2006 Tuolumne River Fall Chinook Salmon Escapement Survey

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INTRODUCTION

The San Joaquin fall-run Chinook salmon is currently a species of concern under the Federal and State Endangered Species Acts. Population levels in the Tuolumne River have declined in the latter half of the 20th century from a high of approximately 130,000 returning adults in 1944 (Fry 1961) to a low of 77 in 1991 (Neillands et al. 1993). Population levels increased to 17,873 in 2000 (Vasques 2001) indicating a slight recovery period, and are once again declining with estimates of 1,634 in 2004 (Blakeman 2005) and just 724 in 2005 (Blakeman 2006), with this years estimate continuing this trend. The decline of the species is believed to be caused by many factors. In general, reduction of spawning and rearing habitat and stream flow management practices are thought to be the major factors limiting overall population numbers. Numerous additional factors including but not limited to predation, streambed alteration, water diversion, gravel mining, land use practices, and ocean angler harvest contribute to a web of complex population dynamics which effect population numbers within the habitat currently available to Tuolumne River Chinook salmon.

The California Department of Fish and Game (CDFG) has reported salmon population estimates on the Tuolumne River since 1940 (Fry 1961). The Schaefer mark recapture escapement estimation model (Schaefer 1951) has been utilized since 1971. The 2006 escapement survey uses the Schaefer as well as reporting the Jolly-Seber (Seber 1973) estimate. Beginning in 1992, CDFG escapement surveys have been utilized as part of the New Don Pedro FERC Project No. 2299 license monitoring program and annual reporting.

The primary objectives of the Tuolumne River escapement survey are to:

- Estimate the escapement of fall run Chinook salmon on the Tuolumne River.
- Collect fork length and sex data.
- Collect scale and otolith samples with which to conduct age determination analysis and subsequent cohort analysis.
- Collect and analyze coded wire tag data from adipose fin clipped fish.
- Evaluate the distribution of salmon redds through the study area.

STUDY AREA

Approximately 26.5 river miles were surveyed during the Tuolumne River escapement survey in 2006 (Figure 1). The survey area was divided into 4 sections with Section 1 being the upstream most reach. Section 1, also referred to as the primary spawning reach, extends from riffle A1 at river mile 52.0 near La Grange Dam downstream to Basso Bridge at river mile 47.5. Section 2 extends from Basso Bridge down to the Turlock Lake State Recreation Area (TLSRA) at river mile 41.9. Section 3 covers the area between TLSRA and riffle S1 at river mile 34. Section 4 extends downstream to Fox Grove (river mile 26). Figure 1 also includes a section 5, which was not surveyed, that extends downstream of Fox Grove to RM 24.1.

All riffles in the study area have been identified and mapped using a Trimble GPS unit and the GIS computer program ArcView. Each riffle has been systematically re-named upstream to downstream using sequential letter/number designations for river mile and riffle number, respectively. For example, the first riffle surveyed below La Grange Dam in the first river mile (51) is named A1. The riffle immediately below La Grange Dam (riffle A1) is surveyed by foot and only redd and live fish counts are made. This numbering system is a departure from the historical riffle numbering system. However, the new riffle identification system is more conducive to editing and tracking riffles as river morphology changes. Changes in riffle locations which may occur during high flow periods will affect riffle names only within that river mile. For example, river mile O (37.9 – 37.0) changed significantly from 2005 – 2006 from 5 to 8 riffles (Table 1). River mile O is always located in the same place (RM 37.9- 37.0) with riffles being created, lost or migrating within that river mile. The riffle identification cross-reference is located in Table 1.

METHODS

Population Estimation

The Schaefer (1951) and Jolly-Seber (Seber 1973) mark recapture models were used to estimate fall salmon escapement on the lower Tuolumne River. With very low numbers of returning adults the simple Peterson (Ricker 1975) method was also used. These methods utilize marked and subsequently recovered carcasses during weekly surveys of the spawning reach. A ratio of marked to unmarked fish is used to calculate weekly population estimates, which are then summed to estimate the total spawning population. The CDFG began the survey on 5 October 2006 (Week 1) and concluded on 28 December 2006 (Week

13). Carcasses were tagged for the first 11 weeks. The last two weeks were recovery weeks only, live and redd counts were made, but no fish were tagged.

All carcasses encountered were handled during weekly drift boat surveys of the study area. Carcasses were gaffed as the sampling crew drifted past and held in the boat until the end of the riffle and adjacent downstream pool. Subsequent to drifting the riffle and downstream pool the riverbanks were walked to collect carcasses that could not be seen or collected from the drift boat. Every carcass handled was designated as fresh, decayed, skeleton or recovery, depending on the degree of decomposition or the presence of an aluminum jaw tag in the case of recoveries. The fresh carcass designation criteria used was at least one clear eye (Figure 2). Decayed fish had cloudy eyes. Skeletons were carcasses judged to be in an advanced state of decay and unlikely to have the same probability of recapture as fresh or decayed specimens (Figure 3 and 4).

All fresh and decayed carcasses were given a unique number by attaching a numbered aluminum tag to the lower jaw. These newly tagged carcasses were redistributed to river current near the lower end of the riffle for recovery in subsequent weeks. For tag recoveries, the unique tag number was noted and the carcass was chopped and returned to the river. All skeletons were enumerated, chopped, and returned to the river to avoid double counting. Estimates were made using the Schaefer (1951) equation and Peterson method, as presented in Ricker (1975) and also using the Jolly-Seber equation (Seber 1973).

Weekly Fish Distribution and Redd Counts

Weekly live fish observation and redd counts were conducted during the survey (Table 2, Figure 5). These counts are conducted for each riffle and pool using the riffle identification system noted earlier. Counts are made using tally counters as field crews drifted through riffles and pools. For consistency the same observer was used each week to make live fish and redd counts.

Individual Fish Data Collection

Fork length (to the nearest 1 centimeter), sex and condition (fresh or decayed) data were recorded for all tagged carcasses. Carcasses that were too decayed were counted and recorded as skeletons. Scale and otolith samples were collected to determine the size and age composition of annual spawning runs. Coded wire tags (CWTs) are collected from marked (adipose fin clipped) carcasses to monitor hatchery production and as part of long term survival testing of releases of marked outmigrating smolts. This also allows for determining the incidence of straying from other river systems. CWT specimens are also used to validate scale and otolith age determination work. Scale and otolith samples were collected from both wild and CWT carcasses and are catalogued at the CDFG La Grange Field Office. CWTs and otolith samples are collected via removal of the head minus the lower jaw. Extraction and analysis of otoliths and CWTs from these heads is conducted after the spawning season. All fish samples are catalogued by the fish's unique jaw tag number, which allows the samples to be tracked to the specific data and riffle number where collected.

RESULTS

Population Estimate

Based on the Schaefer model using all tagged fish and recoveries the 2006 escapement estimate was **625 salmon**. The Jolly-Seber model using all tagged fish yielded an estimate of 331. The Peterson method estimated the population to be 663. The Schaefer and Jolly-Seber models utilize the number of recoveries of tagged carcasses, the total number of tagged fish, and the total number of carcasses handled each week to generate weekly escapement estimates (Table 3). Weekly estimates are summated to obtain the total escapement estimate over the course of the survey. Table 4, the mark-recapture matrix, shows the total number tagged each week in relation to the number of recoveries made in subsequent weeks. Weekly estimates are presented in Table 5. Weekly cumulative Schaefer and Jolly-Seber estimates are graphed in Figure 6. Overall tag recovery rate was very low at just 23.1%.

Weekly Counts

Both live fish and redd counts slowly increased through week 7 then steadily declined through the end of the survey (Table 2, Figure 5). Carcass counts remained low through week 7, peaked in week 8 then decreased through the end of the survey.

Spawning Distribution

The maximum redd count represents counts made when external factors like visibility and turbidity were at optimum conditions. The maximum redd counts for each riffle over the course of the season is listed in Table 6. During the 2006 survey the maximum redd count in any one riffle was 26, 3, 6, and 3 for sections 1 through 4 respectively (Figure 7). The results of total weekly redd counts indicate that the majority (greater than 46%) of spawning activity is concentrated in the riffles of Section 1 (Figure 8). Sections 1 and 3 combined saw nearly 74% of redds in 2006.

Population Composition

There was just one coded wire tagged fish captured during the 2006 escapement survey which was a 69cm female. Females made up 46.2 % of spawning salmon. Fork length frequencies were combined from the entire San Joaquin basin to determine the breakpoint between adult and grilse. The breakpoint was determined to be 66cm for male and female. Adult and grilse composition for returning salmon was 15.4 % male grilse, females 3.3 %, adult males 38.4 % and adult females 42.9 %. Length frequencies of all fish are presented in Figure 9.

Sample Collection

Scale and otolith samples were collected from most tagged fish. Scale and otolith samples will be utilized in the CDFG age determination program and for subsequent cohort analysis of San Joaquin River Basin Chinook salmon populations. This data will also be essential for population models being developed as well as ongoing cohort analysis of factors affecting the populations.

Egg Production Estimate

An estimate of egg production by the 2006 fall run Chinook salmon is done using the relationship of fork length to fecundity. The relationship was developed using 48 San Joaquin fall run Chinook females ranging from fork length 62.5 to 94.0 cm (Loudermilk et al. 1990). The number of eggs was calculated for natural females (n=41, average FL=76.9) and CWT females (n=1, average FL=69.0) and then expanded to the entire estimated female population. Natural females made up 45.1% of the 2006 estimate and produced approximately 1,702,117 eggs. Adipose fin clipped females (1.9%) produced approximately 56,930 eggs.

Tuolumne River Flows

Tuolumne River flows at the La Grange gauge ranged from approximately 309 to 598cfs during the 2006 spawning season (Figure 10). To attract fish into the Tuolumne from the San Joaquin River and improve spawning habitat a pulse flow was initiated on 13 October 2006. Mean daily flow at La Grange averaged approximately 539 cfs from 14 – 26 October 2006 and then reduced to average 353 cfs throughout the remainder of 2006 escapement survey. Flow in the channel directly downstream of the powerhouse outlet at La Grange dam was shut off completely and released from the north side outlet.

Tuolumne River Temperature

Temperatures in the upper reaches of the Tuolumne River ranged from 9.7 – 14.2 °C. Temperatures were recorded using onset temperature monitors throughout the spawning season (Figure 11).

DISCUSSION

Population Estimate

The 2006 tag recovery rate of 23.1% is very low and likely influenced the accuracy of both the Schaefer and Jolly-Seber estimates (Law 1994). From 2001 to 2004 recovery rates were relatively high ranging from 55.3% to 65.4% and saw daily average flows below 200cfs. In 2000, 2005 and 2006 flows were higher (daily average over 300cfs) and saw lower percent recaptures, ranging from 23.1 - 41.7%. Tuolumne River daily average flows were relatively high in 2006 at over 350cfs. Stream flow dynamics affects the likelihood of collecting carcasses in that it effects both how carcasses are distributed in the system and the effectiveness in recovering carcasses by field crews. During the lower flows encountered during the 2001 - 04 surveys carcasses were easily visible and the lower flows allowed for collection in specific locations which were too deep or too swift to survey in 2000, 2005 and 2006 seasons. Furthermore, the banks of riffles were walked in an effort to collect carcasses that could not be seen or collected during the initial float through the riffle and subsequent pool. During 2000 bank efforts were not nearly so extensive. Law (1994) found in simulations of various models, using a similar protocol as this survey, that the Peterson model drastically over estimated and showed much higher bias for all study parameters. While the Schaefer model consistently overestimated and the Jolly-Seber model underestimated at low survival and low catch rates, these methods were still used. When populations are extremely low the inherent problems with estimation methods become more significant therefore the Peterson method was also included. The Tuolumne River escapement estimate for 2006 of 625 salmon is the lowest since the 1994 estimate of 513 returning adults.

Weekly Counts

Live fish, redd and carcass counts as illustrated in Figure 5 shows a typical bell curve shape with counts gradually increasing, peaking near mid-spawning season and gradually decreasing when most fish are done spawning. Live fish and redd counts peaked in week 7 with the peak in carcass counts occurring one week later. Counts were also conducted earlier in the year. Reports of fish entering the Tuolumne River prompted a one day float on 2 August in which 4 live fish, 5 redds and 5 carcasses were observed from La Grange Dam to Basso Bridge (Section 1).

Spawning Distribution

Redd counts are affected by time of day, visibility, sunlight, wind rippling the water surface, redd superimposition, and other physical factors as well as the natural variability between observers. The same observer was used each week during the Tuolumne escapement survey to minimize any bias which may occur when using different observers. Furthermore, redd counts are conducted with a single pass as opposed to an intensive systematic approach which is beyond the scope of current funding. The 2006 survey required just two days per week to cover the entire spawning reach. The majority of spawning occurred within the first section. With so few fish returning to spawn there likely was very little (if any) redd superimposition occurring.

Population Composition

The one CWT fish captured in 2006 was from Merced River Fish Facility and comprised 1.9 % of all fish tagged. Skeletons were not checked for adipose fin clips due to their advanced state of decomposition. However, it is likely that ratios calculated for tagged fish are representative for skeletons as well. Females made up 46.2 % of spawning salmon. Adult and grilse composition for returning salmon was 15.4 % male grilse, females 3.3 %, adult males 38.4 % and adult females 42.9 %.

Sample Collection

Scales and otolith samples were collected from all fish after week 5, only scale samples were taken for the first 5 weeks of the survey. Samples were collected throughout the survey area (Table 7). Distribution throughout entire spawning reach is intended to best represent the spawning population over time, space and origin.

Tuolumne River Flows

Low dissolved oxygen (DO) levels in the San Joaquin River are believed to be a barrier for fall-run salmon migrating up the San Joaquin stem to spawn in the Merced, Tuolumne and Stanislaus Rivers. A fall pulse flow regime has been developed to lower river temperatures and elevate levels of dissolved oxygen in the San Joaquin River in order to attract salmon and prevent straying. Redds were observed immediately at the start of the escapement survey. The 2006 escapement season saw relatively high flows throughout the basin which likely minimized any DO or temperature problems. The flow schedule included a base flow of 300cfs. Additional pulse flow water added 300cfs from 16 - 24 October. Interestingly, flows at the Modesto gauge were much higher at the beginning of the spawning season remaining above 1,200cfs through the end of October. This water was likely diverted around the spawning reach and released back into the river through the Faith Home spill located downstream.

Tuolumne River Temperatures

Temperatures in the Tuolumne River remained below the thermal limit for successful egg incubation of 13.3 ^{o}C (Myrick and Cech 1998) throughout nearly all the spawning reach and season. The thermograph placed in riffle K1 only had the first 2 weeks of the survey when the average daily temperature rose above 13.3 ^{o}C (Figure 11). The thermograph placed below the La Grange Powerhouse outlet recorded some elevated temperatures in the first week of November when TID completely shut-off water flow down the south side channel, releasing all of the water from the north canal outlet. This did cause some stranding of redds which had be constructed in weeks prior.

Table 1. Tuolumne River riffle identification cross-reference, 2006 to 2005.

Section 1		Section 2		Section 3		Section 4	
New ID	**Old ID**	**New ID**	**Old ID**	**New ID**	**Old ID**	**New ID**	**Old ID**
A1	A1	F1	F1	K1	K1	S2	S1
A2	A2	F2	F2	K2	K2	S3	S2
A3	A2	F3	F3	K3	K3	S4	S3
A4	A3	G1	G1S	L1	L1	T1	T1
B1	B1	G2	G1N	L2	L2	T2	T2
B2	B2	G3	G2	L3	L2N	T3	T3
B3	B3	G4	G2N	L4	L3	T4	T4
B4	B4	G5	G3	M1	M1	T5	T5
C1	C1	G6	G4	M2	M2	U1	U1
C2	C2	H1	H1	N1	N1	U2	U2
C3	C3	H2	H2	N2	N2	U3	U3
D1	D1	H3	H3N	N3	N3	V1	V1
D2	D2	H4	H3S	N4	N4	V2	V2
D3	D3	H5	H4	O1	O1	V3	V3
D4	D4N	H6	H5	O2	NONE	V4	V4
D5	D4	H7	H6	O3	O2	W1	W1
D6	D5	I1	I1	O4	NONE	W2	W2
E1	E1	I2	I2	O5	O3	W3	W3
		I3	I3	O6	O4	NONE	X1
		I4	I4	O7	NONE	NONE	X2
		J1	J1	O8	O5		
		J2	J2	O8	P1		
		J3	J3	P1	P2		
		J4	J4	P2	P3		
		J5	J5	P3	P4		
		J6	J6	P4	P5		
		J7	J7	P5	P6		
		J8	J8	Q1	Q1		
				Q2	Q2		
				Q3	Q3		
				R1	R1		
				R2	R2		
				R3	R3		
				S1	R3		

Table 2. Maximum weekly counts of live fish, redds, and carcasses.

Week	Maximum Counts		
	Live	Redds	Carcasses
1	5	1	3
2	4	2	4
3	5	2	1
4	11	4	6
5	11	4	2
6	18	12	11
7	**45**	**26**	13
8	16	17	**36**
9	13	12	15
10	4	4	10
11	4	5	5
12	3	3	1
13	2	17	1

[1]Carcasses includes all tagged carcasses and maximum skeletons but does not include recoveries.

Table 3. Weekly total counts.

Week	Tagged	Skeletons	All Recoveries	Total Counted[1]	Fresh Tagged[2]	CWT's
1	1	2	-	3	0	0
2	4	0	0	4	3	0
3	1	0	0	1	1	0
4	5	1	0	6	4	0
5	2	0	3	5	0	0
6	9	7	0	16	6	0
7	12	3	1	16	11	0
8	31	19	6	56	20	0
9	14	4	6	24	9	1
10	8	8	2	18	3	0
11	4	1	3	8	3	0
12	0	5	0	5	0	0
13	0	11	0	11	0	0
Total	**91**	**61**	**21**	**173**	**60**	**1**

[1]Includes total tagged, skeletons and recoveries.
[2]Includes only fish that were deemed fresh when tagged.

Table 4. Distribution of all tagged fish, tag week versus recovery week.

Recovery Week	Tag Week of Recovered Tags												Weekly Totals
	1	2	3	4	5	6	7	8	9	10	11	12	
2	0												**0**
3	0	0											**0**
4	0	0	0										**0**
5	0	0	0	1									**1**
6	0	0	0	0	0								**0**
7	0	0	0	1	0	1							**2**
8	0	0	0	1	0	0	6						**7**
9	0	0	0	0	0	0	0	5					**5**
10	0	0	0	0	0	0	0	1	1				**2**
11	0	0	0	0	0	0	0	0	0	2			**2**
12	0	0	0	0	0	0	0	0	1	1	0		**2**
13	0	0	0	0	0	0	0	0	0	0	0	0	**0**
All Recoveries	**0**	**0**	**0**	**3**	**0**	**1**	**6**	**6**	**2**	**3**	**0**	**0**	**21**
Total Tagged Carcasses	**1**	**4**	**1**	**5**	**2**	**9**	**12**	**31**	**14**	**8**	**4**	**0**	**Overall Recovery**
Percent Recovery	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**11.1%**	**50.0%**	**19.4%**	**14.3%**	**37.5%**	**0.0%**	**0.0%**	**23.1%**

Table 5. Weekly Schaefer and Jolly-Seber estimates.

Week	Number of Tags Recovered	Total Carcasses Handled	Schaefer Estimate	Jolly-Seber Estimate
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	1	14	155	95
6	0	33	164	-32
7	2	16	67	120
8	7	57	136	23
9	5	24	80	53
10	2	18	24	21
11	2	7	0	29
12	2	7	0	23
13	0	11	0	0
Total Estimate			**625**	**331**

1

Table 6. Maximum redd count for each riffle over the course of the escapement survey by section.

Section 1		Section 2		Section 3		Section 4	
Riffle	Maximum Redd Count	Riffle	Maximum Redd Count	Riffle	Maximum Redd Count	Riffle	Maximum Redd Count
A1	6	F1	2	K1	2	S2	0
A2	2	F2	0	K2	1	S3	0
A3	0	F3	1	K3	6	S4	1
A4	0	G1	2	L1	2	T1	0
B1	26	G2	0	L2	2	T2	2
B2	12	G3	2	L3	0	T3	0
B3	1	G4	1	L4	0	T4	1
B4	0	G5	1	M1	0	T5	0
C1	5	G6	1	M2	3	U1	3
C2	0	H1	1	N1	5	U2	0
C3	9	H2	2	N2	4	U3	1
D1	0	H3	1	N3	1	V1	0
D2	8	H4	1	N4	1	V2	0
D3	2	H5	0	O1	0	V3	3
D4	1	H6	0	O2	0	V4	0
D5	0	H7	1	O3	2	W1	0
D6	2	I1	2	O4	1	W2	2
E1	1	I2	2	O5	0	W3	0
		I3	0	O6	1		
		I4	0	O7	2		
		J1	0	O8	5		
		J2	0	P1	0		
		J3	0	P2	0		
		J4	0	P3	1		
		J5	2	P4	4		
		J6	1	P5	1		
		J7	3	Q1	0		
		J8	2	Q2	1		
				Q3	0		
				R1	1		
				R2	2		
				R3	1		
				S1	0		
Sub Total	**75**		**28**		**45**		**13**
Total	**180**						

Table 7. Distribution of scale and otolith samples collected by section and week for all fish.

Week	Section			
	1	**2**	**3**	**4**
1*	0	0	0	0
2*	2	1	0	1
3*	1	0	0	0
4*	5	0	0	0
5*	1	1	0	0
6	3	1	5	0
7	9	2	1	0
8	24	2	4	1
9	9(1)	3	1	0
10	5	0	3	0
11	4	0	0	0
Total	**64**	**10**	**14**	**2**

* - Indicate weeks which only scale samples were taken, no otolith samples were taken.
Parentheses indicate sample was taken from adipose fin-clipped carcass.

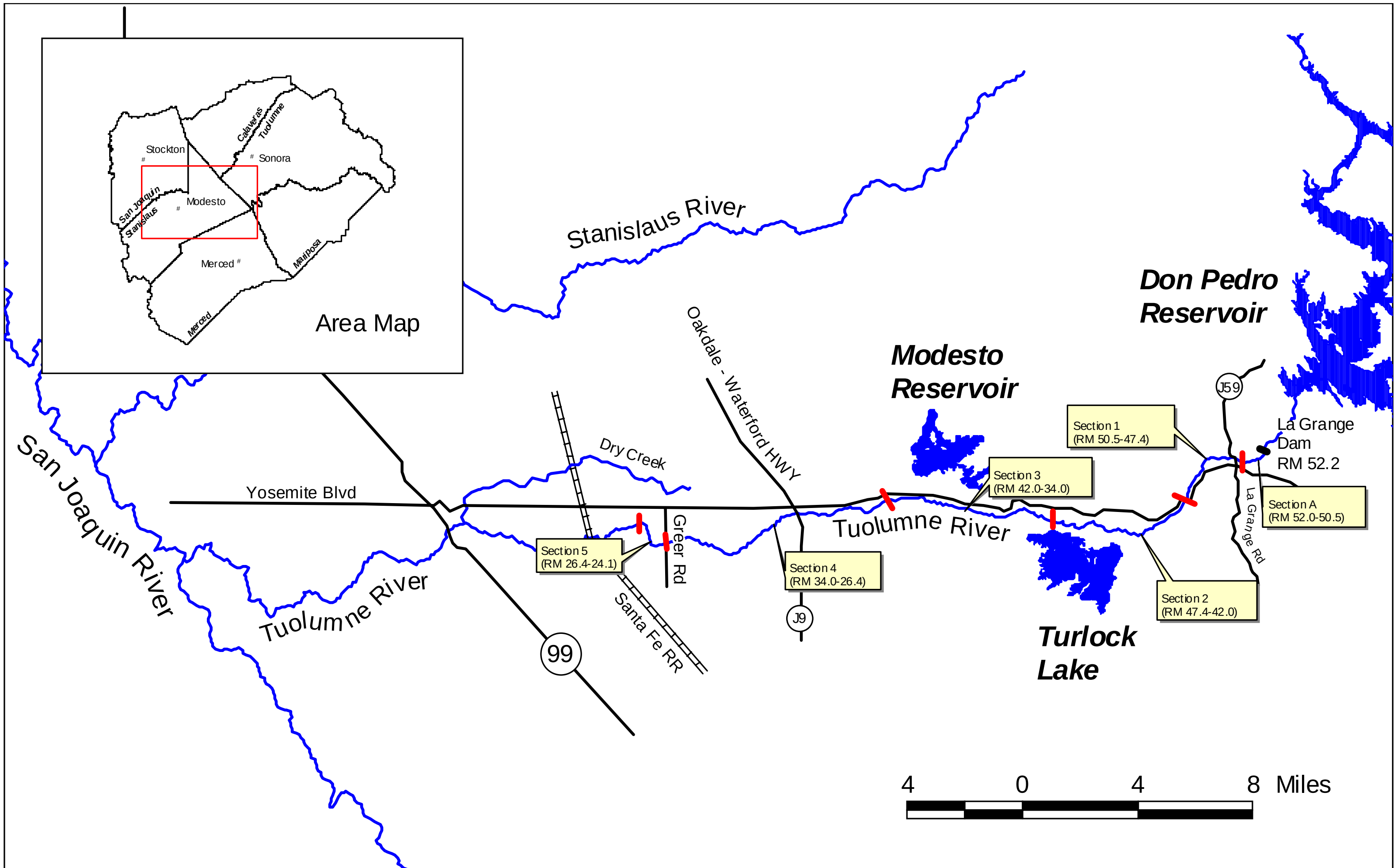

Figure 1. Salmon survey study areas, lower Tuolumne River.

California Department of Fish & Game

Prepared by: Gerald Hatler 01/18/2000

Figure 2. Fresh carcass indicated by clear eye.

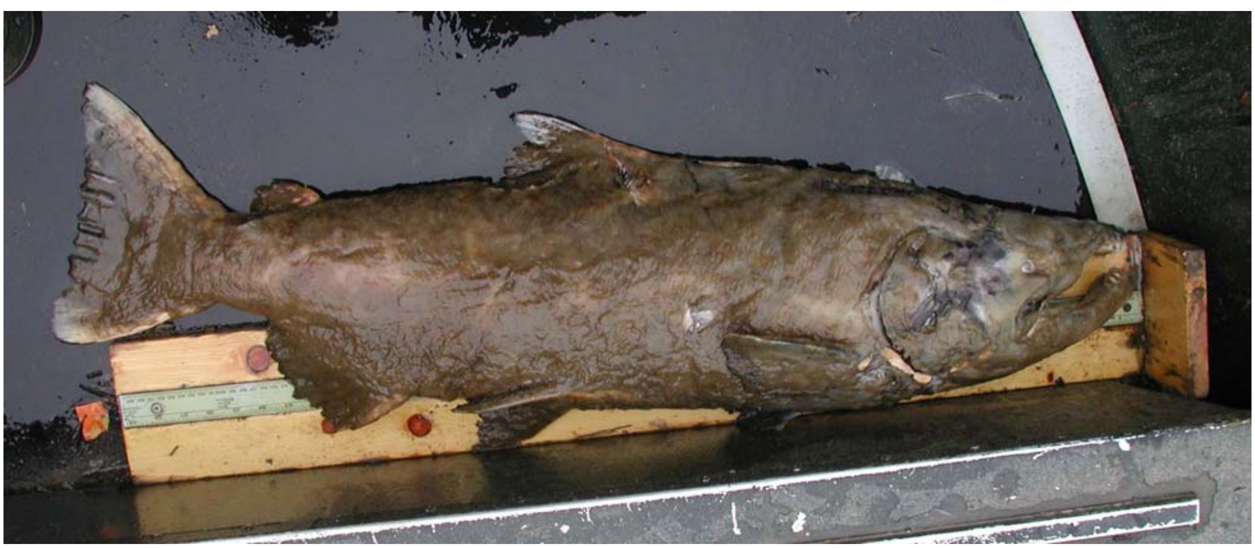

Figure 3. Fungus covered skeleton.

Figure 4. Two skeletons showing varied degrees of decomposition and a fresh carcass.

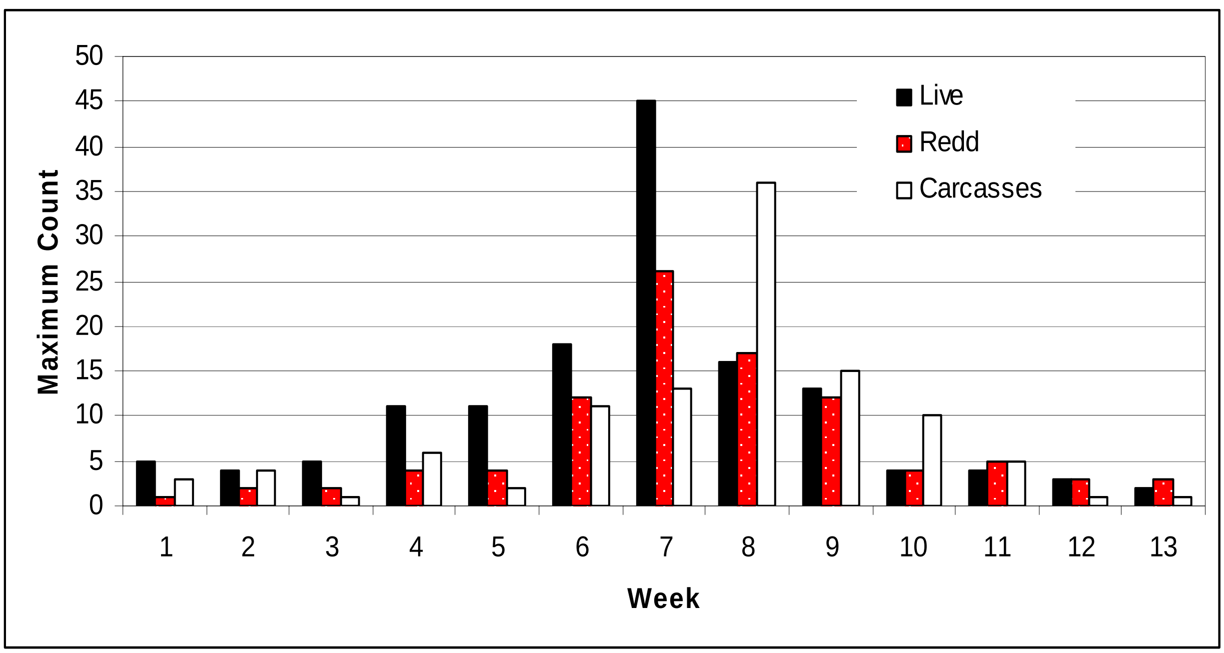

Figure 5. Live fish observation, redd, and total carcass weekly counts. Carcasses include all tagged carcasses and skeletons.

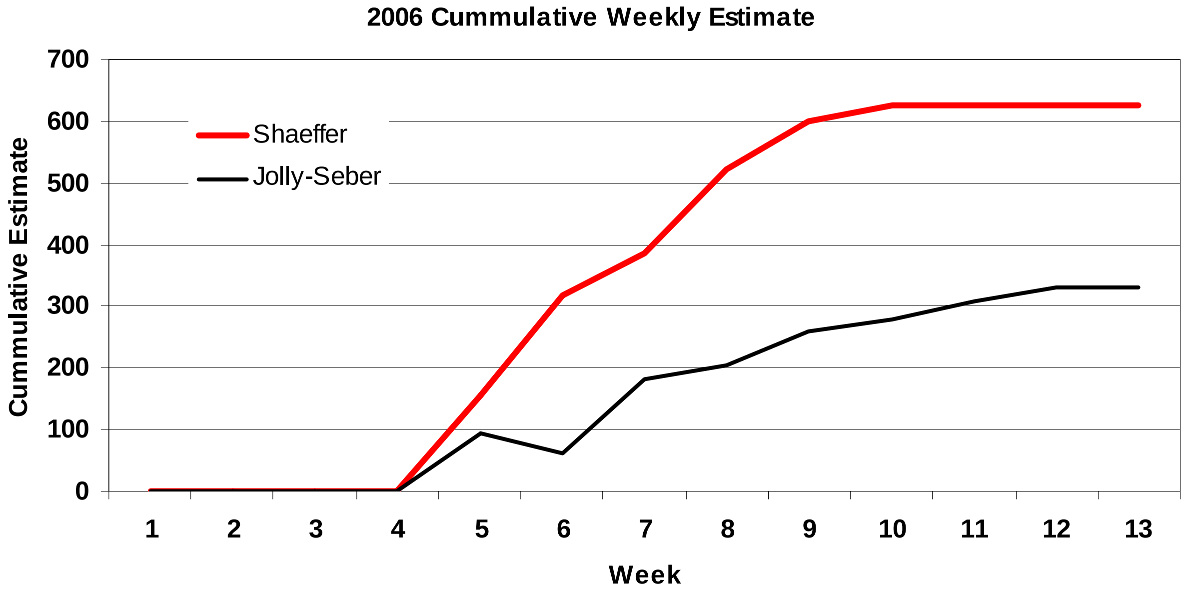

Figure 6. Weekly cumulative Schaeffer and Jolly-Seber escapement estimates.

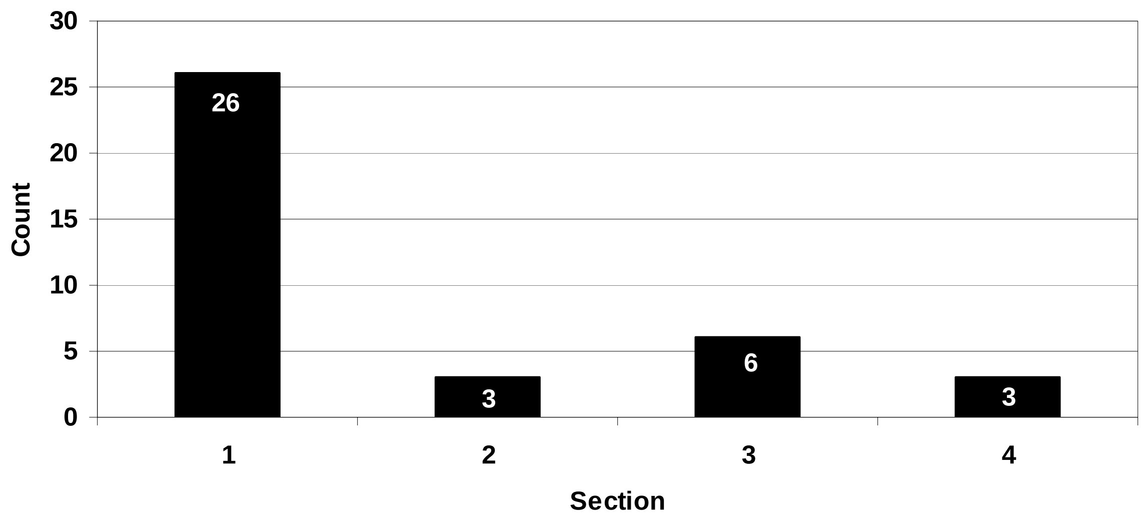

Figure 7. Maximum number of redds counted per section.

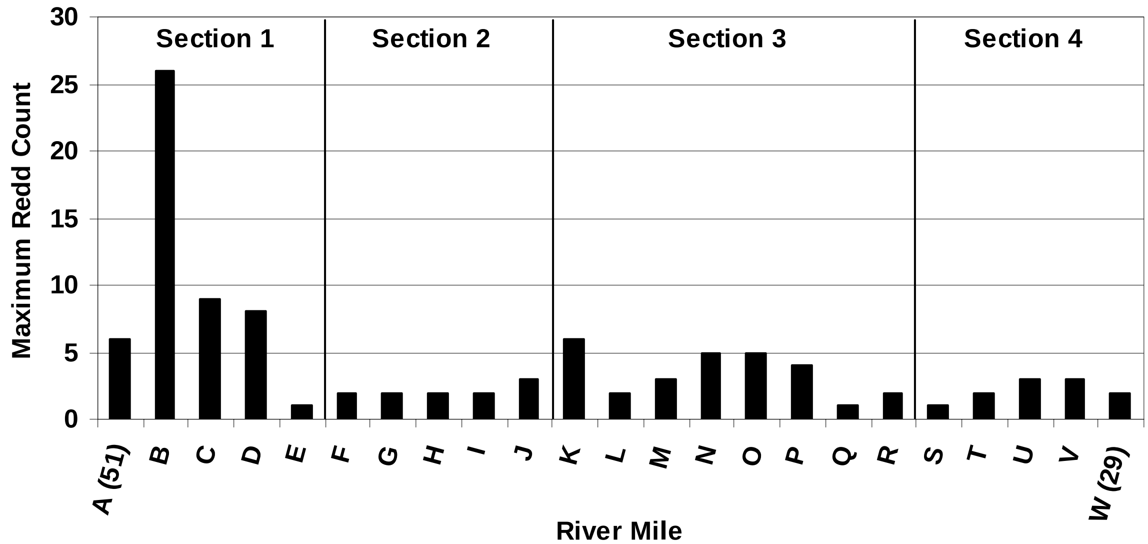

Figure 8. Maximum redds observed by riffle section. Each letter represents one river mile. Actual river miles are in parenthesis.

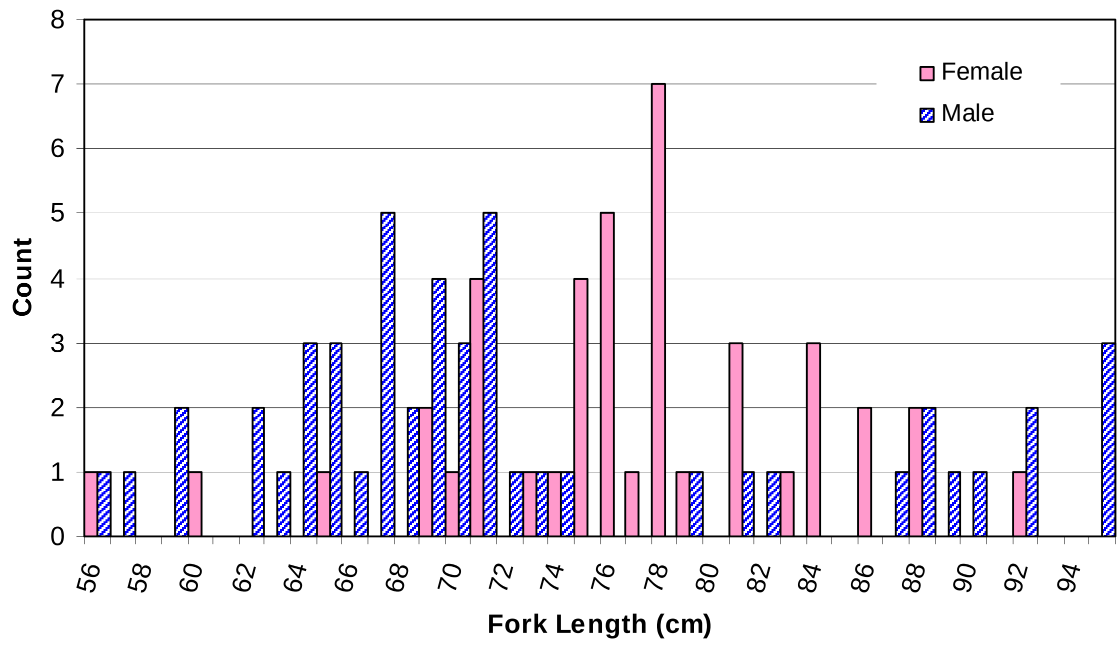

Figure 9. Length frequency histogram of female and male Chinook. Includes one adipose fin clipped female at 69cm.

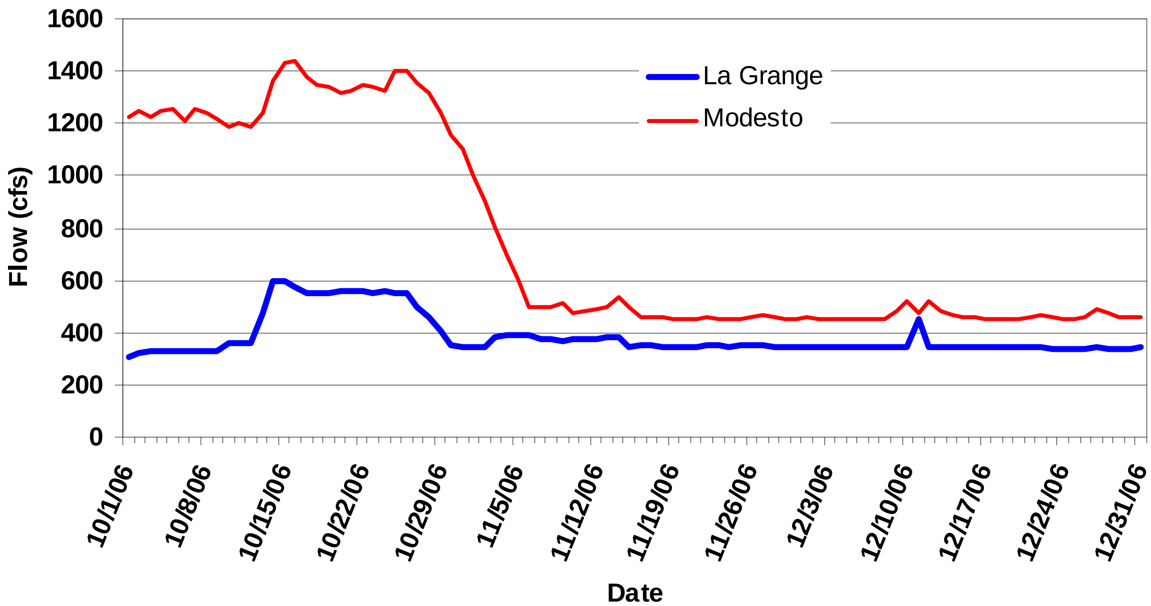

Figure 10. Average daily flow in the Tuolumne River (cubic feet per second) at the Modesto, and La Grange gauges. Preliminary data obtained from California Data Exchange Center (CDEC) website.

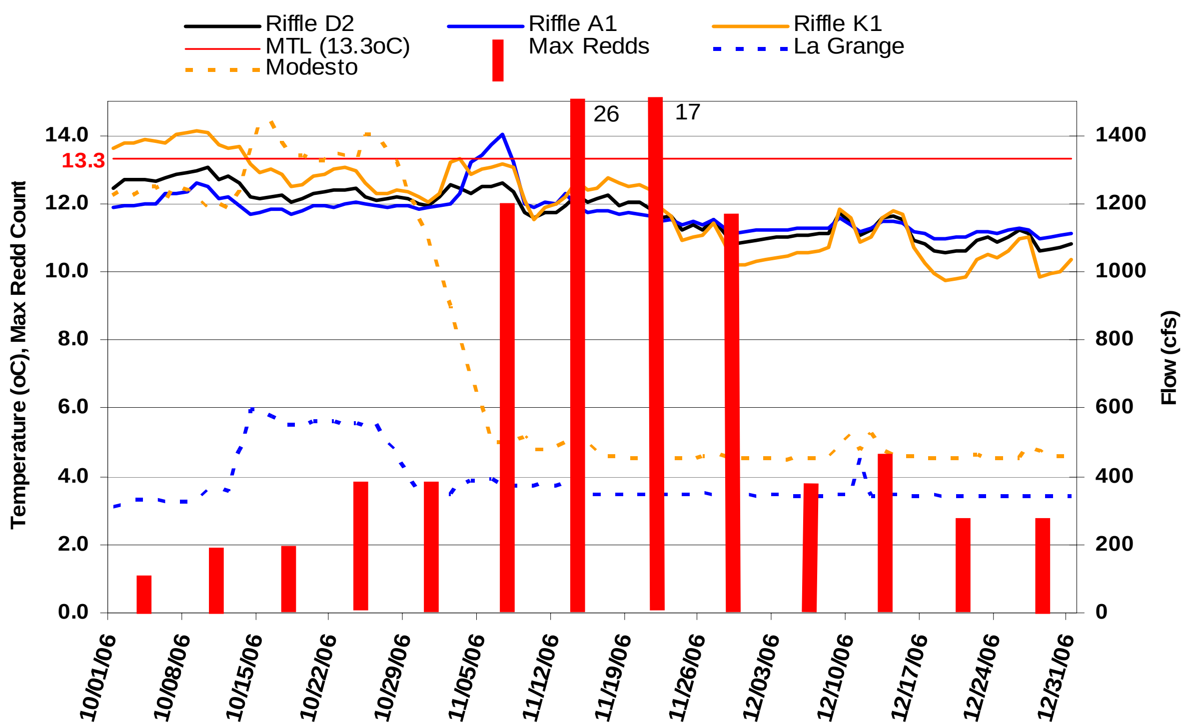

Figure 11. Weekly maximum redd counts for the Tuolumne River escapement survey. Flow (cfs) at La Grange and Modesto gages, temperatures from CDFG monitoring sites and maximum thermal limit.

References

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