upper 68,885	623	635	17.3	107	18 ± 4	390	27 ± 6
2001 Lower 46,443	(651)			399		1,439	
2002 Upper 74,924	1,310	1,274	15.9	179	53 ± 12	859	53 ± 12
2002 Lower 23,871	1,265			116		556	

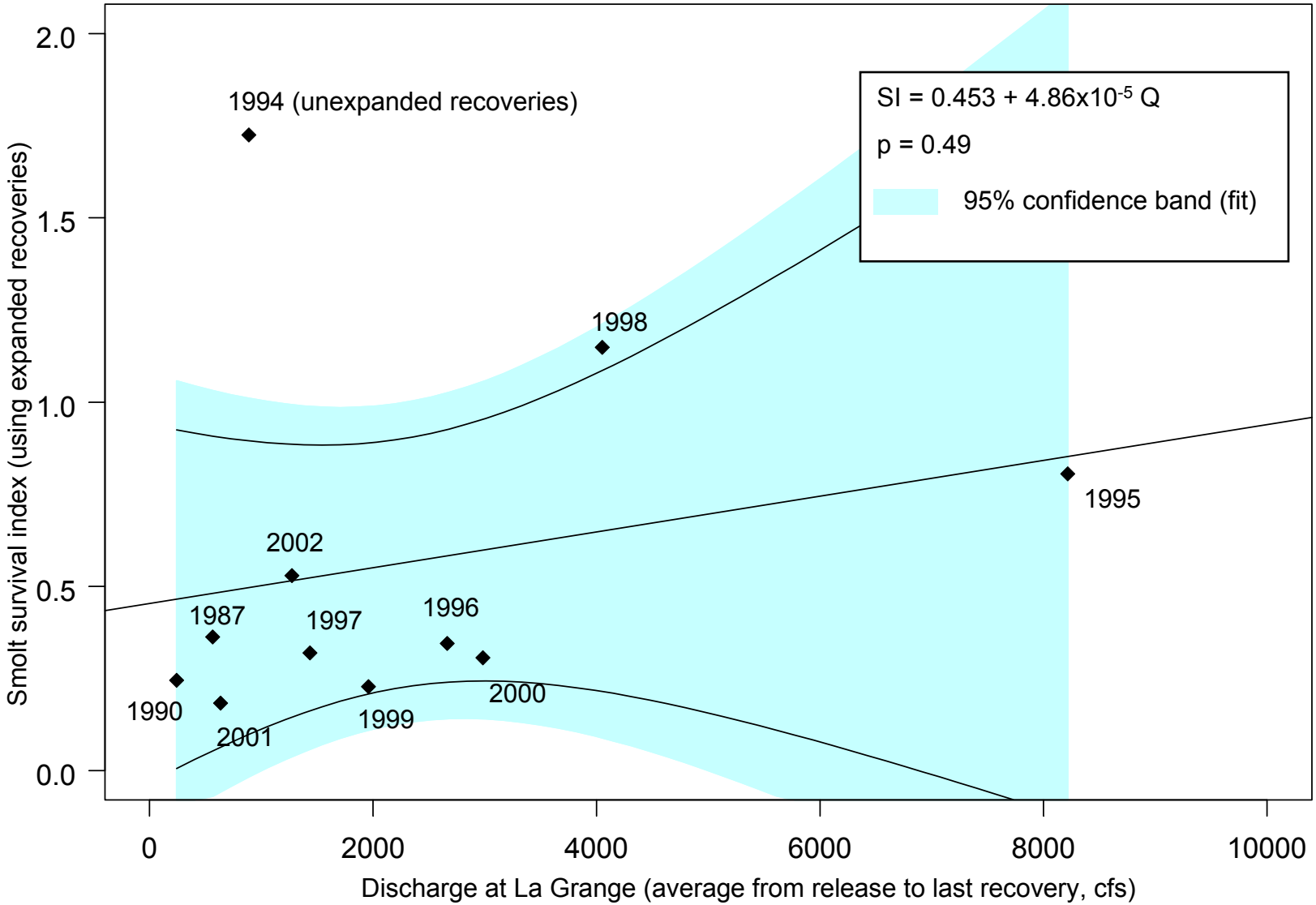

Figure 1: Linear regression of validated smolt survival indices by the recovery-weighted flow (cfs) at La Grange from release to last recapture at Mossdale Trawl

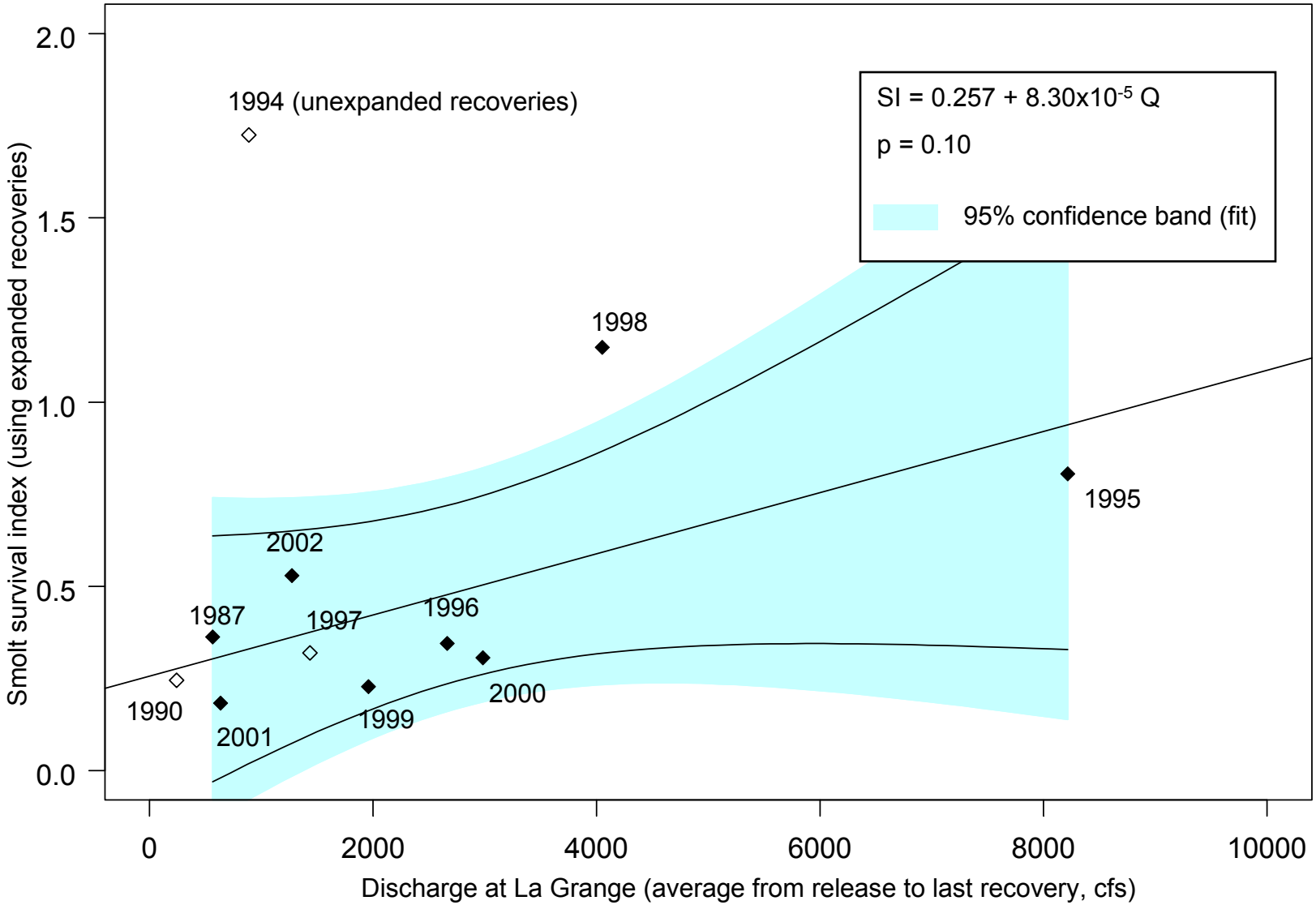

Figure 2: Linear regression of validated smolt survival indices by the recovery-weighted flow (cfs) at La Grange from release to last recapture at Mossdale Trawl

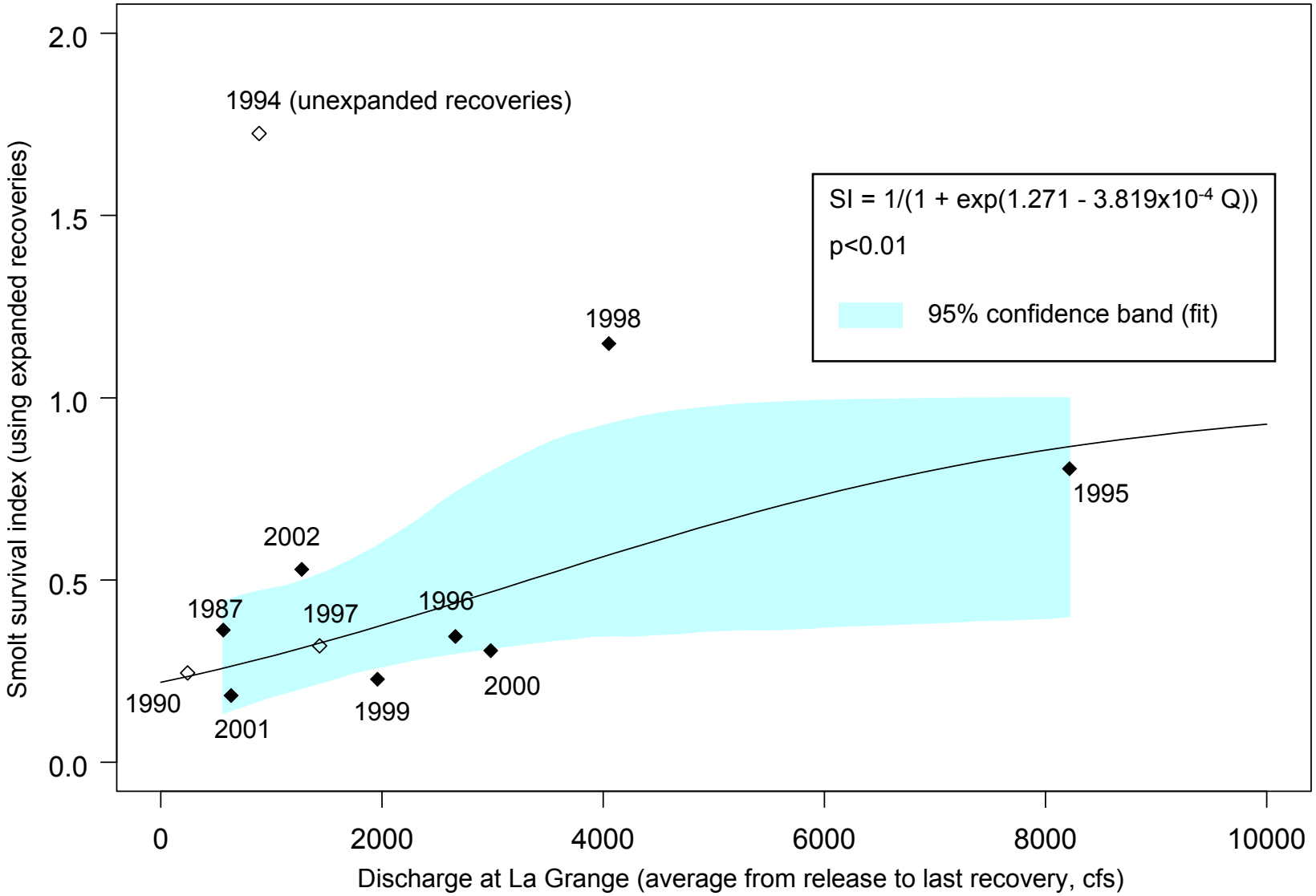

Figure 3: Logistic regression of validated smolt survival indices by the recovery-weighted flow (cfs) at La Grange from release to last recapture at Mossdale Trawl

APPENDIX A

DATA SUMMARY

TUOLUMNE RIVER CHINOOK SALMON CODED WIRE TAG PROGRAM EVALUATION 1987, 1990, 1994–2002

Table A1
Tuolumne River CWT Smolt Release Data

Release Year	Release Date [a]	Tag Code [a]	Release Location		Total River Miles Evaluated	Effective # released [a]	Average Fork Length (mm) [a]		Temperature (°C)						
			Site Name	RM			at release	at recovery	hatchery [a]	trailer [a]	release site [a]	difference between trailer & release site	La Grange [b]	Modesto [c-i]	Vernalis [h]
1987	16-Apr	06-46-60	OLGB	50.5	38	29,953	85	NA	14	14.5	13.0	1.50	11.5	18.0 [c]	17.50
	16-Apr	06-46-61	OLGB	50.5		30,609	85		14	14.5	13.0	1.50	11.5	18.0 [c]	17.50
	16-Apr	06-46-62	OLGB	50.5		29,037	85		14	14.5	13.0	1.50	11.5	18.0 [c]	17.50
	16-Apr	06-46-63	RDP	12.3		30,703	82		14	10.0	18.0	-8.00	11.5	18.0 [c]	17.50
	16-Apr	06-45-01	RDP	12.3		31,869	82		14	10.0	18.0	-8.00	11.5	18.0 [c]	17.50
	16-Apr	06-45-02	RDP	12.3		30,937	82		14	10.0	18.0	-8.00	11.5	18.0 [c]	17.50
1990	30-Apr	11-02-01	OLGB	50.5	50	23,494	83	NA	NA	13.5	11.0	2.50	10.1	19.6 [c]	20.0
	30-Apr	11-02-02	OLGB	50.5		21,766	83			13.5	11.0	2.50	10.1	19.6 [c]	20.0
	30-Apr	11-02-14	OLGB	50.5		24,134	83			13.5	11.0	2.50	10.1	19.6 [c]	20.0
	30-Apr	11-02-15	OLGB	50.5		24,259	83			13.5	11.0	2.50	10.1	19.6 [c]	20.0
	1-May	11-02-03	MAPES	1		27,263	72			13.0	20.0	-7.00	10.0	19.3 [c]	20.6
	1-May	11-02-04	MAPES	1		26,067	72			13.0	20.0	-7.00	10.0	19.3 [c]	20.6
	1-May	11-02-05	MAPES	1		24,905	72			13.0	20.0	-7.00	10.0	19.3 [c]	20.6
1994	23-Apr	601110302	OLGB	50.5	49.5	27,803	85*	85.55	11.56	11.67	10.56	-1.11	10.50	17.75 [b]	17.75
	23-Apr	601110303	OLGB	50.5		27,803	85*	86.64	11.56	11.67	10.56	-1.11	10.50	17.75 [b]	17.75
	23-Apr	601110304	OLGB	50.5		27,802	85*	85.00	11.56	11.67	10.56	-1.11	10.50	17.75 [b]	17.75
	24-Apr	601110305	MAPES	1		25,029	82	89.40	11.39	8.89	16.67	7.78	10.50	15.50 [b]	16.00
	24-Apr	601110306	MAPES	1		25,029	82	86.00	11.39	8.89	16.67	7.78	10.50	15.50 [b]	16.00
1995	4-May	601110311	OLGB	50.5	41.25	29,989	86	107.20	10.28	no data	8.89	- -	10.00	12.15 [d]	18.00
	4-May	601110312	OLGB	50.5		28,988	86	105.69	10.28	no data	8.89	- -	10.00	12.15 [d]	18.00
	4-May	601110313	OLGB	50.5		30,287	86	103.94	10.28	no data	8.89	- -	10.00	12.15 [d]	18.00
	5-May	601110314	SERVICE	9.25		27,770	89	105.23	10.28	8.89	12.00	3.11	10.00	11.60 [d]	17.25
	5-May	601110315	SERVICE	9.25		29,139	89	104.00	10.28	8.89	12.00	3.11	10.00	11.60 [d]	17.25
1996	26-Apr	601110506	OLGB	50.5	41.25	21,501	88	97.05	11.50	9.44	11.67	2.23	11.25	13.45 [f]	17.25
	26-Apr	601110507	OLGB	50.5		22,761	88	94.69	11.50	9.44	11.67	2.23	11.25	13.45 [f]	17.25
	26-Apr	601110508	OLGB	50.5		22,893	88	96.65	11.50	9.44	11.67	2.23	11.25	13.45 [f]	17.25
	27-Apr	601110509	SERVICE	9.25		22,715	90	90.38	11.50	10.00	13.89	3.89	11.00	13.30 [f]	17.00
	27-Apr	601110510	SERVICE	9.25		27,745	90	90.63	11.50	10.00	13.89	3.89	11.00	13.30 [f]	17.00
1997	22-Apr	601110607	OLGB	50.5	41.25	35,004	71	91.25	11.39	12.78	8.89	-3.89	9.75	13.50 [e]	17.50
	22-Apr	601110608	OLGB	50.5		33,695	71	94.17	11.39	12.78	8.89	-3.89	9.75	13.50 [e]	17.50
	22-Apr	601110609	OLGB	50.5		27,622	71	88.10	11.39	12.78	8.89	-3.89	9.75	13.50 [e]	17.50
	22-Apr	601110610	OLGB	50.5		8,882	71	89.00	11.39	12.78	8.89	-3.89	9.75	13.50 [e]	17.50
	23-Apr	601110604	SERVICE	9.25		31,739	75	79.71	11.39	13.33	13.33	0	10.00	12.35 [e]	16.75
	23-Apr	601110605	SERVICE	9.25		32,297	75	81.45	11.39	13.33	13.33	0	10.00	12.35 [e]	16.75
	23-Apr	601110606	SERVICE	9.25		27,075	75	81.75	11.39	13.33	13.33	0	10.00	12.35 [e]	16.75
1998	15-Apr	601110703	OLGB	50.5	53.5	32,787	83	92.78	10.00	10.00	10.56	0.56	10.25	10.95 [e]	13.25
	15-Apr	601110704	OLGB	50.5		26,633	83	94.20	10.00	10.00	10.56	0.56	10.25	10.95 [e]	13.25
	15-Apr	601110705	OLGB	50.5		27,404	83	98.53	10.00	10.00	10.56	0.56	10.25	10.95 [e]	13.25
	15-Apr	601110706	OLGB	50.5		7,234	83	96.33	10.00	10.00	10.56	0.56	10.25	10.95 [e]	13.25
	16-Apr	601110707	CLUB	-3		25,754	86	88.82	10.00	no data	no data	n/a	10.25	11.05 [e]	14.00
	17-Apr	601110708	CLUB	-3		22,006	86	90.83	10.00	13.33	15.00	1.67	10.25	11.15 [e]	14.75

Table A1
Tuolumne River CWT Smolt Release Data

Release Year	Release Date [a]	Tag Code [a]	Release Location		Total River Miles Evaluated	Effective # released [a]	Average Fork Length (mm) [a]		Temperature (°C)						
			Site Name	RM			at release	at recovery	hatchery [a]	trailer [a]	release site [a]	difference between trailer & release site	La Grange [b]	Modesto [c-i]	Vernalis [h]
1999	17-Apr	06-46-01	OLGB	50.5	53.5	25,534	86 (73-98)	92	11	13.3	11.1	2.22	10.8	13.3 [e]	16.72
	18-Apr	06-46-02	OLGB	50.5		25,679	86 (76-99)	90	11	12.8	11.1	1.67	10.50	13.1 [e]	16.80
	19-Apr	06-46-03	OLGB	50.5		25,008	86 (68-95)	88	11	12.2	12.8	-0.56	10.50	12.8 [e]	16.46
	18-Apr	06-46-04	OFC (SJR)	-3		25,121	86 (71-94)	85	11	15.0	18.9	-3.89	10.50	14.3 [g]	16.80
	19-Apr	06-46-05	OFC (SJR)	-3		25,836	85 (73-99)	85	11	13.9	18.3	-4.44	10.50	14.0 [g]	16.46
2000	13-Apr	06-45-56	OLGB (CWT)	50.5	53.5	23,603	74 (4.09)	85	12	13.3	11.1	2.19	11.00	15.8 [e]	17.36
	15-Apr	06-45-57	OLGB (CWT)	50.5		22,096	74 (4.81)	83	12	13.3	11.1	2.20	11.00	12.2 [e]	14.27
	15-Apr	06-45-58	OLGB (CWT)	50.5		26,975	75 (4.42)	85	12	12.2	10.6	1.60	11.00	12.2 [e]	14.27
	16-Apr	06-45-59	OFC (SJR)	-3		21,698	73 (4.47)	84	12	12.2	13.3	-1.10	11.00	12.3 [g]	13.93
	14-Apr	06-45-60	OFC (SJR)	-3		23,071	75 (5.08)	80	12	12.2	15.6	-3.40	11.00	14.2 [g]	16.80
2001	22-Apr	06-44-12	OLGB	50.5	53.5	24,600	82	86	12	10.0	11.0	-1.00	11.34 [i]	13.2 [e]	14.27
	22-Apr	06-44-13	OLGB	50.5		22,758	82	85	12	13.0	12.0	1.00	11.34 [i]	13.2 [e]	14.27
	23-Apr	06-44-14	OLGB	50.5		21,527	82	86	12	10.0	11.0	-1.00	11.34 [i]	13.2 [e]	14.27
	28-Apr	06-44-43	OFC (SJR)	-3		22,051	82	84	13	13.0	19.0	-6.00	11.38 [i]	13.2 [e]	17.48
	26-Apr	06-44-44	OFC (SJR)	-3		24,393	85	85	13	14.0	21.0	-7.00	11.57 [i]	13.2 [e]	18.63
2002	24-Apr	06-44-67	OLGB	50.5	53.5	24,770	86	NA	15	13.3	11.8	1.50	10.50	16.00	17.61
	24-Apr	06-44-68	OLGB	50.5		25,176	86		15	13.3	11.8	1.50	10.50	16.00	17.61
	25-Apr	06-44-06	OLGB	50.5		24,978	86		15	13.3	11.8	1.50	10.50	15.06	17.40
	29-Apr	06-44-69	OFC (SJR)	-3		23,871	86		15	13.0	16.0	-3.00	10.50	12.89	14.66
	26-Apr	06-44-61	OFC (SJR)	-3		25,701	85		15	13.0	16.7	-3.70	10.25	14.33	16.84

* Regional Mark Information Systems (RMIS) maintained by Pacific States Marine Fisheries Council (PSMFC) report 71 mm for these fish.

[ ] indicates violation of assumption of <5% variability.

sources:
a. California Department of Fish and Game, La Grange, CA.
b. USGS gauge 11289650 - Tuolumne River below La Grange Dam, near La Grange, CA
c. USGS gauge 11290000 - Tuolumne River at Modesto, CA
d. TID thermograph Riverdale Park (RM 12.3)
e. TID thermograph Hughson (RM 23.6)
f. TID thermograph Charles Road (RM 24.9)
g. TID thermograph Shiloh Road (RM 3.4)
h. USGS gauge San Joaquin River near Vernalis, CA (11303500)
i. TID thermograph Riffle 3B (RM 49.0)

Table A2
Tuolumne River CWT Smolt Recovery Data

Year	Tag Code [a]	Release Location		Release Date [a]	Release Totals (upper & lower) [a]	Lower Tuolumne Recapture Period (days)		Mossdale Recapture Period					
		Site Name	RM			from Release to 70% of Total Recovery	from Release to 90% of Total Recovery	First Recovery Date	Days to 70% Recapture (Expanded)	Days to 90% Recapture (Expanded)	Last Recovery Date	Actual Smolt Recovery (Expanded)	Percentage of Smolts Recovered at Mossdale
1987	06-46-60 06-46-61 06-46-62	OLGB	50.5	16-Apr	89,599	NA	NA	16-Apr	6 days (5 days)	7 days (7 days)	29-Apr	128 (2,494)	0.14%
	06-46-63 06-45-01 06-45-02	RDP	12.3	16-Apr	93,509			19-Apr	2 days (2 days)	6 days (3 days)	7-May	317 (7,174)	0.34%
1990	11-02-01 11-02-02 11-02-14 11-02-15	OLGB	50.5	30-Apr	93,653	NA	NA	2-May	3 days (5 days)	8 days (9 days)	21-May	63 (698)	0.07%
	11-02-03 11-02-04 11-02-05	MAPES	1	1-May	77,425			2-May	11 days (12 days)	19 days (20 days)	29-May	173 (2,357)	0.22%
1994	601110302 601110303 601110304	OLGB	50.5	23-Apr	83,408	NA	NA	25-Apr	10 days (NA)	13 days (NA)	12-May	207 (NA)	0.25%
	601110305 601110306	MAPES	1	24-Apr	50,058			25-Apr	9 days (NA)	15 days (NA)	15-May	72 (NA)	0.14%
1995	601110311 601110312 601110313	OLGB	50.5	4-May	89,264 [b]	14	21	6-May	26 days (26 days)	32 days (32 days)	17-Jun	58 ± 7.6 (827 ± 109)	0.06%
	601110314 601110315	SERVICE	9.25	5-May	56,909[b]			6-May	21 days (21 days)	30 days (30 days)	15-Jun	47 ± 6.9 (655 ± 96)	0.08%
1996	601110506 601110507 601110508	OLGB	50.5	26-Apr	67,155	4	12	28-Apr	4 days (9 days)	22 days (25 days)	29-May	66 ± 8.1 (525 ± 69)	0.10%
	601110509 601110510	SERVICE	9.25	27-Apr	50,460			28-Apr	1 day (1 day)	3 days (4 days)	7-May	156 ± 12.5 (1,143 ± 94)	0.31%
1997	601110607 601110608 601110609 601110610	OLGB	50.5	22-Apr	105,203	6	15	9-May	25 days (25 days)	26 days (26 days)	19-May	32 ± 6 (273 ± 50)	0.03%
	601110604 601110605 601110606	SERVICE	9.25	23-Apr	91,111			25-Apr	23 days (17 days)	26 days (26 days)	20-May	56 ± 7 (663 ± 92)	0.06%
1998	601110703 601110704 601110705 601110706	OLGB	50.5	15-Apr	94,058	2	22	17-Apr	25 days (27 days)	34 days (34 days)	2-Jun	130 ± 11 (816 ± 74)	0.14%
	601110707 601110708	CLUB	-3	17-Apr	47,760	NA	NA	17-Apr	11 days (12 days)	15 days (15 days)	5-May	64 ± 8 (361 ± 48)	0.13%
1999	06-46-01 06-46-02 06-46-03	OLGB	50.5	17-Apr	76,221	12	22	18-Apr	13 days (13 days)	33 days (34 days)	22-May	45 (248)	0.06%
	06-46-04 06-46-05	OFC (SJR)	-3	18-Apr	50,957			18-Apr	2 days (2 days)	3 days (4 days)	30-Apr	158 (728)	0.31%
2000	06-45-56 06-45-57 06-45-58	OLGB	50.5	13-Apr	72,674	13	33	15-Apr	12 days (12 days)	20 days (20 days)	22-May	37 (210)	0.05%
	06-45-59 06-45-60	OFC (SJR)	-3	14-Apr	44,769			17-Apr	4 days (4 days)	8 days (8 days)	29-Apr	81 (422)	0.18%
2001	06-44-12 06-44-13 06-44-14	OLGB	50.5	22-Apr	68,885	7	9	26-Apr	6 days (6 days)	7 days (7 days)	3-May	107 (390)	0.16%
	06-44-43 06-44-44	OFC (SJR)	-3	26-Apr	46,443			27-Apr	3 days (3 days)	3 days (3 days)	9-May	399 (1,439)	0.86%
2002	06-44-67 06-44-68 06-44-06	OLGB	50.5	24-Apr	74,924	4	7	27-Apr	4 days (4 days)	5 days (5 days)	12-May	179 (859)	0.24%
	06-44-69 06-44-61	OFC (SJR)	-3	26-Apr	23,871			27-Apr	2 days (2 days)	5 days (5 days)	10-May	116 (556)	0.49%

a. California Department of Fish and Game, La Grange, CA.
b. 1995 CWT Summary Update indicates 83,549 fish released from the upper site, and 53,298 fish released from the lower site.
c. 2002 Recoveries of 2nd release group not included in analysis due to mmajority of fish passing Mossdale on day with no trawls

Table A3
Flow Variation During CWT Recovery at Lower Tuolumne RSTs and Mossdale Trawl

Release Year	Flow at Release (cfs) at:			Flow Variability During 70% Lower Tuolumne Recapture Period at:				Flow Variability During 70% Mossdale Recapture Period at:				Flow Variability During CPUE Expanded [d, e] 70% Mossdale Recapture Period at:			
	La Grange [a]	Modesto [b]	Vernalis [c]	La Grange [a]		Modesto [b,d]		Modesto [b,d]		Vernalis [c]		Modesto [b,d]		Vernalis [c]	
				Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1987	563	741	2,790	NA	NA	NA	NA	761	741 - 776	2,716	2,580 - 2,790	761	741 - 776	2,738	2,690 - 2,790
	563	741	2,790					750	741 - 762	2,757	2,720 - 2,790	750	741 - 762	2,757	2,720 - 2,790
1990	599	414	1,260	NA	NA	NA	NA	535	414 - 589	1,365	1,260 1,440	534	414 - 589	1,388	1,260 - 1,480
	573	556	1,350					347	145 - 589	1,307	1,080 - 1,480	331	134 - 589	1,294	1,080 - 1,480
1994	1,160	424	1,410	N/A	N/A	N/A	N/A	736	398 - 1,150	2,577	1,410 - 3,640	736	398 1,150	2,577	1,410 - 3,640
	1,260	862	1,730					736	398 - 1,150	2,577	1,730 - 3,640	767	398 - 1,150	2,694	1,730 - 3,640
1995	7,730	7,270	19,000	7,743	7,630 - 8,000	7,771	7,270 - 8020	8,097	7,270 - 8,610	22,730	19,000 - 23,500	8,097	7,270 - 8,610	22,730	19,000 - 23,500
	7,640	7,740	20,800	NA	NA	NA	NA	8,045	7,630 - 8,610	22,827	20,800 - 23,500	8,045	7,630 - 8,610	22,827	20,800 - 23,500
1996	2,580	2,740	6,690	2,616	2,570 - 2,700	2,816	2,740 - 2860	2,816	2,740 - 2,860	6,668	6,600 - 6,700	2,772	2,230 - 3,200	6,558	6,230 - 6,700
	2,610	2,810	6,700	NA	NA	NA	NA	2,835	2,810 - 2,860	6,690	6,680 - 6,700	2,835	2,810 - 2,860	6,690	6,680 - 6,700
1997	2,860	1,690	5,790	2,790	2,740 - 2,860	2,777	1,690 - 2970	2,093	550 - 2,970	5,865	4,410 - 6,350	2,093	550 - 2,970	5,865	4,410 - 6,350
	2,800	2,970	6,080	NA	NA	NA	NA	2,174	879 - 2,970	5,928	4,860 - 6,350	2,377	1,140 - 2,970	6,007	5,540 - 6,350
1998	6,400	7,100	24,900	6,523	6,400 - 6,650	7,083	7,050 - 7100	4,228	2,300 - 7,100	19,885	16,300 - 25,000	4,175	2,300 - 7,100	19,646	16,300 - 25,000
	6,650	7,100	24,900	NA	NA	NA	NA	5,354	4,450 - 7,100	22,200	19,300 - 25,000	5,354	4,450 - 7,100	22,200	19,300 - 25,000
1999	1,930	1,680	6,630	2,689	1,870 - 3,460	5,041	4,180 - 7,050	2,006	1,300 - 3,270	6,915	6,630 - 7,280	2,006	1,300 - 3,270	6,915	6,630 - 7,280
	1,970	1,780	6,780												
	1,960	1,750	6,930												
	1,970	1,780	6,780	NA	NA	NA	NA	2,340	1,300 - 3,270	7,017	6,730 - 7,340	2,340	1,300 - 3,270	7,017	6,730 - 7,340
	1,960	1,750	6,930												

Table A3
Flow Variation During CWT Recovery at Lower Tuolumne RSTs and Mossdale Trawl

Release Year	Flow at Release (cfs) at:			Flow Variability During 70% Lower Tuolumne Recapture Period at:				Flow Variability During 70% Mossdale Recapture Period at:				Flow Variability During CPUE Expanded [d, e] 70% Mossdale Recapture Period at:			
	La Grange [a]	Modesto [b]	Vernalis [c]	La Grange [a]		Modesto [b,d]		Modesto [b,d]		Vernalis [c]		Modesto [b,d]		Vernalis [c]	
				Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
2000	3,780	1,600	3,120	2,310	1,040 - 3,830	3,790	2,340 - 4,830	2,711	1,100 - 4,430	5,908	3,120 - 7,070	2,711	1,100 - 4,430	5,908	3,120 - 7,070
	3,800	4,290	5,660												
	3,800	4,290	5,660												
	3,670	4,260	5,900	NA	NA	NA	NA	4,345	4,260 - 4,430	5,860	4,360 - 7,070	4,345	4,260 - 4,430	5,860	4,360 - 7,070
	3,830	4,060	4,360												
2001	623	858	4530	706	618 - 1,240	796	748 - 877	784	748 - 858	4,304	4,100 - 4,530	784	748 - 858	4,304	4,100 - 4,530
	684	775	4200	NA	NA	NA	NA	790	748 - 877	4,160	4,100 - 4,210	790	748 - 877	4,160	4,100 - 4,210
	618	748	4100												
2002	1310	978	3220	1,305	1,290 - 1,310	1,194	978 - 1,280	1,194	978 - 1,280	3,378	3,220 - 3,500	1,194	978 - 1,280	3,378	3,220 - 3,500
	1310	978	3220												
	1310	1210	3310												
	1310	1290	3610	NA	NA	NA	NA	1,285	1,280 - 1,290	3,555	3,500 - 3,610	1,285	1,280 - 1,290	3,555	3,500 - 3,610
	1290	1240	3410												

indicates violation of assumption of <20% variability.

sources:
a. USGS gauge Tuolumne River below La Grange Dam, near La Grange, CA (11289650)
b. USGS gauge Tuolumne River at Modesto, CA (11290000)
c. USGS gauge San Joaquin River Basin near Vernalis, CA (11303500)
d. In 1994, flow variability during 70% and 90% Mossdale recapture period does not represent expanded CPUE.
e. In 1999, flows at Modesto were estimated by new USGS rating curve.

Table A4
Temperature Variation During CWT Recovery at Lower Tuolumne RSTs and Mossdale Trawl

Release Year	Temperature (°C) at Release:			Temperature Variability During 70% Lower Tuolumne Recapture Period at:				Temperature Variability During 70% Mossdale Recapture Period at:				Temperature Variability During CPUE Expanded [d] 70% Mossdale Recapture Period at:			
	La Grange [a]	Modesto [b]	Vernalis [c]	La Grange [a]		Modesto [b,e]		Modesto [b,e]		Vernalis [c]		Modesto [b]		Vernalis [c]	
				Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1987	11.5	18.00	17.50	NA	NA	NA	NA	16.6	15.0 - 18.0	17.1	16.0 - 18.0	16.9	16.0 - 18.0	16.4	15.0 - 17.5
	11.5	18.00	17.50					17.0	16.0 - 17.5	17.7	17.0 - 18.0	17.7	17.0 - 18.0	17.0	16.0 - 17.5
1990	10.1	19.6	20.0	NA	NA	NA	NA	19.0	18.4 - 19.6	22.3	20.5 - 24.3	19.3	18.4 - 20.3	23.3	20.5 - 25.6
	10.0	19.3	20.6					19.5	17.5 - 21.1	22.7	20.5 - 25.6	19.4	17.5 - 21.1	22.6	20.5 - 25.6
1994	10.50	17.75 [b]	17.75	N/A	N/A	N/A	N/A	15.9	13.5 - 19.5	16.7	15.0 - 19.8	15.9	13.5 - 19.5	16.7	15.0 - 19.8
	10.50	15.50 [b]	16.00					15.7	13.5 - 19.5	16.6	15.0 - 19.8	15.7	13.5 - 19.5	16.6	15.0 - 19.8
1995	10.00	12.15 [c]	18.00	10.6	10.50 - 10.8	10.8	10.30 - 11.3 [c]	12.2	11.0 - 13.0	17.9	15.8 - 20.3	11.1	10.3 - 11.6	17.9	15.8 - 20.3
	10.00	11.60 [c]	17.25					12.0	11.0 - 12.8	17.6	15.8 - 19.5	11.0	10.3 - 11.4	17.6	15.8 - 19.5
1996	11.25	13.45 [d]	17.25	11.2	11.00 - 11.3	13.3	13.00 - 13.5	13.3	13.1 - 13.6	16.8	16.0 - 17.3	13.4	12.9 - 13.8	17.2	16.0 - 18.0
	11.00	13.30 [d]	17.00					13.2	13.1 - 13.3	16.5	16.0 - 17.0	13.2	13.0 - 13.3	16.5	16.0 - 17.0
1997	9.75	13.50 [f]	18.25	9.9	9.80 - 10	12.6	12.20 - 13.8 [f]	13.7	12.1 - 18.6	17.5	15.0 - 20.8	13.7	12.0 - 18.5	17.4	15.0 - 20.8
	10.00	12.35 [f]	16.75					13.5	12.1 - 16.4	17.3	15.0 - 20.8	13.0	12.0 - 14.6	16.4	15.0 - 18.3
1998	10.25	10.95 [f]	13.25	10.3	10.30 - 10.3	11.0	10.90 - 11.2 [f]	12.0	11.0 - 13.1	17.4	13.3 - 19.8	12.0	10.9 - 13.0	17.3	13.3 - 19.8
	10.25	11.05 [f]	14.00	NA	NA	NA	NA	11.6	11.0 - 12.4	16.3	13.3 - 18.5	11.7	11.0 - 12.3	16.7	14.0 - 18.5
	10.25	11.15 [f]	14.75												
1999	10.8	13.3	16.7	10.3	9.5 - 11.5	13.6	10.5 - 15.5	13.5	11.7 - 14.8	16.2	14.0 - 18.0	13.5	11.7 - 14.8	16.2	14.0 - 18.0
	10.5	13.1	16.8												
	10.5	12.8	16.5												
	10.5	14.3	16.8	NA	NA	NA	NA	13.1	11.5 - 14.4	15.7	14.0 - 18.0	13.1	11.5 - 14.4	15.7	14.0 - 18.0
	10.5	14.0	16.5												

Table A4
Temperature Variation During CWT Recovery at Lower Tuolumne RSTs and Mossdale Trawl

Release Year	Temperature (°C) at Release:			Temperature Variability During 70% Lower Tuolumne Recapture Period at:				Temperature Variability During 70% Mossdale Recapture Period at:				Temperature Variability During CPUE Expanded [d] 70% Mossdale Recapture Period at:			
	La Grange [a]	Modesto [b]	Vernalis [c]	La Grange [a]		Modesto [b,e]		Modesto [b,e]		Vernalis [c]		Modesto [b]		Vernalis [c]	
				Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
2000	11.0	15.80	17.4	11.1	10.5 - 12.0	14.1	11.2 - 19.6	13.6	11.9 - 15.4	16.0	14.3 - 17.3	13.6	11.9 - 15.4	16.0	14.3 - 17.3
	11.0	12.20	14.3												
	11.0	12.20	14.3												
	11.0	12.30	13.9	NA	NA	NA	NA	12.2	11.9 - 12.7	14.8	14.3 - 15.5	12.2	11.9 - 12.7	14.8	14.3 - 15.5
	11.0	14.20	16.8												
2001	11.34[g]	13.20	14.27	11.5	11.2 - 11.6	17.2	13.8 - 18.8	16.4	13.2 - 17.8	17.7	14.9 - 19.5	16.4	13.2 - 17.8	17.7	14.9 - 19.5
	11.38[g]	13.20	17.48	NA	NA	NA	NA	17.1	16.0 - 17.8	18.6	17.6 - 19.5	17.1	16.0 - 17.8	18.6	17.6 - 19.5
	11.57[g]	13.20	18.63												
2002	10.5	16.0	17.6	10.4	10.3 - 10.5	14.3	12.7 - 16.0	14.3	12.7 - 16.0	16.4	14.7 - 17.6	14.3	12.7 - 16.0	16.4	14.7 - 17.6
	10.5	16.0	17.6												
	10.5	15.1	17.4												
	10.5	12.9	14.7	NA	NA	NA	NA	13.0	12.9 - 13.0	14.5	14.3 - 14.7	13.0	12.9 - 13.0	14.5	14.3 - 14.7
	10.25	14.3	16.8												

indicates violation of assumption of <20% variability.

sources:
a. USGS gauge Tuolumne River below La Grange Dam, near La Grange, CA (11289650)
b. USGS gauge Tuolumne River at Modesto, CA (11290000)
c. TID thermograph Riverdale park (RM 12.3)
d. TID thermograph Charles Road (RM 24.9)
e. TID thermograph Shiloh Rd. (RM 3.4) used for 1987, 1999-2001
f. TID thermograph Hughson (RM 23.6)
g. USGS gauge San Joaquin River near Vernalis, CA (11303500)
h. In 1994, temperature variability during 70% and 90% Mossdale recapture period does not represent expanded CPUE.

Table A5

Daily recapture counts at Mossdale Trawl by Tuolumne River release group (1987, 1990, 1994-2002).

Date	1987		1990		1994		1995		1996		1997		1998		1999		2000		2001		2002	
Site	upper	lower	upper	lower	upper	lower	upper	lower	upper	lower	upper	lower	upper	lower	upper	lower	upper	lower	upper	lower	upper	lower
15-Apr	-	-	-	-	-	-	-	-	0	0	0	0	-	-	0	0	0	0	-	-	0	0
16-Apr	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17-Apr	0	59	-	-	-	-	-	-	0	0	0	0	5	7	1	7	0	0	0	0	0	0
18-Apr	0	177	-	-	-	-	-	-	0	0	0	0	6	3	-	-	2	4	0	0	0	0
19-Apr	10	43	-	-	-	-	-	-	0	0	0	0	6	3	0	28	3	0	0	0	0	0
20-Apr	43	2	-	-	-	-	-	-	0	0	0	0	6	3	0	92	9	7	0	0	0	0
21-Apr	27	3	-	-	-	-	-	-	0	0	0	0	6	3	5	17	3	1	0	0	0	0
22-Apr	20	6	-	-	-	-	-	-	0	0	0	0	6	3	3	4	6	3	0	0	0	0
23-Apr	17	6	-	-	-	-	-	-	0	0	0	0	6	3	3	2	-	-	0	0	0	0
24-Apr	6	3	-	-	-	-	-	-	0	0	0	0	6	3	3	0	0	0	0	0	0	0
25-Apr	2	4	-	-	1	10	-	-	0	0	0	4	-	-	2	1	6	2	0	0	0	0
26-Apr	0	2	-	-	43	13	-	-	0	0	0	0	-	-	7	5	1	1	32	0	0	0
27-Apr	0	2	-	-	58	4	-	-	0	0	0	0	2	5	0	1	0	1	42	249	72	78
28-Apr	2	3	-	-	20	5	-	-	19	113	0	1	1	6	2	0	0	0	17	10	56	30
29-Apr	1	2	-	-	4	3	-	-	16	17	0	1	6	3	4	0	6	3	10	134	34	5
30-Apr	0	3	-	-	4	3	-	-	17	13	0	1	2	2	5	1	-	-	1	2	0	0
1-May	0	1	-	-	2	5	-	-	3	6	0	2	2	2	0	0	0	0	3	1	5	19
2-May	-	-	8	10	21	5	-	-	0	1	0	0	2	1	-	-	0	0	-	-	0	1
3-May	-	-	38	12	10	6	-	-	0	0	0	1	6	3	0	0	1	0	2	0	1	3
4-May	-	-	-	-	13	5	-	-	0	5	0	5	6	3	1	0	0	0	0	0	2	2
5-May	-	-	2	20	6	2	-	-	2	0	0	7	6	3	-	-	0	0	0	2	3	0
6-May	-	-	0	4	9	5	1	1	0	0	0	1	6	3	0	0	-	-	0	0	3	0
7-May	0	1	8	24	6	2	0	1	1	1	0	3	6	3	1	0	-	-	0	0	0	2
8-May	-	-	2	11	5	3	0	2	0	0	0	3	6	3	1	0	0	0	0	0	0	0
9-May	-	-	3	8	1	0	1	0	0	0	1	4	6	3	-	-	0	0	0	1	0	0
10-May	-	-	1	6	-	-	-	-	0	0	0	1	6	3	0	0	0	0	0	0	0	1
11-May	-	-	0	12	3	0	-	-	0	0	1	0	4	0	1	0	0	0	0	0	2	0
12-May	-	-	0	16	1	0	-	-	0	0	1	2	7	0	-	-	0	0	0	0	1	0
13-May	-	-	0	7	-	-	-	-	0	0	0	1	6	3	0	0	-	-	0	0	0	0
14-May	-	-	0	6	-	-	-	-	0	0	2	1	2	0	0	0	-	-	0	0	0	0
15-May	-	-	0	3	0	1	1	0	0	0	8	4	3	0	0	0	0	0	0	0	0	0
16-May	-	-	0	6	-	-	-	-	0	0	5	2	2	0	0	0	0	0	0	0	0	0
17-May	-	-	-	-	-	-	3	3	1	0	7	5	6	3	0	0	1	0	0	0	0	0
18-May	-	-	0	3	-	-	3	11	1	0	6	4	3	0	0	0	0	0	0	0	0	0
19-May	-	-	0	6	-	-	1	1	2	0	1	4	5	0	1	0	0	0	0	0	0	0
20-May	-	-	0	2	-	-	6	2	0	0	0	2	-	-	1	0	6	3	0	0	0	0
21-May	-	-	1	1	-	-	2	2	2	0	0	0	0	0	1	0	0	0	0	0	0	0
22-May	-	-	0	3	-	-	4	3	0	0	0	0	2	0	3	0	1	0	0	0	0	0
23-May	-	-	0	8	-	-	6	2	0	0	0	0	0	0	-	-	0	0	0	0	0	0
24-May	-	-	0	2	-	-	2	2	0	0	-	-	-	-	0	0	0	0	0	0	0	0
25-May	-	-	0	2	-	-	3	2	0	0	-	-	-	-	0	0	0	0	0	0	-	-
26-May	-	-	-	-	-	-	5	3	-	-	-	-	2	0	-	-	0	0	0	0	-	-
27-May	-	-	-	-	-	-	-	-	-	-	0	0	6	3	0	0	-	-	0	0	-	-
28-May	-	-	-	-	-	-	-	-	1	0	0	0	0	0	0	0	-	-	0	0	0	0
29-May	-	-	0	1	-	-	-	-	1	0	0	0	0	0	0	0	-	-	0	0	0	0
30-May	-	-	-	-	-	-	4	0	0	0	0	0	1	0	-	-	0	0	0	0	0	0
31-May	-	-	-	-	-	-	2	0	0	0	0	0	-	-	-	-	-	-	0	0	0	0
1-Jun	-	-	-	-	-	-	0	2	0	0	-	-	0	0	0	0	0	0	0	0	-	-
2-Jun	-	-	-	-	-	-	-	-	0	0	0	0	2	0	-	-	0	0	-	-	-	-
3-Jun	-	-	-	-	-	-	5	1	0	0	0	0	-	-	0	0	-	-	-	-	0	0
4-Jun	-	-	-	-	-	-	2	5	0	0	0	0	0	0	0	0	-	-	0	0	0	0
5-Jun	-	-	-	-	-	-	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6-Jun	-	-	-	-	-	-	1	0	0	0	0	0	0	0	-	-	0	0	0	0	0	0
7-Jun	-	-	-	-	-	-	-	-	0	0	-	-	-	-	0	0	-	-	0	0	0	0
8-Jun	-	-	-	-	-	-	-	-	0	0	-	-	0	0	0	0	0	0	0	0	-	-
9-Jun	-	-	-	-	-	-	-	-	0	0	0	0	0	0	-	-	0	0	-	-	-	-
10-Jun	-	-	-	-	-	-	-	-	0	0	-	-	-	-	0	0	-	-	-	-	0	0
11-Jun	-	-	-	-	-	-	0	1	0	0	0	0	0	0	0	0	-	-	0	0	-	-
12-Jun	-	-	-	-	-	-	0	1	0	0	0	0	0	0	-	-	0	0	0	0	0	0
13-Jun	-	-	-	-	-	-	0	0	0	0	0	0	0	0	-	-	0	0	0	0	-	-
14-Jun	-	-	-	-	-	-	-	-	0	0	-	-	-	-	0	0	0	0	0	0	0	0
15-Jun	-	-	-	-	-	-	1	1	-	-	-	-	0	0	0	0	0	0	0	0	-	-
16-Jun	-	-	-	-	-	-	-	-	-	-	0	0	0	0	-	-	0	0	-	-	-	-
17-Jun	-	-	-	-	-	-	1	0	0	0	-	-	-	-			-	-	-	-	-	-

Note: " - " indicates no trawls confirmed to occur on this date

Table A6
Daily trawl effort (No. of trawls and minutes) at Mossdale for 1987, 1990, 1994-2002)

Date	1987		1990		1994		1995		1996		1997		1998		1999		2000		2001		2002	
Site	No.	(min)	(n)	(min)	(n)	(min)	(n)	(min)	(n)	(min)	(n)	(min)	(n)	(min)	(n)	(min)	(n)	(min)	(n)	(min)	(n)	(min)
15-Apr	-	-	-	-	-	-	-	-	3	30	10	100	-	-	10	200	10	200	-	-	15	300
16-Apr	-	-	-	-	-	-	-	-	10	100	10	100	10	200	10	200	10	200	10	200	15	300
17-Apr	10	100	-	-	-	-	-	-	10	100	10	100	10	200	10	200	10	200	10	200	16	320
18-Apr	5	50	-	-	-	-	-	-	10	100	10	100	10	200	-	-	17	340	10	200	15	300
19-Apr	10	100	-	-	-	-	-	-	10	100	10	100	10	200	10	200	20	390	10	200	15	300
20-Apr	5	50	-	-	-	-	-	-	10	100	10	100	10	200	10	200	20	382	7	140	15	300
21-Apr	10	100	-	-	-	-	-	-	10	100	10	100	10	200	10	200	10	200	10	200	15	300
22-Apr	8	80	-	-	-	-	-	-	10	100	10	100	10	200	6	120	10	200	10	200	15	300
23-Apr	12	120	-	-	-	-	-	-	10	100	15	150	10	200	10	200	-	-	10	200	15	300
24-Apr	10	100	-	-	-	-	-	-	10	100	15	150	10	200	10	200	14	280	20	400	15	300
25-Apr	10	100	-	-	-	-	-	-	10	100	15	150	-	-	10	200	10	200	20	400	16	303
26-Apr	11	110	-	-	-	-	-	-	10	100	15	150	-	-	10	200	10	200	20	400	15	300
27-Apr	5	50	-	-	-	-	-	-	10	100	10	100	10	200	10	200	10	200	20	400	15	300
28-Apr	10	100	10	101	-	-	-	-	10	100	10	100	10	200	10	200	10	200	20	400	15	300
29-Apr	10	100	10	100	-	-	-	-	13	130	10	100	10	200	10	200	10	200	20	400	15	300
30-Apr	10	100	10	100	-	-	-	-	10	100	10	100	10	200	10	200	-	-	20	400	15	300
1-May	11	110	10	100	-	-	-	-	13	130	10	100	6	120	10	200	11	220	14	280	15	300
2-May	10	100	16	158	-	-	-	-	10	100	10	100	10	200	-	-	10	200	-	-	15	300
3-May	10	100	14	140	-	-	10	100	10	100	10	100	10	200	10	200	10	200	20	400	15	303
4-May	5	50	10	100	-	-	10	100	10	101	10	100	10	200	10	200	10	200	20	399	15	300
5-May	10	100	10	100	-	-	15	150	10	100	10	100	10	200	-	-	10	200	20	400	15	300
6-May	10	100	10	100	-	-	20	200	10	100	10	100	10	200	10	200	-	-	20	400	15	300
7-May	10	100	11	110	-	-	10	100	10	100	10	100	10	200	10	200	-	-	20	400	15	300
8-May	-	-	10	100	-	-	20	200	10	100	10	100	10	200	10	200	10	200	17	340	15	300
9-May	-	-	10	100	-	-	20	200	10	100	10	100	10	200	-	-	10	200	20	400	15	300
10-May	-	-	10	100	-	-	20	200	10	100	10	100	10	200	10	200	10	200	17	340	15	300
11-May	-	-	10	100	-	-	15	150	10	100	10	100	10	210	10	200	10	200	20	400	15	300
12-May	-	-	10	100	-	-	20	200	10	100	10	100	10	200	-	-	10	200	20	400	15	300
13-May	-	-	10	100	-	-	7	70	10	100	10	100	10	200	10	200	-	-	10	200	15	300
14-May	-	-	10	100	-	-	10	100	10	100	10	100	10	200	10	200	-	-	14	280	15	297
15-May	-	-	10	100	-	-	10	100	10	100	21	203	10	200	10	200	10	200	16	321	15	300
16-May	-	-	10	100	-	-	10	100	10	100	20	200	10	199	0	0	10	200	20	400	15	300
17-May	-	-	10	100	-	-	10	100	10	100	20	200	10	200	10	200	10	200	20	400	15	300
18-May	-	-	10	100	-	-	10	110	10	100	19	190	10	200	7	140	10	200	18	360	10	200
19-May	-	-	10	100	-	-	0	0	10	100	15	150	10	200	10	200	10	200	20	400	10	200
20-May	-	-	10	100	-	-	10	100	10	100	10	100	-	-	10	200	10	200	20	400	10	200
21-May	-	-	10	100	-	-	10	100	10	100	10	100	10	200	10	200	20	400	15	300	10	200
22-May	-	-	10	100	-	-	10	91	10	100	10	100	10	192	10	200	20	400	20	400	10	200
23-May	-	-	10	100	-	-	10	100	10	100	10	100	10	200	-	-	20	400	21	420	11	220
24-May	-	-	10	100	-	-	10	220	1	10	-	-	-	-	10	200	18	360	20	400	10	185
25-May	-	-	10	100	-	-	10	100	10	100	-	-	-	-	10	200	10	200	15	300	-	-
26-May	-	-	-	-	-	-	10	100	-	-	-	-	10	200	-	-	10	200	20	400	-	-
27-May	-	-	10	100	-	-	0	0	-	-	10	100	10	200	11	220	-	-	20	400	-	-
28-May	-	-	-	-	-	-	0	0	10	100	10	100	10	200	10	200	-	-	18	360	10	200
29-May	-	-	10	100	-	-	0	0	10	100	10	100	10	200	9	180	-	-	10	200	10	200
30-May	-	-	-	-	-	-	10	100	10	100	10	100	10	200	-	-	10	200	10	200	10	200
31-May	-	-	10	100	-	-	10	100	10	100	10	100	-	-	-	-	-	-	10	200	10	200
1-Jun	-	-	-	-	-	-	10	100	10	100	-	-	10	200	10	200	10	200	10	200	-	-
2-Jun	-	-	10	100	-	-	1	10	10	100	10	100	10	200	-	-	10	200	-	-	-	-
3-Jun	-	-	-	-	-	-	10	100	10	100	10	100	-	-	10	200	-	-	-	-	10	200
4-Jun	-	-	-	-	-	-	10	100	10	100	10	100	10	200	10	200	-	-	10	200	10	200
5-Jun	-	-	-	-	-	-	10	100	10	100	10	100	10	200	9	180	5	100	10	200	10	200
6-Jun	-	-	-	-	-	-	7	70	10	100	10	100	10	200	-	-	10	200	10	200	10	200
7-Jun	-	-	-	-	-	-	0	0	10	100	-	-	-	-	10	200	-	-	7	140	10	200
8-Jun	-	-	-	-	-	-	0	0	10	100	-	-	10	200	10	200	10	200	10	200	-	-
9-Jun	-	-	-	-	-	-	10	100	10	100	10	100	10	200	-	-	5	100	-	-	-	-
10-Jun	-	-	-	-	-	-	10	100	10	100	-	-	-	-	10	200	-	-	-	-	9	180
11-Jun	-	-	-	-	-	-	10	100	10	100	10	100	10	200	10	200	-	-	10	200	-	-
12-Jun	-	-	-	-	-	-	10	100	10	100	0	0	10	200	-	-	10	200	10	200	10	200
13-Jun	-	-	-	-	-	-	10	100	10	100	10	100	10	200	-	-	10	200	7	133	-	-
14-Jun	-	-	-	-	-	-	10	100	10	100	-	-	-	-	10	200	10	200	10	200	10	200
15-Jun	-	-	-	-	-	-	10	100	-	-	-	-	10	200	10	200	10	200	10	200	-	-
16-Jun	-	-	-	-	-	-	10	100	-	-	10	100	10	200	-	-	10	200	-	-	-	-
17-Jun	-	-	-	-	-	-	10	100	10	100	-	-	-	-	2	40	-	-	-	-	-	-

Notes " - " indicates no trawls confirmed to occur on this date
1. Trawl data from 1996-2004 downloaded from IEP online database 8 March 2005.
2. Trawl data for 1987, 1990, and 1995 data partially reconstructed from CWT recovery data provided by CDFG

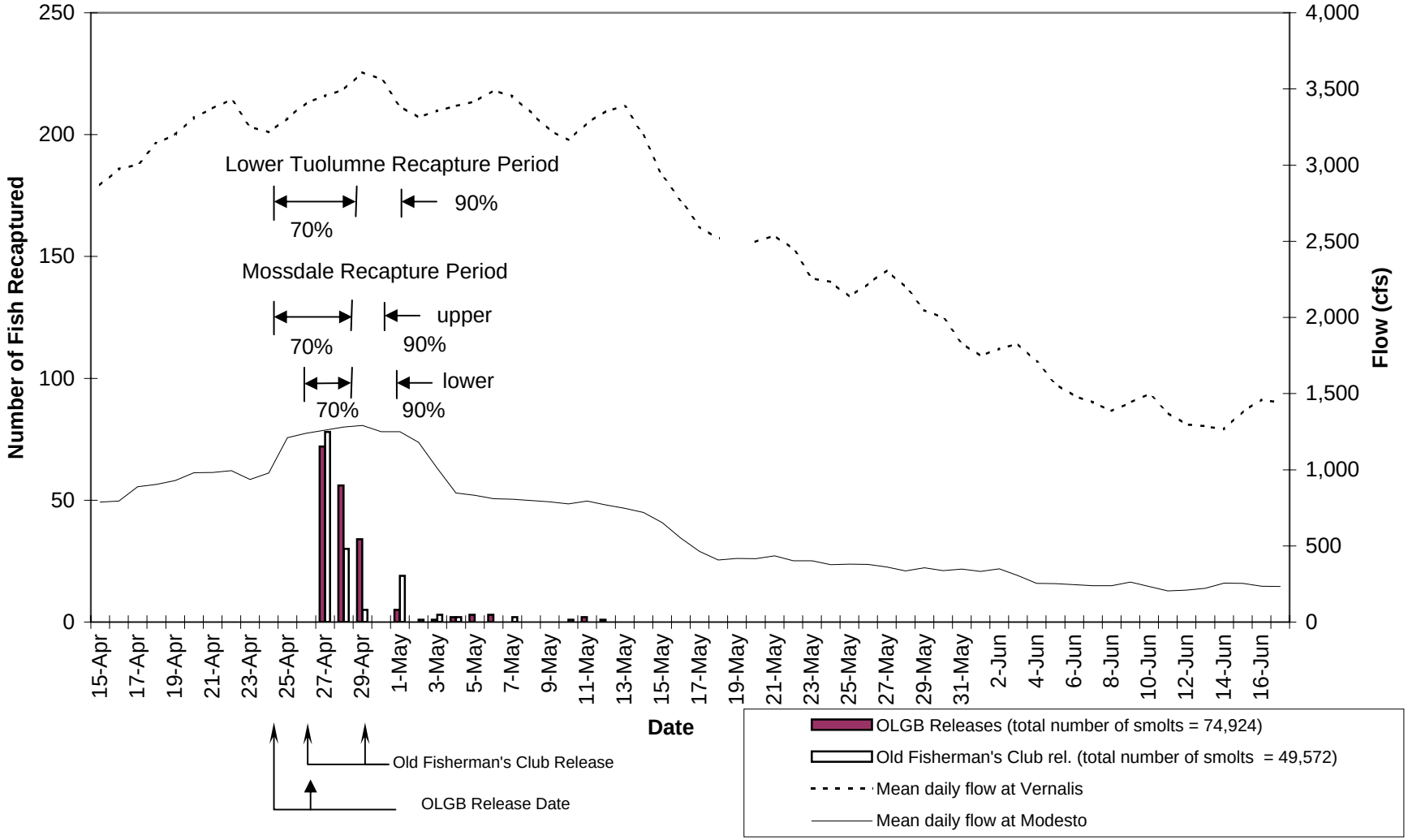

Figure A1. Recovery at Mossdale of CWT smolts released in the Tuolumne River vs. FLOW - 2002

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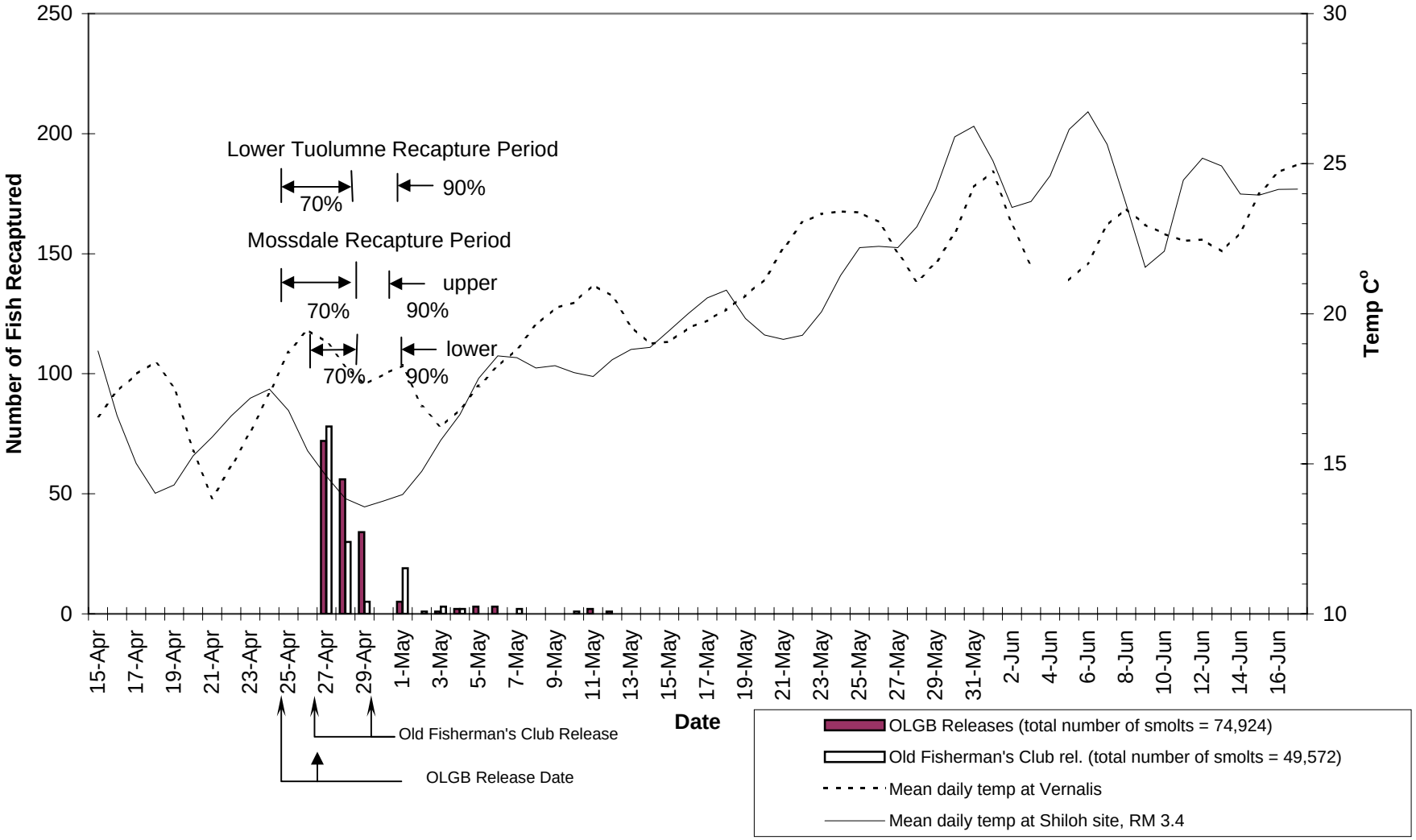

Figure A2. Recovery at Mossdale of CWT smolts released in the Tuolumne River vs. TEMPERATURE - 2002

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