TASK 17. SURVIVAL ESTIMATES OF MOKELUMNE CHINOOK SALMON

17.1 OBJECTIVE

The objective of this study was to compare the overall survival rates (from incubation through out-migration) of salmon which migrate into the Mokelumne River under different temperature conditions. The in-migrating salmon were separated into two groups based on their temperature exposure; the warm water group included fish that spawned at temperatures greater than 15° C, while the cold water group included fish that spawned when temperatures were less than 15° C. The survival of the offspring of these two groups of spawners was compared at three different times: just prior to out-migrating from the river, during out-migration after passing through Lake Lodi, and after migrating through the Delta.

17.2 METHODS

According to the results found in our emergence studies (Task 12), there are different egg-to-fry survival rates for Mokelumne River chinook salmon depending on whether the water is cold ($\leq$ 15° C) or warm ($>$ 15° C) during spawning and early incubation. However, in this task, the survival rates were estimated from egg-to-smolt passing through the Delta. The overall survival rate was broken down into the following phases: egg-to-fry emergence; fry rearing; and smolt out-migration through the river, Lake Lodi, and the Delta.

Using the results of the 1991 fry emergence study (Task 12), the survival rate of egg-to-fry emergence (i.e., egg-to-fry survival) was estimated. Because the survival rate during the fry rearing period (i.e., rearing survival) is relatively stable, a constant survival rate was assumed. The survival rates of smolts passing through the river (i.e., in-river survival) and Lake Lodi (i.e., Lake Lodi survival) were estimated using the data collected from the 1991 smolt mortality study (Task 15). The USFWS smolt survival indices were utilized for estimating the survival rate of smolt out-migrating from Woodbridge Dam through the Delta (i.e., Delta survival) across time; therefore, these indices were used in this task to estimate the Delta survival rate. The overall egg-to-fry, rearing, in-river, Lake Lodi, and Delta survival rates were integrated for both cold and warm water for salmon populations. Then their overall survival rates were compared. The methodology used to estimate the survival rate in each phase is described below.

17.2.1 Egg-to-Fry Emergence

The results of the 1991 egg survival experiments (Task 12) indicate that egg daily-cohorts (i.e., eggs spawned on the same day) can be categorized as either cold or warm water cohorts with different egg-to-fry survival rates. The cold water population developed in water of less than 15°C had a survival rate of 0.405; the survival rate of the warm water populations was 0.095.

17.2.2 Fry Rearing

The survival rate for fry rearing in the Mokelumne River is believed to fluctuate from year to year. Because no further data are available, a constant survival rate was used for this phase.

17.2.3 Smolts Out-migration Through the Mokelumne River and Lake Lodi

Using the daily capture of marked smolts recorded at Woodbridge Dam during the 1991 smolt mortality study (Task 15), the in-river and Lake Lodi survival rates were determined to be exponentially decayed over time (Figure 16-3 in Task 16). In Task 16, the survival rates were examined as a function of time and two exponential equations were developed to express the relationships. In this task, the same equations were used to estimate the in-river and Lake Lodi survival rates for a given day using 1 October 1990 as Day 1 (Table 16.1 in Task 16).

17.2.4 Smolts Out-migration Through the Delta

The USFWS established indices for the survival of smolts passing through the Delta from studies conducted during smolt out-migration between the Sacramento River and Chipps Island. Two years (1988 and 1989) of USFWS survival indices were used to estimate the Delta survival rate. However, the indices derived from mean catches of less than one salmon per trawl and from large-scale releases at the Coleman National Fish Hatchery were excluded from the analysis.

For each year, the highest survival index was standardized to one (1.0), and the relative values of the remaining indices were calculated accordingly as the Delta survival rate. As a function of time, the survival rate was expressed using the following exponential equation:

$$\begin{aligned} &\textit{if } x_i \le x_0 \quad \textit{then } y_i = 1 \\ &\textit{otherwise } y_i = e^{a+bx_i} \quad 0 \le y_i \le 1 \end{aligned} \tag{1}$$

where x_i is a given day (e.g. x_i= 223 at Day 223), x_0 is the day when the survival rates start to decline, and y_i is the survival rate at Day i. (a and b are constants.)

The exponential equation was used to express the survival rate over time for both years (1988 and 1989). Using logarithms, the equations were transformed linearly. Analysis of covariance (ANCOVA) was conducted to determine whether the intercepts of the two linear regressions were the same. If they proved to be the same, the two years' data could be combined.

17.2.5 Survival Estimates from Egg-to-Smolt Out-migration Through the Delta

Because the in-river and Lake Lodi smolt survival rates were only available for the 1990-1991 year class, the survival rates from egg-to-smolt passing through the Delta were estimated only for that period.

Using the logistic function (equation 2 in Task 16), each of the egg, fry, smolt and out-migration temporal distributions established in Task 16 were divided evenly into ten parts. Because approximately ten days were required for a smolt to travel from the Lower Mokelumne River to the Delta (USFWS 1987), the smolt distribution at the Delta was established by shifting the out-migration distribution at Woodbridge Dam forward ten days.

Within the temporal distribution for each phase, the survival rate was estimated for each tenth of the cumulative population. The overall survival rate was calculated by multiplying the survival rates from all the phases.

17.3 RESULTS

Fifty-five percent of eggs were deposited in warm water before 18 November 1990; 45 percent were subsequently deposited in cold water. As the accumulated egg population had been divided into ten parts, the first five parts contained the water populations (egg-to-fry survival rate 0.095), four parts contained the cold water population (egg-to-fry survival rate 0.405) and the remaining part contained eggs from both warm and cold water populations (the egg-to-fry survival rate was 0.25, calculated by averaging 0.095 and 0.405).

The highest value in the survival indices was assigned as one. The relative values of the remainder were calculated accordingly as the Delta survival rate for 1988 and 1989 (Table 17.1). The results of ANCOVA (Table 17.2) showed there was a significant exponential relationship of survival rates over time (i.e., slope) but the relationships derived from each of the two years were not significantly different. Therefore, the exponential equation for Delta survival as a function of time was obtained by combining the two years' data:

$$\begin{aligned} &\textit{if} \quad x_i \le 190 \quad \textit{then} \quad y_i = 1 \\ &\textit{otherwise} \quad y_i = \exp(3.80 + 0.02 x_i) \quad R^2 = 0.73 \quad df = 33 \end{aligned} \tag{2}$$

For each tenth part of the population, Table 17.3 shows the survival rates of the egg-to-fry, in-river, Lake Lodi, and the Delta phases. Assuming the survival rate of fry rearing as a constant, the integrated survival rates from egg-to-fry, from egg-to-smolt in the river, at Lake Lodi, and passing through the Delta were also estimated for each tenth (Table 17.4 and Figure 17-1).

The survival rates for egg-to-smolt out-migration in the river were less than 0.10 for the warm water population, but ranged from 0.24 to 0.39 for the cold water population. The

survival rate of smolts in Lake Lodi decreased exponentially over time. The difference in the survival rate between the warm and cold water salmon populations after leaving Lake Lodi became smaller but was still significant (F-value= 16.59, $p < 0.05$). The overall survival rate of the salmon population in warm water ranged between 0.006 and 0.015 with an average of 0.011 (SD= 0.003); in cold water, it ranged between 0.010 and 0.019 with an average of 0.014 (SD= 0.003). However, the difference between the overall survival rates of the warmwater and coldwater salmon populations from egg deposition in the Mokelumne River to smolt out-migration through the Delta was not significant (F-value= 1.54, $p > 0.05$).

Table 17.1. The survival indices estimated by USFWS during 1988 and 1989 sampling periods (1 October 1987 was Day 1 for 1988 and 1 October 1988 was Day 1 for 1989) and the Delta survival rates estimated by assigning the highest value of the survival indices in a year as one.

1988				1989			
Day	Date	Survival		Day	Date	Survival	
		Index	Rate			Index	Rate
193	Apr 11	0.66	1.00	202	Apr 21	1.38	1.00
195	13	0.65	0.99	206	25	1.13	0.82
197	15	0.52	0.79	208	27	0.92	0.67
199	17	0.49	0.74	210	29	0.70	0.51
201	19	0.44	0.67	213	May 1	0.65	0.47
203	21	0.42	0.64	215	3	0.97	0.70
205	23	0.39	0.59	225	13	0.13	0.09
207	25	0.33	0.50	226	14	0.14	0.10
209	27	0.27	0.41	227	15	0.24	0.17
211	29	0.31	0.47	228	16	0.41	0.30
213	May 1	0.40	0.61	229	17	0.45	0.33
215	3	0.43	0.65	231	19	0.55	0.40
239	7	0.09	0.14				
241	29	0.10	0.15				
243	31	0.13	0.20				
245	Jun 2	0.14	0.21				
247	4	0.14	0.21				
249	6	0.17	0.26				
251	8	0.22	0.33				
253	10	0.20	0.30				
255	12	0.19	0.29				
257	14	0.20	0.30				

Table 17.2. Analysis of covariance of the linear regressions transformed from the two exponential functions over time used to estimate Delta survival rates.

Model $lny_i = a + b\,x_i$, Year 1988 and 1989

Source	df	Type III SS	F-value
Slope (x_i)	1	7.3165	94.17*
Intercept	1	0.0000	0.00

* 0.01 significance level

Table 17.3. The survival rates of egg-to-fry, and smolts passing through the river (in-river), Lake Lodi, and the Delta for every ten part of the cumulative population.

% Population	Egg-to-Fry	Smolt		
		In-river	Lake Lodi	Delta
0.1	0.095	1.000	0.377	0.432
0.2	0.095	0.999	0.301	0.391
0.3	0.095	0.993	0.264	0.368
0.4	0.095	0.988	0.231	0.347
0.5	0.095	0.982	0.211	0.333
0.6	0.250	0.977	0.184	0.314
0.7	0.405	0.971	0.161	0.295
0.8	0.405	0.967	0.135	0.273
0.9	0.405	0.955	0.108	0.247

Table 17.4. The integrated survival rates from egg-to-fry, from egg-to-smolt in river, at Lake Lodi, and passing through the Delta for every tenth part of the cumulative population.

% Population	Egg-to-Fry	Smolt		
		In-river	Lake Lodi	Delta
0.1	0.095	0.095	0.036	0.015
0.2	0.095	0.095	0.029	0.011
0.3	0.095	0.094	0.025	0.009
0.4	0.095	0.094	0.022	0.007
0.5	0.095	0.093	0.021	0.006
0.6	0.250	0.244	0.045	0.014
0.7	0.405	0.393	0.063	0.019
0.8	0.405	0.391	0.053	0.014
0.9	0.405	0.387	0.042	0.010

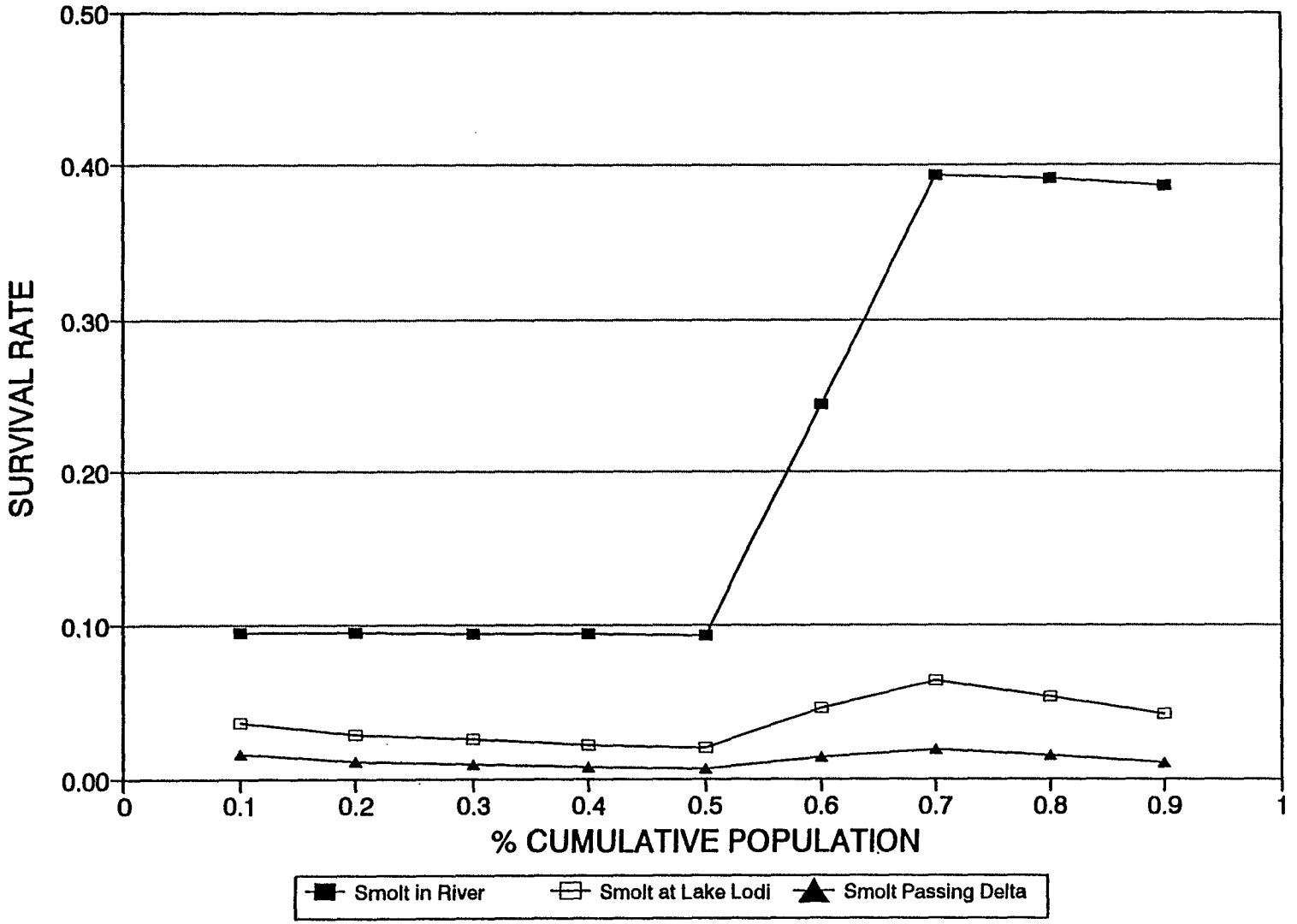

Figure 17-1. The integrated survival rates from egg-to-fry, from egg-to-smolt in-river, at Lake Lodi, and passing through the Delta for every tenth part of cumulative population.

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