# A MODEL FOR ESTIMATING MORTALITY AND SURVIVAL OF FALL-RUN CHINOOK SALMON SMOLTS IN THE SACRAMENTO RIVER DELTA BETWEEN SACRAMENTO AND CHIPPS ISLAND

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## ABSTRACT

A multiple regression model is described that predicts fall-run chinook salmon smolt survival through the Sacramento River Delta between Sacramento and Chipps Island (near Pittsburg, CA). The model uses water temperature at Freeport, CA, the fraction of water diverted from the Sacramento River at Walnut Grove, CA, and total exports of the State Water and Central Valley Projects in the south delta. Each of these three factors is negatively related to smolt survival. Survival indices were based on coded wire tagged (CWT) smolts released at several delta sites and subsequently recovered at Chipps Island. CWT smolts were released under various environmental conditions. Correlation and regression analyses were used to choose those factors that explained a significant part (p=0.95) of the variation in smolt mortality. The model predicts the survival of smolts migrating from Sacramento to Chipps Island via the Sacramento River, and through the central delta via the Mokelumne and lower San Joaquin River systems. The greatest mortality was observed for smolts diverted into the central delta, indicating that keeping smolts out of that region would be highly beneficial to salmon production. Simulations of survival under varying temperature, fractions diverted and exports are provided to quantify the benfits of alternative salmon protective measures.

# A Model for Estimating Mortality and Survival of Fall-Run Chinook Salmon Smolts in the Sacramento River Delta between Sacramento and Chipps Island

by M. Kjelson, S. Greene and P. Brandes

## INTRODUCTION

During Phase I of the California State Water Resources Control Board (CSWRCB) Bay/Delta Proceedings of 1987, the United States Fish and Wildlife Service (USFWS) presented testimony which described the relationships between survival of salmon smolts and streamflow, diversions and water temperature as smolts migrate downstream from Sacramento to Chipps Island (Figure 1). The relationship between survival and flow was used to represent the response of smolts to changes in flow, water temperature and diversion.

The USFWS noted that they had been unable to separate the independent effects of these three factors, but noted that smolt survival increased with increased river flows, decreases in the fraction diverted off the Sacramento River at Walnut Grove, and decreased water temperatures.

The inability to separate the effects of these physical factors was due to the fact that experimental coded wire tagged (CWT) smolts had most frequently been released at high water temperatures, high diversion fractions and low flows, or at low water temperatures, low diversion fractions and high flows. These two sets of conditions reflect how the State Water Project (SWP) and Central Valley Project (CVP) have operated in recent years, and the fact

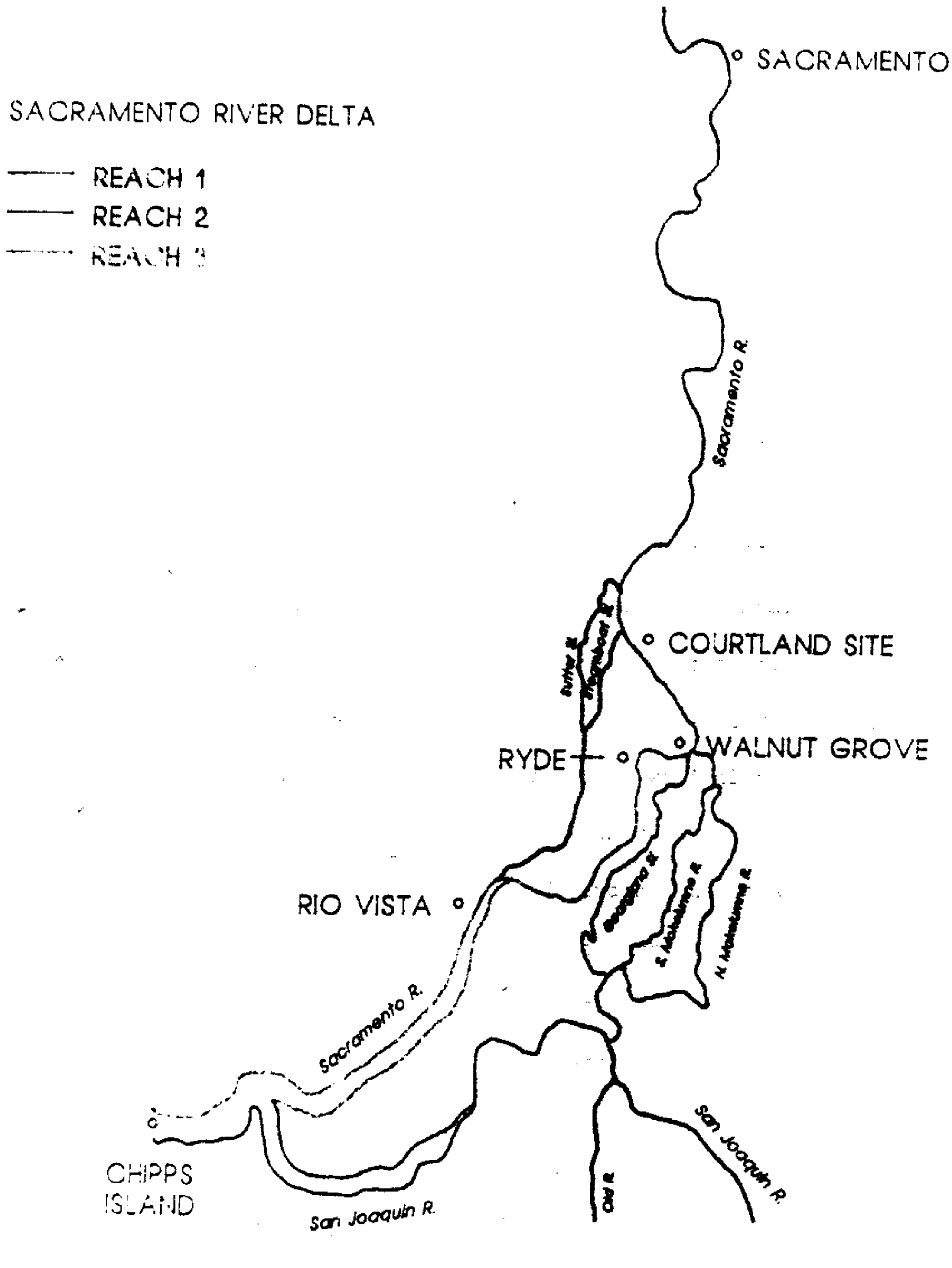


Figure 1 Reach diagram for Delta Survival Model.

that water temperatures naturally increase as flows decrease as the spring progresses. Survival was not measured when both flows and temperatures were low, when lower temperatures could have increased survival. The above conditions resulted in the three physical factors being intercorrelated (termed colinearity). Hence, as noted in our 1987 testimony, survival may have been underestimated during cooler, low flow periods using the flow:survival relationship.

During the spring of 1988 and 1989, management of the delta and upstream reservoir system allowed us to estimate the effects of the three factors independently. In these years CWT smolts were released in early May at relatively low flows and low temperatures and in June at low flows and higher temperatures. Diversion fractions were both high and low during both the May and June releases in 1988. These additional data enabled us to better separate the effects of flow, diversion and water temperature, and to develop a model that quantifies the smolt survival response to changes in several environmental parameters in the Sacramento River Delta.

The data used to develop the model has some limitations. (1) Survival measurements were not made over a broad range of conditions, (2) sample variability or potential error is present in both sample and environmental measurements, (3) some colinearity remains between factors, (4) there is a lack of survival measurements for specific reaches in the delta.

We have developed a multiple regression model that relies on the use of those environmental variables that account for a statistically significant fraction of the variation in survival. The model is conservative in that the environmental variables chosen were individually significant in each equation at the 95% level, and each regression equation was significant at 95%. This approach, along with the data limitations described, may have prevented us from including certain factors at this time in the model that influence smolt survival. Further analysis with additional data may allow us to improve the model in the future.

Our goal was to develop a model that explains a large degree of the variation in observed survival, that uses factors which are statistically significant in the equation, and appears ecologically sound. The model will be used to help quantify the benefits of varied salmon protective measures in the Sacramento River portion of the delta.

The purpose of this report is to summarize the methods used to develop the smolt survival model, describe the model, present model simulations that help quantify the relative benefits of decreased water temperature and varied operational measures.

This report reflects efforts and review comments by members, staff and consultants of the Delta Salmon Team under the Five Agency Salmon Management Group. The Five Agency Group was established to evaluate relative benefits and costs of both operational and structural protective measures to improve salmon production in the Central Valley and Bay/Delta Estuary. Primary support and guidance is through the Fisheries/Water Quality Committee of the Interagency Ecological Study Program.

## ACKNOWLEDGMENTS

We would like to thank Dave Dettman, who initiated this modeling effort and developed the first version; and Steve Cramer, who reviewed the model and suggested important physical restructuring of the model. We are grateful to Randy Brown, Pat Coulston, Chuck Hanson, Don Kelley, Wim Kimmerer, William Mitchell, and Don Stevens for reviewing the model and offering important criticism and advise. Appreciation is also extended to the SWP and CVP operations staffs for their assistance in helping provide experimental hydraulic conditions, to the many field personnel that assisted in tagging, sampling and CWT reading, and to the personnel at Feather River Hatchery for providing smolts for our studies.

## METHODS

### Sources of Smolt Survival and Mortality Indices

Survival indices were based entirely on trawl recoveries at Chipps Island from the years 1978 through 1989 (USFWS, 1987). All indices were adjusted by dividing by 1.8 to bring those indices greater than 1 into the range of 0 to 1, in order to maintain biologically meaningful survival rates. This adjustment procedure assumes consistent, not skewed, error in the raw survival rates. To support the adjustment an examination of the frequency distribution plot of the survival indices indicated an approximately normal distribution with a median near 1.0 and a maximum near 1.8. Adjusted survivals were converted to adjusted mortalities by subtracting from 1.0.

Sources of Environmental and Physical Data

Flow estimates, delta exports for the SWP and CVP were obtained from the California Department of Water Resources (CDWR) - Central District DAYFLOW model. Temperature data were obtained from the United States Geological Survey (USGS) or CDWR continuous recorders, and CDFG and USFWS grab-samples taken at the time of CWT releases. Fish sizes, defined as the number smolts per pound smolts (smaller values indicate a larger mean size of individual smolts), were obtained from CDFG and USFWS hatchery truck planting receipts. Tide phase at Martinez was estimated using a USGS tide predictor program, modified by CDWR, and National Oceanographic and Atmospheric Administration (NOAA) records. The effect of tide velocity at Walnut Grove was estimated by lagging the tide phase at Martinez three hours. The tide velocity effect was assigned a value between 1 (estimated strongest ebb) to 8 (estimated strongest flood) to facilitate regression analysis.

Estimating Mortality in each of Three Reaches

The Sacramento River portion of the delta was divided into three reaches. Reach 1 extended from Sacramento to Walnut Grove; Reach 2, from Walnut Grove to Chipps Island, via the Mokelumne and lower San Joaquin River systems (the central delta); Reach 3, from Walnut Grove to Chipps Island, via the Sacramento River system below Walnut Grove (Figure 1).

Using equations described below, mortality in each reach was estimated from mortality indices of CWT smolts released at Sacramento, just below the mouth of Steamboat Slough ("Courtland" site), and at Ryde (Figure 1). The mortality indices of CWT smolts released at Sacramento represent $M_T$, the total mortality from Sacramento to Chipps Island. The mortality indices of CWT smolts released at the "Courtland" site represent $M_{23}$, the combined mortality in Reaches 2 and 3; and the mortality indices of CWT smolts released at Ryde represent $M_3$, mortality in Reach 3.

Mortality in Reach 1 was treated sequentially with the mortality below Reach 1, the combined mortality in Reaches 2 and 3. In our model, smolts which survived in Reach 1 were subsequently subjected to mortality in either Reaches 2 or 3, depending in their migration route.

Ricker (1975) developed an approach to describe the combined effect of two independent sources of mortality (e.g. fishing and natural). We adapted Ricker's approach to mortality occuring sequentially over two distinct time periods in order to apply it to the population of smolts migrating first through Reach 1 and second through Reaches 2 or 3. Ricker's equation states that the combined mortality due to two separate sources equals the sums of the mortalities minus the product of the mortalities, or

$$M_T = M_a + M_b - (M_a * M_b).$$

Applying this equation to the Sacramento River portion of the delta, we get,

$$M_T = M_1 + M_{23} - (M_1 * M_{23}), \qquad \text{Eq. 1}$$

where $M_T$ = total mortality from Sacramento to Chipps Island, $M_1$ = mortality from Sacramento to Walnut Grove, and $M_{23}$ = combined mortality in Reaches 2 and 3, the central delta and the Sacramento River below Walnut Grove to Chipps Island. Since $M_T$ and $M_{23}$ were measured, we solved Eq. 1 for $M_1$ to get

$$M_T = M_{23} + [(M_1 * (1 - M_{23})]$$

$$M_T - M_{23} = M_1 * (1 - M_{23})$$

$$M_1 = (M_T - M_{23}) / (1 - M_{23}) \qquad \text{Eq. 2}$$

We assumed negligible mortality from the "Courtland" site to Walnut Grove, a distance of about 3.5 miles.

Mortality in Reach 2, the central delta, was treated in parallel, and isolated from mortality in Reach 3, the Sacramento River below Walnut Grove to Chipps Island. At the downstream boundary of Reach 1, the proportion of the smolts entering Reach 2 was defined by the fraction of the Sacramento River flow diverted into the central delta via the Delta Cross Channel and Georgiana Slough. The proportion of smolts entering Reach 3 is defined by the fraction of Sacramento River flow remaining in the Sacramento River below Walnut Grove. The fraction diverted was not included as an independent variable in the regression analyses, because it entered the model mechanistically, but still influenced the predicted survival through the delta by determining the porportion of smolts diverted into the central delta. In previous versions of the model, the fraction diverted was the most highly correlated parameter with the mortality, $M_{23}$, of CWT smolts released at the "Courtland" site ($r = 0.54$).

Applying a proportionality equation to the Sacramento River portion of the delta below Walnut Grove, we get

$$M_{23} = M_2 * P_2 + M_3 * P_3, \qquad \text{Eq. 3}$$

where $M_2$ = mortality from Walnut Grove to Chipps Island via the central delta, $P_2$ = proportion of Sacramento River flow diverted in the central delta, $M_3$ = mortality from Walnut Grove to Chipps Island via the Sacramento River, and $P_3$ = proportion of Sacramento River flow remaining in the Sacramento River below Walnut Grove. Since $M_{23}$ and $M_3$ were measured, we solved Equation 3 for $M_2$ to get

$$M_2 * P_2 = M_{23} - M_3 * P_3$$

$$M_2 = (M_{23} - M_3 * P_3) / P_2 \qquad \text{Eq. 4}$$

Morta'  y in Reach 3, the Sacramento River below Walnut Grov  to  hipps Island, was treated in parallel, and isolated from, mortality in Reach 2. $M_3$ was measured directly, therefore no computations were  volved.

We assumed negligible mortality between Walnut Grove and Ryde, a distance of about 3 miles.

In cases where the application of our equations to isolate the estimated mortality in Reaches 1 and 2 produced mortality values less than 0 or greater than 1, mortality was truncated to 0.0 and 1.0 respectively. We truncated estimated mortalities to maintain biologically meaningful mortality values, and to remain consistent with the subsequent use of this model in a Salmon Population Model (Mitchell, 1989). We were aware that truncating reduced the variation in the non-truncated data.

Migration Rate/Time Intervals

We estimated the migration rates and time intervals, in days, of CWT smolts as they emigrated through each of the three reaches. The migration rates enabled us to calculate how long the smolts were exposed to the environmental conditions in a specific reach during a specific time interval. The minimum and maximum migration rates of CWT smolts released at Ryde were estimated by dividing the total distance of Reach 3 by the time interval between smolt release at Ryde and recapture at Chipps Island. Assuming smolts migrated at the same rate throughout Reach 3, the minimum and maximum migration time intervals in several subsections of Reach 3 were calculated by multiplying the minimum and maximum migration rates by the subsection distance.

The minimum and maximum migration time intervals in Reach 2 using CWT smolts released at the "Courtland" site were determined by the time intervals between smolt release at the "Courtland" site and recapture at Chipps Island. We realized this approach may have underestimated the minimum migration time interval in Reach 2 because some of the smolts released at the "Courtland" site migrated via the Sacramento River, considered a shorter migration route.

The migration time intervals in Reach 1 using CWT smolts released at Sacramento from 1978 to 1982 were based on existing information on smolt migration and estimated water velocity through Reach 1. For detailed discussion, refer to Dettman, 1989.

By estimating the migration time interval and dates of smolts in a given reach we estimated the environmental conditions to which they were exposed (Appendix 2). To provide the reader with a general knowledge of migration time intervals for smolts passing from Sacramento to Chipps Island, we developed the following :

| REACH | TIME PERIOD |
|---|---|
| Sacramento to Walnut Grove | Two days |
| Walnut Grove to Chipps Island via the central delta | Ten days |
| Walnut Grove to Chipps Island via the Sacramento River | Seven days |
| Sacramento to Chipps Island | Twelve days |

Correlation and Regression

We compared our mortality estimates to the environmental c aitions at the time the fish were migrating using correlation and interact multiple linear regression techniques to determine how the varied enviror ital parameters affected mortality by reach (Snedecor and Cochran, 19 ). These analyses justified our selection of the environmental parameters sed in the model.

We analyzed correlations between smolt mortality and several flow parameters, export rates and water temperatures as marked smolts pass through the Sacramento River portion of the delta. We also evaluated the potential influence of smolt size and tide phase at the time of release to assess how variation in these experimental conditions might effect survival. Neither size nor tide phase were considered as a model parameter since they were not factors that could be managed for increased smolt survival.

We performed multiple linear regression analyses between estimated smolt mortality and the individual factors described above for each of the three reaches. Whereas correlation analysis allowed us to examine the relationships between mortality and individual parameters, multiple regression analysis enabled us to evaluate the effects of multiple factors in combination with each other on mortality. F-test values were used to determine the order in which factors were incorporated into the regression equation. An additional factor was incorporated only if the combination of parameters yielded a better r-squared value and a significant F-test value, and all factors were individually significant in the regression equation at 95% based on their t-statistic. Only those parameters whose t-test values were significant at 95% or greater were included in the regression equation.

## RESULTS AND DISCUSSION

### Estimated Mortality in Reach 3 (Walnut Grove to Chipps Island)

We used our survival indices from smolts releases at Ryde to estimate the mortality in Reach 3. These data were obtained from 1983 through 1989 (Table 1, Appendix 1). Releases were made with the Delta Cross Channel gates both open and closed. Adjusted mortalitites averaged 0.56 and ranged from 0.29 to 0.91.

### Environmental Influences in Reach 3

We correlated estimated mortality in Reach 3 to a variety of factors that appeared to have an ecological basis to influence smolt mortality in that reach (Table 2).

A significant positive correlation was found between mortality and both instantaneous water temperature at release site and average daily water temperature at Freeport (Table 2). Water temperature affects smolts both directly through acute (lethal) effects and indirectly through chronic (sublethal) effects. Laboratory experiments have demonstrated that juvenile chinook salmon all die at about 78°F (Brett, 1952). Chronic temperature effects are more difficult to quantify, but are those related to physiological stress, predator and smolt metabolic demands, disease, growth, and other factors whose effects on smolt survival have been shown to increase with a rise in temperature (Hanson, 1989).

There has been some concern that the linear nature of the temperature:mortality relationship depicted in Figure 2 may be unrealistic due

Table 1. Trawl survival indexes, mortality indexes ($M_3$) and environmental data for CWT chinook salmon smolts released at Ryde from 1983 through 1989.

| CWT Number | Release Year | Trawl Surv Index | Adjusted Mort, $M_3$ | Inst Water Temp °F @ Release Site (Ryde) | Average Daily Water Temp °F @ Freeport On Release Date | Mean Daily Flows (CFS) at: Freeport (QSAC)[1] | Rio Vista (QRIO)[2] | Jersey Pt QWEST)[3] | Chipps Is (DOUT)[4] | Daily SWP+CVP Exports cfs[5] | Size, No Smolts per Pound Smolts | Tide Phase Index |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66223 | 1983 | 1.18 | 0.34 | 61 | 62.5 | 52400 | 42989 | 35026 | 77042 | 4150 | 77 | 5 |
| 66229 | 1984 | 1.05 | 0.42 | 66 | 66.8 | 13900 | 6395 | 1108 | 8083 | 5497 | 88 | 3 |
| 66235 | 1985 | 0.77 | 0.57 | 66 | 61.3 | 14000 | 7051 | -147 | 8898 | 6690 | 78 | 5 |
| 66248 | 1986 | 0.68 | 0.62 | 74 | 72.0 | 13700 | 6870 | 6964 | 13439 | 5612 | 85 | 5 |
| 66255 | 1987 | 0.85 | 0.53 | 67 | 67.4 | 11600 | 6451 | 1046 | 5619 | 5524 | 76 | 3 |
| 66258 | 1987 | 0.88 | 0.51 | 64 | 67.5 | 10900 | 5046 | 511 | 4367 | 5147 | 73 | 1 |
| 63101 | 1988 | 0.94 | 0.48 | 63 | 63.9 | 7970 | 6029 | 285 | 8032 | 7025 | 54 | 3 |
| 63102 | 1988 | 1.26 | 0.29 | 61 | 59.9 | 12100 | 7322 | -271 | 8146 | 7959 | 53 | 1 |
| 66263 | 1988 | 0.40 | 0.78 | 75 | 73.4 | 11100 | 7357 | -2569 | 3117 | 6500 | 55 | 6 |
| 63103 | 1988 | 0.34 | 0.81 | 74 | 72.9 | 13400 | 5588 | -1736 | 2491 | 6253 | 52 | 6 |
| 63112 | 1989 | 1.19 | 0.34 | 62 | 62.1 | 11178 | 4280 | -247 | 7594 | 3942 | 64.8 | 3 |
| 63107 | 1989 | 0.48 | 0.73 | 67 | 68.7 | 13151 | 7847 | -1563 | 7673 | 5373 | 48 | 3 |
| H6114102 | 1989 | 0.16 | 0.91 | 73 | 70.0 | 14036 | 7709 | -1243 | 5702 | 4709 | 57.9 | 6 |

[1] - Mean of the mean daily Sacramento River flows at Freeport on the day(s) smots were released at Ryde.
[2] - Mean of the mean daily Sacramento River flows at Rio Vista on the day(s) smolts passed Rio Vista.
[3] - Mean of the mean daily San Joaquin River flows at Jersey Point on the day(s) smolts passed Chipps Island.
[4] - Mean of the mean daily Net Delta Outflows on the day(s) smolts passed Chipps Island.
[5] - Mean of the daily SWP plus CVP exports during the period smolts passed from release point to Chipps Island.

Table 2. Correlation coefficients between estimated mortality using CWT chinook salmon smolts released in the Sacramento River at Ryde and recovered at Chipps Island ($M_J$), and selected environmental variables. Symbols: **, correlation significant at the 0.01 level.

| | Inst Water Temp °F @ Release Site (Ryde) | Average Daily Water Temp °F @ Freeport on Release Date | Mean Daily Flow (CFS) at: Freeport (QSAC)[1] | Rio Vista (QRIO)[2] | Jersey Pt (QWEST)[3] | Chipps Is (QOUT)[4] | Daily SWP+CVP Exports cfs[5] | No Smolts per Pound Smolts | Tide Phase Index |
|---|---|---|---|---|---|---|---|---|---|
| Correlation Coefficients (r) | 0.87** | 0.81** | -0.29 | -0.30 | -0.39 | -0.39 | 0.00 | -0.37 | 0.74** |

1 - Mean of the mean daily Sacramento River flows at Freeport on the day(s) smolts were released at Ryde.
2 - Mean of the mean daily Sacramento River flows at Rio Vista on the days(s) smolts passed Rio Vista.
3 - Mean of the mean daily San Joaquin River flows at Jersey Point on the days(s) smolts passed Chipps Island.
4 - Mean of the mean daily Net Delta Outflow on the days(s) smolts passed Chipps Island.
5 - Mean of the daily SWP plus CVP exports on the day(s) smolts pass from release point to Chipps Island.

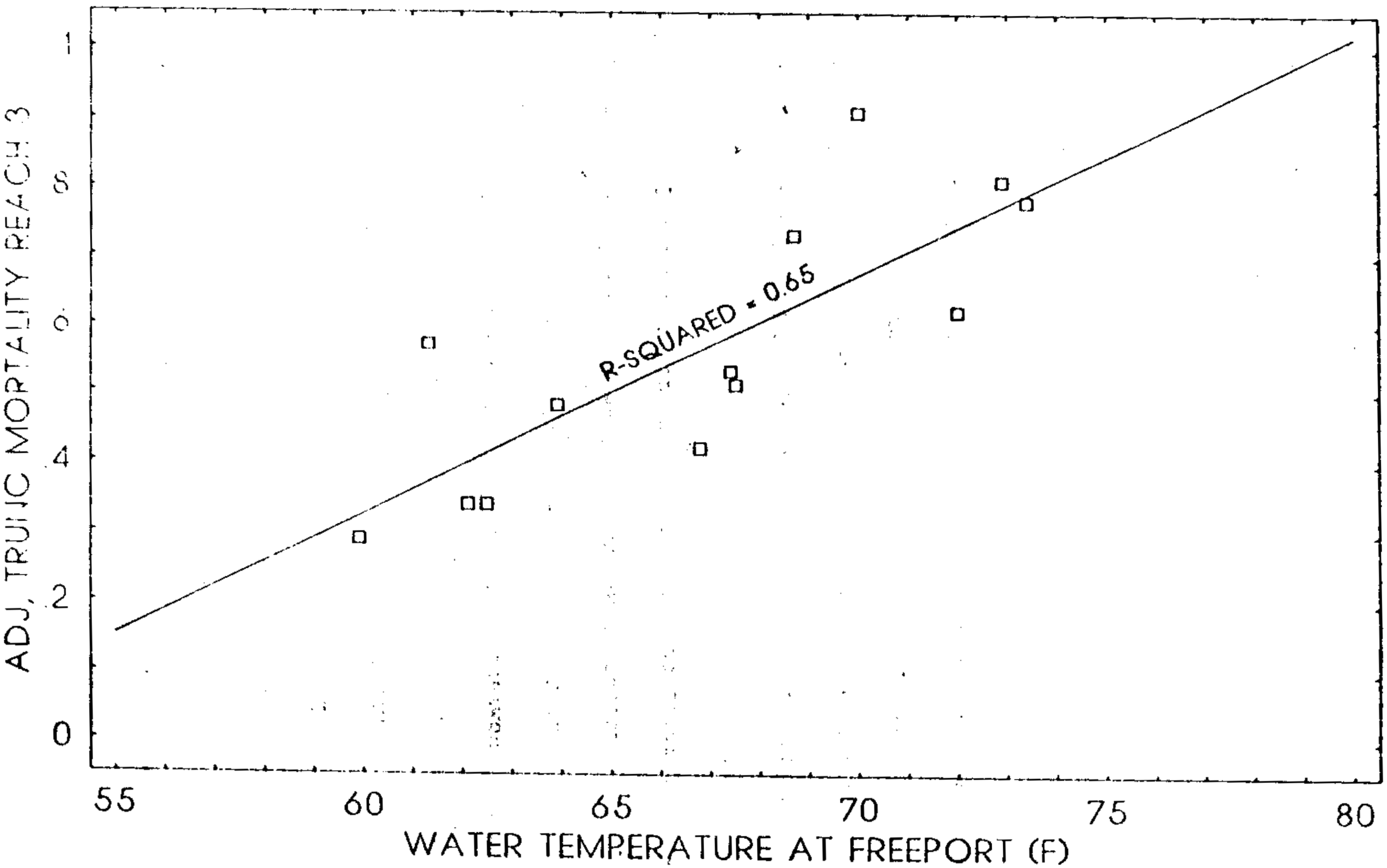


FIGURE 2. ESTIMATED CHINOOK SALMON SMOLT MORTALITY VERSUS AVERAGE DAILY WATER TEMPERATURE AT FREEPORT ON RELEASE DAY, REACH 3

to potential biases associated with the use of CWT hatchery smolts, and the belief that the chronic (sublethal) temperature effects described above are unlikely to have much influence on survival at the lower temperatures (~60 to 63°F). We have not answered these concerns fully and uncertainty remains. For instance, there is limited data to suggest that the survival of naturally produced smolts also is negatively correlated with temperature in a linear manner, and there is also other CWT data not used in modeling that indicates survival can be relatively high at high temperatures. Refer to discussion in Hanson, 1989 and USFWS, 1989.

The only other significant correlation was between estimated mortality in Reach 3 and the tide phase index (Table 2.). Smolts released at Ryde on a flood tide may be carried upstream and into the Delta Cross Channel and Georgiana Slough and therefore exposed to mortality in Reach 2. This suggests that our estimate of mortality in Reach 3 may be biased high for releases made when the tide was flooding.

There was no significant correlation between mortality and flow. It has been hypothesized that increased flows would reduce smolt mortality through increased migration rate, and thus lessened exposure times to any adverse conditions. We have not, however, demonstrated a correlation between smolt migration rate and flow in the delta presumably due to the complexity of smolt migration behavior in tidal waters. Higher flow could provide dilution of contaminants, and is typically accompanied by higher turbidity which may reduce smolt mortalities caused by sight feeding predators.

The lack of a significant correlation with exports is not unexpected since smolts released at Ryde, while vulnerable to diversion into the lower

San Joaquin via Threemile Slough, are less likely to be carried into the southern delta than, for instance, smolts released at the "Courtland" site.

The negative correlation between estimated smolt mortality and the number of smolts per pound was opposite to what we expected and suggests mortality decreases as smolt size decreases. It is counter to population biology and data from fry, smolt and yearling CWT releases that indicate mortality typically increases as size decreases. It has been hypothesized that net avoidance by the larger CWT smolts may have caused the above relationship between size and mortality. However, for the relatively narrow range of smolt sizes we used and the high turbidity seen at Chipps Island which should hinder avoidance by smolts of all sizes, we doubt that the net avoidance hypothesis is supportable. Thus, we believe the correlation is spurious.

Our interactive multiple regression analysis indicated that average daily temperature at Freeport on release day by itself accounted for 65% of the variation in smolt mortality in Reach 3 (Table 3). We chose water temperature at Freeport, rather than at the release site, since we have an historic record of water temperature at Freeport and it is highly correlated with the temperature at Ryde ($r = 0.94$).

Tide phase index was the only other parameter individually significant at 95%. By itself, it explained 54% of the variation, however, incorporating it into the equation with water temperature severely reduced the significance of both coefficients in the equation based on the t-statistic. In other words, tide phase did not account for a significant portion of the residual variation in mortality after the mortality due to water temperature was removed. Our tide phase index was crude and it is not surprising that it

Table 3. Linear regression between estimated mortality using CWT chinook salmon smolts released in the Sacramento River at Ryde and recovered at Chipps Island ($M_1$) and average daily water temperature at Freeport on release day.

| Variable | Regression Coefficient | Standard Error | T-Statistic | Partial Correlation | Cumulative Percent Variation Explained |
|---|---|---|---|---|---|
| Intercept | -1.766 | 0.5136 | -3.440 | ---- | ---- |
| Average Daily Water Temp °F @ Freeport on Release Day | 0.03489 | 0.007672 | 4.547 | 0.81 | 65.3 |

**R-Squared = 0.6527**
**F-test: F ratio = 20.68**
**Standard error or regression = 0.1211**

reduced significance in the equation. We are still interested in designing a better estimate of tide influence at release site.

The equation predicting smolt mortality through Reach 3 is as follows :

$M_3$ = -1.766 + (0.03489 * ave water temperature °F at Freeport, CA)

Mortality in Reach 2 (Walnut Grove to Chipps Island via the central delta)

Table 4 lists estimates of $M_2$ for each release made at the "Courtland" site since 1983. Adjusted mortalities in Reach 2 are the highest of all three reaches, averaging 0.85 and ranging from 0.63 to 1.00 (Table 4, Appendix 1).

Environmental Influences in Reach 2

We correlated the estimated mortality in Reach 2 to the factors listed in Table 4. The environmental factors chosen for Reach 2 analyses were those believed most applicable to that reach, hence flow in the Sacramento River, used on Reach 3 analysis, was omitted.

Our water temperature parameter used in Reach 2 was, again, measured at Freeport due to the availability of historic data and the fact that there was a reasonable correlation between water temperature at Freeport and the "Courtland" site (r = 0.97), and between water temperature at Freeport and in the Mokelumne River system (r = 0.92). Temperature data for the delta portion of the Mokelumne River were only available for the spring of 1989.

Results of our correlation analysis (Table 5) indicated mortality in Reach 2 was positively correlated to water temperature at Freeport (r = 0.73, p = 0.99) and water temperature at the release site. Weaker negative correlations were seen between mortality and net delta outflow (QOUT) at Chipps Island (r = -0.53, p = 0.90) and flow at Jersey Point (QWEST) (r =

TABLE 4. Trawl mortality indexes ($M_2$) and environmental data using CWT chinook salmon smolts released at the "Courtland" site from 1984 through 1989.

| CWT Number | Release Year | Trawl Surv Index | Adjusted Truncated Mort, $M_2$ | Inst Water Temp °F @ Release Site (Walnut Grove) | Average Daily Water Temp °F @ Freeport on Release Date | Mean Daily Flows (CFS) at: Jersey Pt (QWEST)[1] | Chipps Is (QOUT)[2] | Daily SWP+CVP Exports cfs[3] | Size, No Smolts per Pound Smolts | Tide Phase Index |
|---|---|---|---|---|---|---|---|---|---|---|
| 65224 | 1983 | 1.08 | 0.65 | 60 | 60.1 | 35241 | 77531 | 3730 | 87 | 1 |
| 66227 | 1984 | 0.81 | 0.81 | 68 | 65.5 | 1085 | 8051 | 5598 | 74 | 8 |
| 66238/41 | 1985 | 0.34 | 0.94 | 64 | 61.3 | -80 | 6727 | 6517 | 78 | 1 |
| 66243 | 1986 | 0.35 | 0.82 | 73 | 71.8 | 6923 | 13401 | 5281 | 80 | 1 |
| 66253/4 | 1987 | 0.67 | 0.77 | 66.5 | 67.3 | 889 | 5698 | 5618 | 74 | 3 |
| 66256/7 | 1987 | 0.40 | 1.00 | 66.5 | 67.5 | 558 | 4816 | 5436 | 71 | 1 |
| 651402/3 | 1988 | 0.70 | 0.81 | 62 | 63.5 | -2361 | 6384 | 7497 | 81 | 3 |
| 651404/5 | 1988 | 0.76 | 0.82 | 61 | 62.1 | -2957 | 5854 | 8020 | 84.5 | 1 |
| 66259/60 | 1988 | 0.17 | 1.00 | 73 | 72.0 | -2569 | 3117 | 8454 | 57 | 5 |
| 66250 | 1988 | 0.02 | 1.00 | 76 | 74.3 | -1477 | 2423 | 6094 | 59 | 8 |
| 63111 | 1989 | 0.84 | 0.63 | 60.5 | 60.8 | -299 | 7578 | 4224 | 60.7 | 8 |
| 63108 | 1989 | 0.35 | 0.84 | 69 | 68.7 | -2581 | 8140 | 4919 | 44 | 3 |
| 65805/3 | 1989 | 0.21 | 0.87 | 71 | 70.9 | -1262 | 6698 | 4568 | 54.1 | 8 |

[1] - Mean of the mean daily San Joaquin River flows at Jersey Point on the days(s) smolts passed Chipps Island.
[2] - Mean of the mean daily Net Delta Outflows on the days(s) smolts passed Chipps Island.
[3] - Mean of the daily SWP plus CVP exports on the days(s) smolts passed from release point to Chipps Island.

Table 5. Correlation coefficients betwe stimated mortality using CWT chinook salmon smolts released at "Courtland" site and recovered at Chipps Island [illegible] Reach 2, Walnut Grove to Chipps Island via the central delta, ($M_2$) and selected environmental variables. Symbols : **, correlation significant at 99% level, correlation significant at 95% level.

| | Inst Water Temp °F @ Release Site (Walnut Grove) | Average Daily Water Temp °F @ Freeport On Release Date | Mean Daily Flow (CFS) at: Jersey Pt (QWEST)1 | Mean Daily Flow (CFS) at: Chipps Is (QOUT)2 | Daily SWP+CVP Exports cfs3 | No Smolts per Pound Smolts | Tide Phase Index |
|---|---|---|---|---|---|---|---|
| Correlation Coefficients (r) | 0.73** | 0.89** | -0.47 | -0.53* | 0.41 | -0.19 | -0.07 |

1 - Mean of the mean daily San Joaquin River flows at Jersey Point on the day(s) smolts passed Chipps Island.
2 - Mean of the mean daily Net Delta Outflow on the day(s) smolts passed Chipps Island.
3 - Mean of the SWP plus CVP exports on the day(s) smolts passed from release point to Chipps Island.

$-0.47$, $p = 0.90$). The net delta outflow correlation probably reflects colinearlity with water temperature. As outflow increases we typically see a decrease in water temperature at the same time. We believe reverse (negative) flows at Jersey Point in the lower San Joaquin (QWEST) may increase smolt mortality, again, by increasing exposure times, or causing the smolts to migrate toward the southern delta pumping plants rather than toward the ocean. It is probable that the DAYFLOW estimates of net flow at Jersey Point in the western San Joaquin River are somewhat inaccurate due to the lack of appropriate tidal influence in the calculation of that flow parameter which could lessen our ability to demonstrate a correlation between mortality and QWEST should one exist.

Multiple regression analysis indicated that the combination of water temperature at Freeport and total SWP plus CVP exports explained 66% of the variation in mortality in Reach 2 (Table 6). Temperature alone explained 48% of the variation, and exports alone explained 17% of the variation. Combining water temperature and exports increased the significance of both water temperature and exports regression coefficients (t-statistic) to 99.5% and 95%, respectively and increased r-squared to 66% (Appendix 3). The mortality as related to water temperature is shown in Figure 3, and the residual mortality (that remaining after the mortality explained by water temperature alone is removed) as related to total exports is shown in Figure 4.

Total exports is considered an index parameter to reflect the influence of drawing water and smolts toward the southern delta pumping plants from the central delta. Mortalities were greater for CWT smolts released in the lower portion of Old River in the southern delta when compared to those released in the central and northern delta (USFWS, 1987). Higher smolt mortality in the

Table 6. Stepwise multiple linear regression between estimated mortality using CWT chinook salmon smolts released at "Courtland" site and recovered at Chipps Island for Reach 2, Walnut Grove to Chipps Island via the central delta, ($M_2$) and average daily water temperature at Freeport on the day of release, daily State Water Project plus Central Valley Project exports during the period smolts passed from release point to Chipps Island.

| Variable | Regression Coefficient | Standard Error | T-Statistic | Partial Correlation | Cumulative Percent Variation Explained |
|---|---|---|---|---|---|
| Intercept | -0.5808532 | 0.3343113 | -1.737462 | ---- | ---- |
| Average Daily Water Temp °F @ Freeport on Release Day | 0.0179269 | 0.0047439 | 3.778932 | 0.77 | 48.71 |
| SWP plus CVP Exports | 0.0000418 | 0.0000184 | 2.279014 | 0.58 | 66.43 |

R-Squared = 0.6589
F-test = 9.658
Standard error of regression = 0.07834

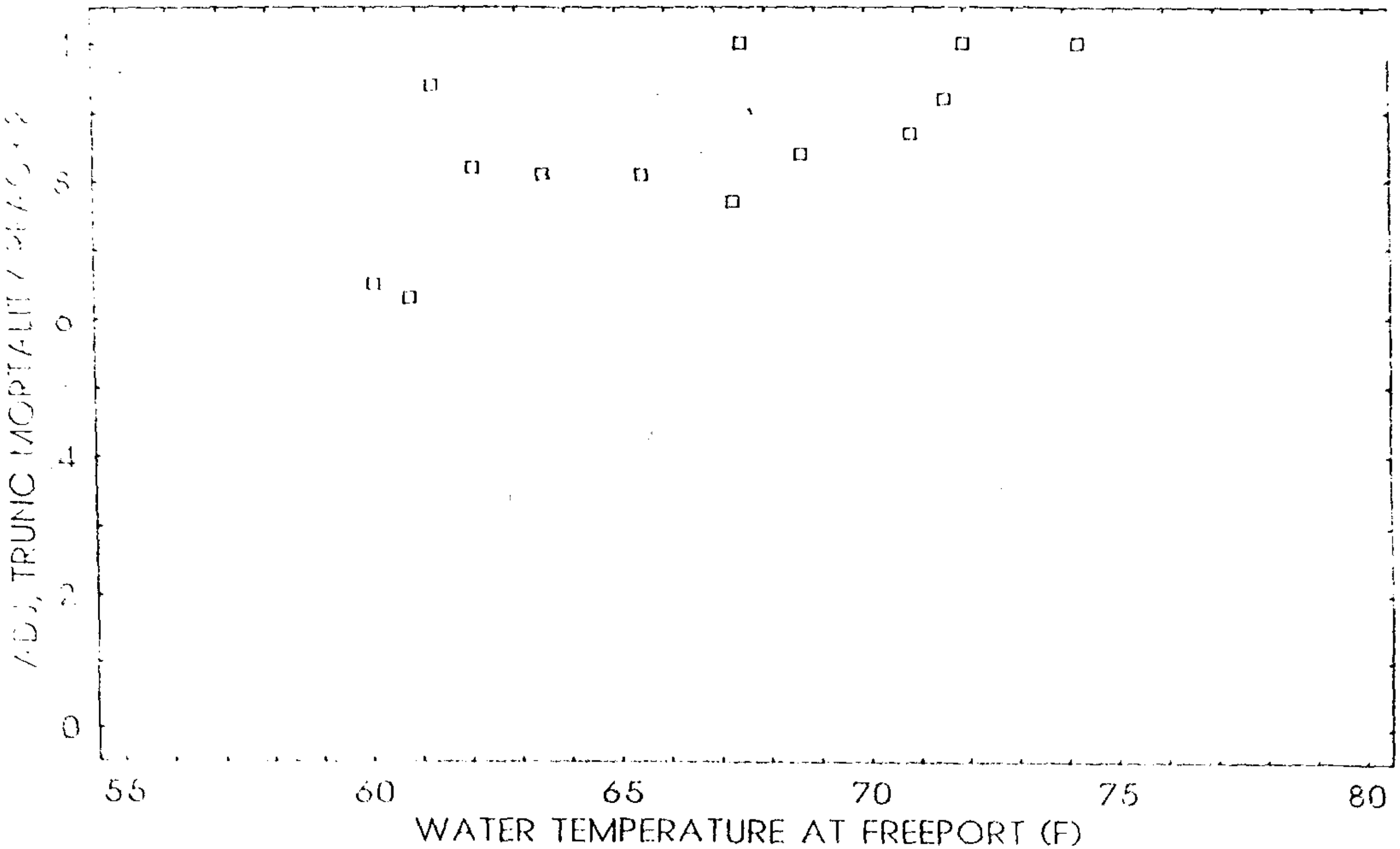


FIGURE 3. ESTIMATED CHINOOK SALMON SMOLT MORTALITY VERSUS AVERAGE DAILY WATER TEMPERATURE AT FREEPORT ON RELEASE DAY, REACH 2

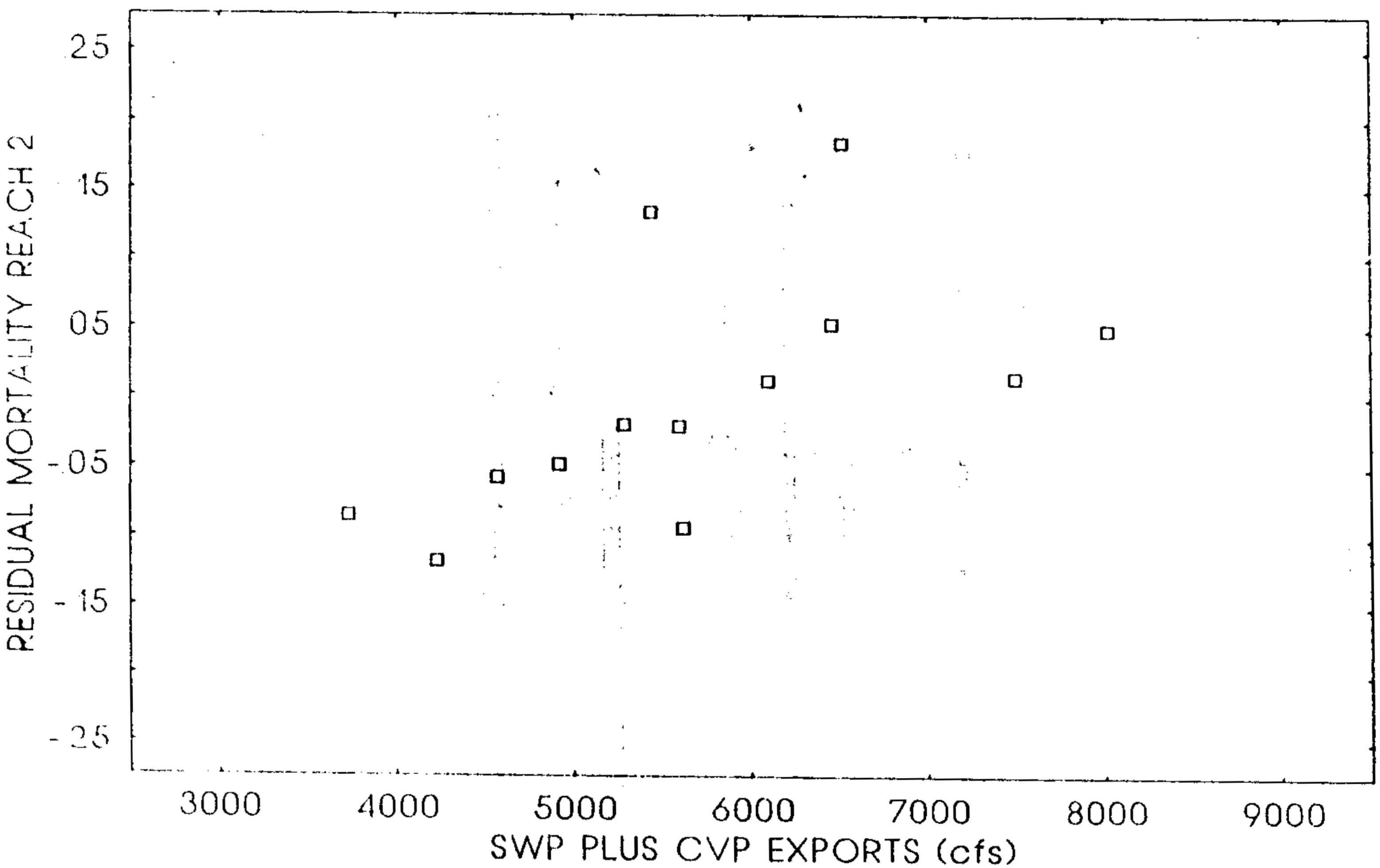


FIGURE 4. RESIDUAL CHINOOK SALMON SMOLT MORTALITY VERSUS AVERAGE DAILY WATER TEMPERATURE AT FREEPORT ON RELEASE DAY, REACH 2

southern delta may reflect the warmer water there than in the Sacramento River, losses of smolts exposed to the intakes of the CVP and SWP, and a longer travel route which increases the chance of loss to predation and other negative factors, such as contaminants.

The combination of water temperature and total exports explained the greatest portion of smolt mortality in Reach 2. It is important to realize that while water temperature and exports explained 66% of the variation in mortality there is still a great deal of mortality at the low temperature of 60°F and relatively low export (~3000 cfs). This indicates that while low temperatures and exports will lessen smolt mortality there are other factors that are not included in the model that influence smolt survival. Further efforts will be made to better define these factors.

The equation used to predict mortality in Reach 2 is :

$$M_2 = -0.5809 + (0.01793 * \text{ave water temp °F at Freeport}) + (0.0000418 * \text{mean SWP plus CVP export pumping rate})$$

Mortality in Reach 1 (Sacramento to Walnut Grove)

One objective of the 1988 and 1989 experiments was to estimate the mortality in Reach 1, using mortality indices from concurrent releases at Sacramento and the "Courtland" site. Equation 2 was used to isolate the mortality in Reach 1,

$$M_1 = (M_T - M_{23}) / (1 - M_{23}) \qquad \text{Eq. 2}$$

This is important because we wanted to know how much of the overall mortality between Sacramento and Chipps Island was due to conditions in Reach 1 alone. Unfortunately, while we did estimate mortality in Reach 1 in 1988 and 1989, there were no concurrent releases below Courtland from 1978 through 1982 from which to estimate mortality in Reach 1. Hence, while mortality estimates based on mortality indices from concurrent releases would have been preferable, reconstructed mortality estimates for Reach 1 were used as described in the next section.

Reconstruction of Mortality Estimates for Reach 1

We reconstructed mortality estimates during years when total survival was measured between Sacramento and Chipps Island. To do this we reconstructed estimated mortality in Reaches 2 and 3 based on the respective regression equations for those two reaches discussed earlier. Then we applied the Ricker's and proportionality equations (Eq. 2 and Eq. 3, respectively) to reconstruct estimated mortality in Reach 1. Beginning with Eq. 2,

$$M_1 = (M_T - M_{23}) / (1 - M_{23}), \quad \text{Eq. 2}$$

and substituting Eq. 3 for $M_{23}$,

$$M_{23} = M_2*P_2 + M_3*P_3, \quad \text{Eq. 3}$$

we get,

$$M_1 = [M_T - (M_2*P_2 + M_3*P_3)] / [1 - (M_2*P_2 + M_3*P_3)]$$

$$M_1 = (M_T - M_2*P_2 - M_3*P_3) / (1 - M_2*P_2 - M_3*P_3) \quad \text{Eq. 5}$$

The data set used to estimate mortality in Reach 1 is provided in Table 7. It is based on:

$M_3$ as a function of water temperature at Freeport (Table 3).

$M_2$ as a function of water temperature at Freeport and total SWP and CVP export pumping rates (Table 6).

$M_T$ based on trawl mortality indices, 1978-82 plus 1988 and 1989 (Table 7).

TABLE 7. Trawl survival indexes, mortality indexes and environmental data using CWT chinook salmon smolts released at Sacramento from 1978 through 1982, 1988 and 1989.

| CWT Number | Release Year | Trawl Surv Index | Reconst Mort Index ($M_I$)[1] | Inst Water Temp °F @ Release Site (Sacramento) | Average Daily Water Temp °F @ Freeport On Release Date | --Mean Daily Flow(CFS) at:-- Freeport on Release Date (QSAC)[2] | Freeport - (Sac to Court) (QSAC)[3] | Size No Smolts per Pound Smolts |
|---|---|---|---|---|---|---|---|---|
| 66202 | 1978 | 0.00 | 1.00 | 73 | 69.8 | 13200 | 13400 | 59 |
| 66205 | 1979 | 0.42 | 0.00 | 68 | 68.8 | 11980 | 12650 | 93 |
| 66208 | 1980 | 0.32 | 0.49 | 62 | 66.9 | 13400 | 13367 | 61 |
| 66211 | 1980 | 0.35 | 0.37 | 62 | 66.2 | 13350 | 13800 | 57 |
| 66214 | 1981 | 0.016 | 0.94 | 78 | 72.4 | 10650 | 10170 | 52 |
| 66217 | 1981 | 0.00 | 1.00 | 78 | 74.3 | 9690 | 9485 | 55 |
| 66220 | 1982 | 1.48 | 0.00 | 59.5 | 59.5 | 45200 | 44500 | 95 |
| 66218 | 1982 | 1.54 | 0.00 | 59.4 | 59.3 | 43800 | 42650 | 71 |
| 66221 | 1982 | 0.64 | 0.29 | 68 | 62.7 | 32400 | 31800 | 93 |
| 661406/7 | 1988 | 0.65 | 0.00 | 62 | 63.5 | 9670 | 11123 | 68 |
| 66261/2 | 1988 | 0.09 | 0.17 | 74 | 74.3 | 12000 | 12800 | 55 |
| 63110 | 1989 | 0.18 | 0.64 | 67 | 67.5 | 13604 | 13319 | 54 |
| 63115/7 | 1989 | 0.21 | 0.40 | 69.5 | 70.0 | 12748 | 12748 | 61.9 |

[1] - Reconstructed mortality reflects adjusted, truncated mortality.
[2] - Mean of the mean daily Sacramento River flows at Sacramento on the day(s) smolts were released.
[3] - Mean of the mean daily Sacramento River flows at Freeport on the day(s) smolts passed from Sacramento to "Courtland".

Our reconstructed mortalities for Reach 1 ranged from 0.00 to 1.00 and averaged 0.41 (Table 7, Appendix 1). With the exception of 1978 and 1981, estimated mortalities for Reach 1 are quite low.

Structural Limitations in Reach 1

It is important to clarify that our estimates of mortality in Reach 1 were not restricted to the stretch of Sacramento River between Sacramento and Chipps Island. Smolts passing the city of Sacramento can follow not only the Sacramento River but also travel via Sutter and Steamboat Sloughs (Figure 1). The latter sloughs divert about 20 to 30% of the Sacramento River flow which reenters the Sacramento just above Rio Vista. Hence our reconstructed estimates of mortality in Reach 1 are actually the net results of mortality through several potential routes and we assume they represent mortality between Sacramento and Chipps Island not attributable to Reaches 2 and 3. Ideally, Reach 1 should be replaced by several new reaches of the Sacramento River and separate reaches for the two sloughs. We do not have sufficient data to construct such a model. CWT smolts were only released in Steamboat Slough in 1988 and 1989. The raw survival index was 0.38 in 1988 and 0.91 in 1989. The only release made in Sutter Slough was in 1989 the raw survival index was very high (1.11). The sparse data from Steamboat and Sutter Sloughs suggest that survival in these sloughs can be relatively high which could explain the relatively low mortalities we often see in Reach 1 (Table 7).

Environmental Influences in Reach 1

We examined relationships between the reconstructed estimates of mortality in Reach 1 and the factors shown in Table 7.

Water temperature at release site and at Freeport were the only significant environmental factors with a correlation coefficient of 0.69 and 0.63 (Table 8, Figure 5). The correlation coefficient for size of smolts was significant, but the sign indicated, again, that mortality increased as size increased which is contrary to population biology. Streamflows were not significantly correlated with mortality (Table 8).

We used multiple regression analysis to determine whether combinations of the environmental factors account for more variation than temperature, and to make sure that the temperature correlation was not masking the importance of streamflow. After the temperature factor was incorporated into the regression equation, streamflow did not account for any significant variation in the residual mortalities.

Water temperature at Freeport on release day accounted for 40% of the variation in mortality in Reach 1 (Table 9, Figure 5). The equation used to predict mortality through Reach 1 is :

$M_1 = -2.858 + (0.04851 * \text{ave water temperature °F at Freeport, CA})$.

Table 8. Correlation coefficients between estimated mortality using CWT chinook salmon smolts released at Sacramento and recovered at Chipps Island for Reach 1, Sacramento to Walnut Grove, ($M_1$), and selected environmental variables. Symbols: *, correlation significant at 0.05 level; **, correlation significant at the 0.01 level.

| | Inst Water Temp °F @ Release Site (Sacramento) | Average Daily Water Temp °F @ Freeport on Release Date | Mean Daily Flow(CFS) at: Freeport on Release Date (QSAC)[1] | Mean Daily Flow(CFS) at: Freeport - (Sac to Court) (QSAC)[2] | No Smolts per Pound Smolts |
|---|---|---|---|---|---|
| Correlation Coefficients (r) | 0.69** | 0.83* | -0.49 | -0.51 | -0.66* |

[1] - Mean of the mean daily Sacramento River flows at Sacramento on the day(s) smolts were released at Sacramento.
[2] - Mean of the mean daily Sacramento River flows at Freeport on the day(s) smolts passed from Sacramento to Courtland.

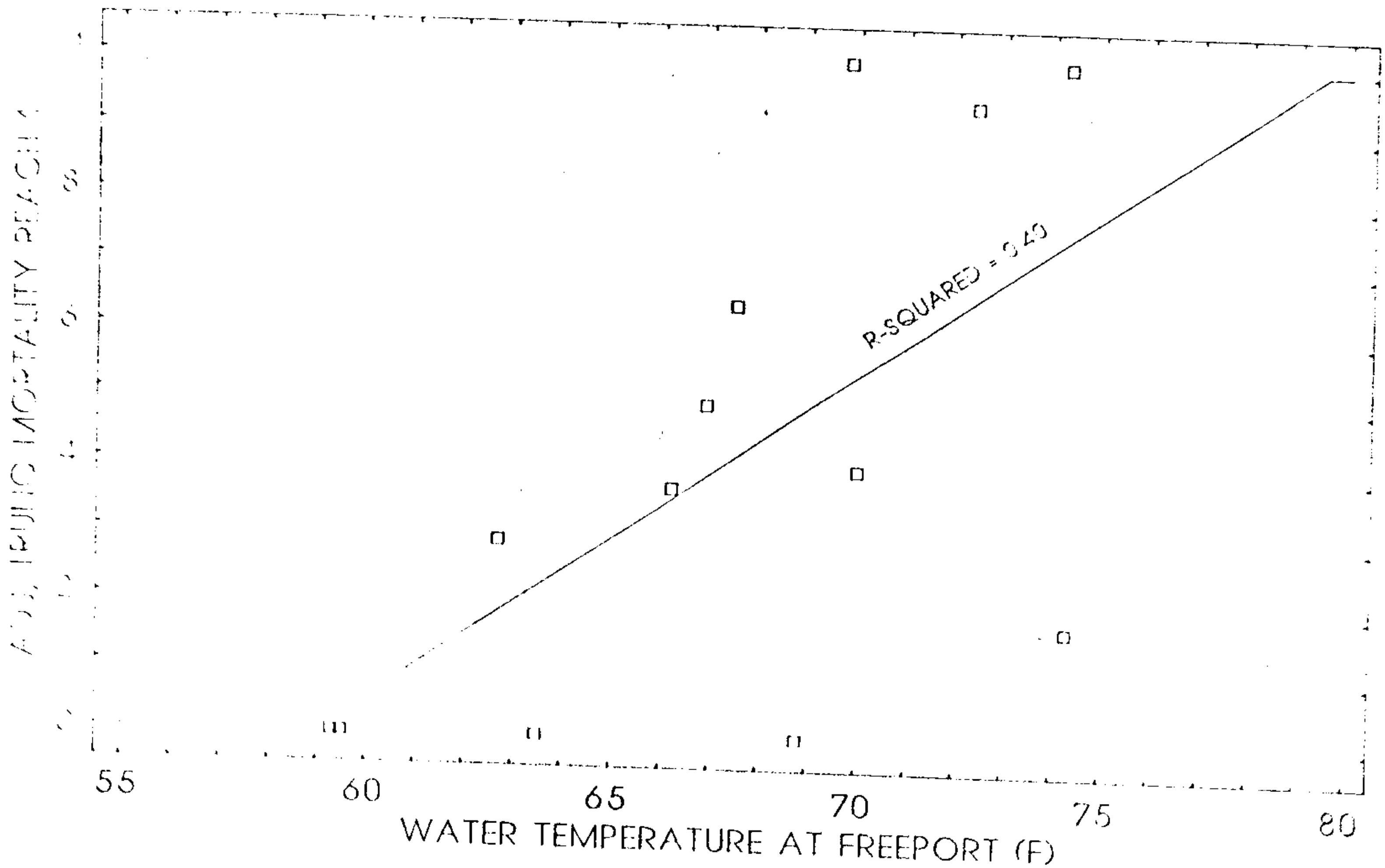


FIGURE 5. ESTIMATED CHINOOK SALMON SMOLT MORTALITY VERSUS AVERAGE DAILY WATER TEMPERATURE AT FREEPORT ON RELEASE DAY, REACH 1

Table 9. Linear regression between estimaetd mortality using CWT chinook salmon smolts released at Sacramento and recovered at Chipps Island for Reach 1, Sacramento To Walnut Grove, ($M_1$) and the average daily water temperature at the Freeport on release day.

| Variable | Regression Coefficient | Standard Error | T-Statistic | Partial Correlation | Percent Variation Explained |
|---|---|---|---|---|---|
| Intercept | -2.858 | 1.211 | -2.355 | ---- | ---- |
| Average Daily Water Temp °F @ Freeport on Release Day | 0.04851 | 0.01798 | 2.698 | 0.63 | 39.8 |

R-Squared = 0.3982
F-test: F ratio = 7.280
Standard error of regression = 0.3123

## SIMULATIONS OF SURVIVAL BETWEEN SACRAMENTO AND CHIPPS ISLAND

Figures 6 and 7, and Table 10 illustrate simulations of overall predicted survival at varied water temperatures at Freeport, fractions diverted at Walnut Grove, and SWP plus SVP export pumping rates in the southern delta. Total mortality was calculated using Equations 1 and 3,

$$M_T = M_1 + M_{23} - (M_1 * M_{23}) \text{ and} \qquad \text{Eq. 1}$$

$$M_{23} = M_2 * P_2 + M_3 * P_3. \qquad \text{Eq. 3}$$

Substituting Equation 3 into Equation 1 gives,

$$M_T = M_1 + (M_2 * P_2 + M_3 * P_3) - [M_1 * (M_2 * P_2 + M_3 * P_3)]$$

$$M_T = M_1 + M_2 * P_2 + M_3 * P_3 - M_1 * M_2 * P_2 - M_1 * M_3 * P_3 \qquad \text{Eq. 6}$$

Total survival was calculated using the equation,

$$S_T = (1 - M_T) \qquad \text{Eq. 7}$$

Survival values for environmental conditions not shown here can be calculated using Equations 6 and 7 and the three regression equations (Table 11).

The examples provided in the text below are meant to reflect some of the survival changes predicted by the model as the three parameters vary through conditions often seen in the delta.

The reader is cautioned in use of this model output. While specific values of survival are given, by necessity, for each environmental condition, it is wise to emphasize general trends and the relative magnitude of change in survival as conditions change. While changes in the absolute magnitude of survival often appear small with a given change in an environmental parameter, the relative magnitude of change is often great and will be reflected directly by increases in adult production. Since we used all available mortality indices in the regression analyses, we had no means to develop meaningful

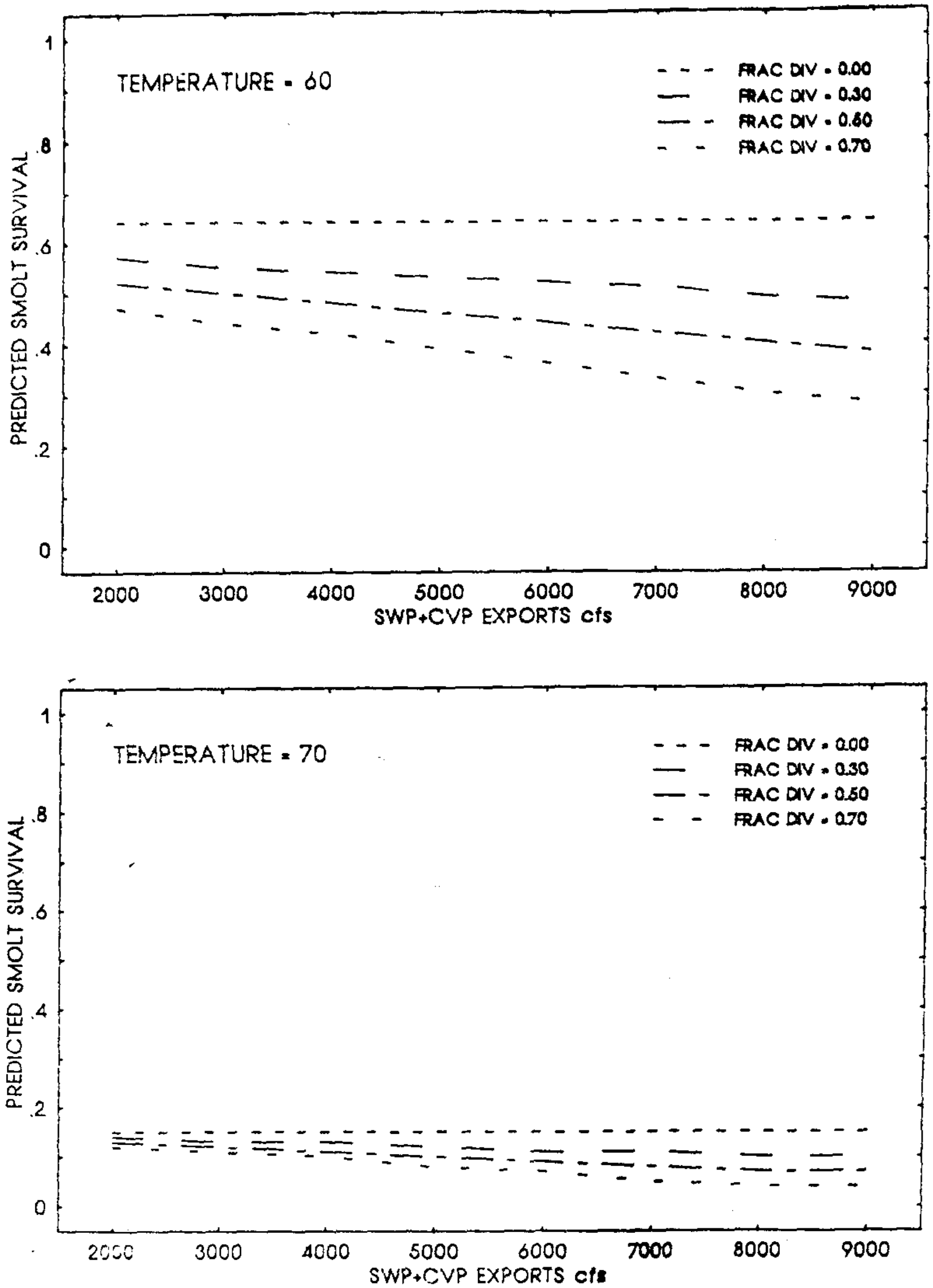


FIGURE 6. PREDICTED SMOLT SURVIVAL AT A SERIES OF WATER TEMPERATURES AND FRACTIONS DIVERTED AND SWP PLUS CVP EXPORT RATES

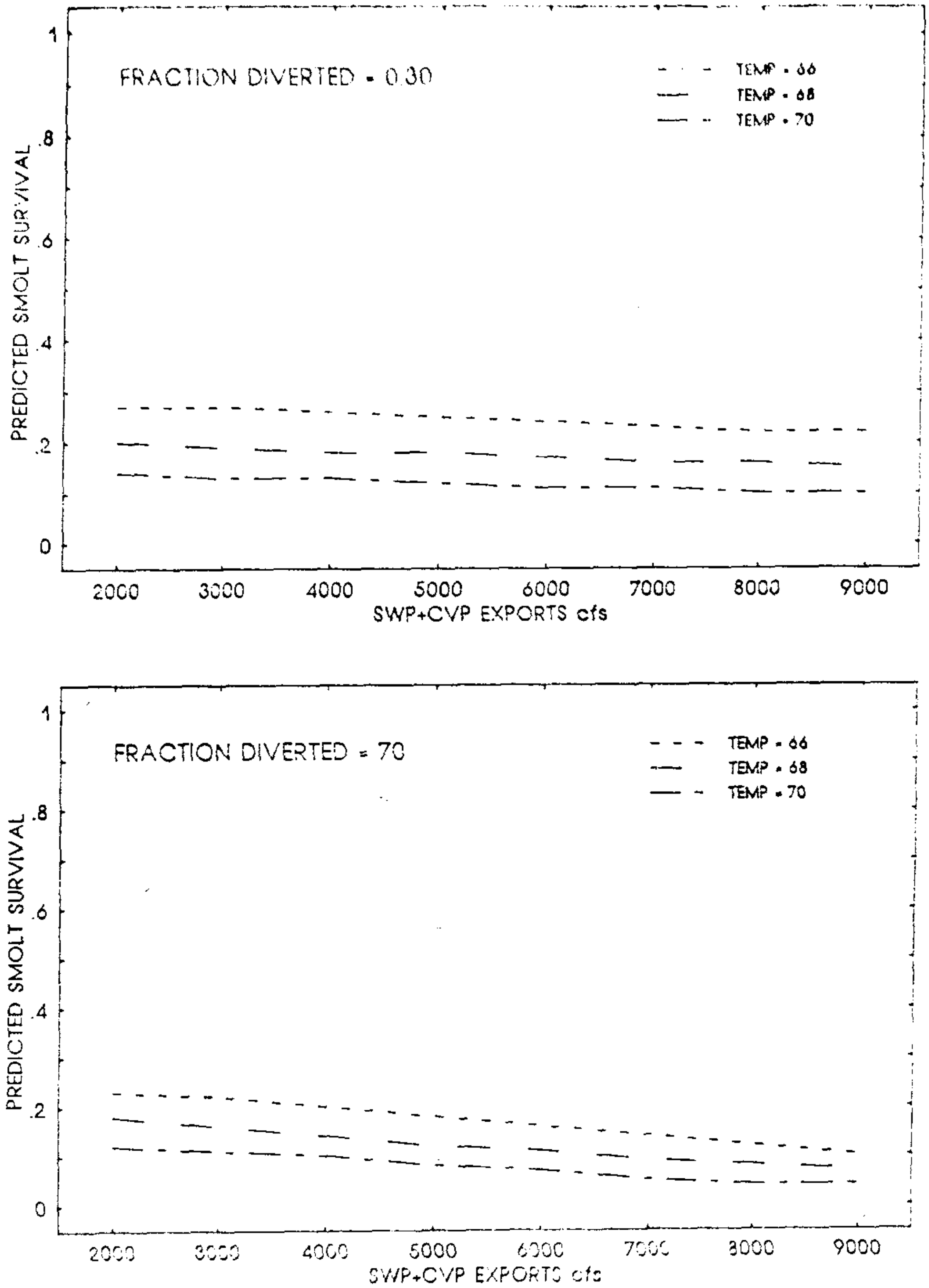


FIGURE 7 PREDICTED SMOLT SURVIVAL AT A SERIES OF WATER TEMPERATURES AND FRACTIONS DIVERTED AND SWP PLUS CVP EXPORT RATES

Table 10. Environmental parameters of the Sacramento River delta and corresponding total smolt survival through the three reaches, TFREE - water temperature at Freeport, °F; DIV - Fraction of water diverted at Walnut Grove; EXPORTS - total SWP and CVP exports from the southern delta; SURV123 - total survival of chimook salmon smolts between Sacramento and Chipps Island.

| TFREE | DIV | EXPORTS | SURV123 | TFREE | DIV | EXPORTS | SURV123 |
|---|---|---|---|---|---|---|---|
| 60. | 0. | 2000. | 0.64 | 70. | 0. | 2000. | 0.15 |
| 60. | 0. | 3000. | 0.64 | 70. | 0. | 3000. | 0.15 |
| 60. | 0. | 4000. | 0.64 | 70. | 0. | 4000. | 0.15 |
| 60. | 0. | 5000. | 0.64 | 70. | 0. | 5000. | 0.15 |
| 60. | 0. | 6000. | 0.64 | 70. | 0. | 6000. | 0.15 |
| 60. | 0. | 7000. | 0.64 | 70. | 0. | 7000. | 0.15 |
| 60. | 0. | 8000. | 0.64 | 70. | 0. | 8000. | 0.15 |
| 60. | 0. | 9000. | 0.64 | 70. | 0. | 9000. | 0.15 |
| 60. | 0.3 | 2000. | 0.57 | 70. | 0.3 | 2000. | 0.14 |
| 60. | 0.3 | 3000. | 0.55 | 70. | 0.3 | 3000. | 0.13 |
| 60. | 0.3 | 4000. | 0.54 | 70. | 0.3 | 4000. | 0.13 |
| 60. | 0.3 | 5000. | 0.53 | 70. | 0.3 | 5000. | 0.12 |
| 60. | 0.3 | 6000. | 0.52 | 70. | 0.3 | 6000. | 0.11 |
| 60. | 0.3 | 7000. | 0.51 | 70. | 0.3 | 7000. | 0.11 |
| 60. | 0.3 | 8000. | 0.49 | 70. | 0.3 | 8000. | 0.1 |
| 60. | 0.3 | 9000. | 0.48 | 70. | 0.3 | 9000. | 0.1 |
| 60. | 0.5 | 2000. | 0.52 | 70. | 0.5 | 2000. | 0.13 |
| 60. | 0.5 | 3000. | 0.5 | 70. | 0.5 | 3000. | 0.12 |
| 60. | 0.5 | 4000. | 0.48 | 70. | 0.5 | 4000. | 0.11 |
| 60. | 0.5 | 5000. | 0.46 | 70. | 0.5 | 5000. | 0.1 |
| 60. | 0.5 | 6000. | 0.44 | 70. | 0.5 | 6000. | 0.09 |
| 60. | 0.5 | 7000. | 0.42 | 70. | 0.5 | 7000. | 0.08 |
| 60. | 0.5 | 8000. | 0.4 | 70. | 0.5 | 8000. | 0.07 |
| 60. | 0.5 | 9000. | 0.38 | 70. | 0.5 | 9000. | 0.07 |
| 60. | 0.7 | 2000. | 0.47 | 70. | 0.7 | 2000. | 0.12 |
| 60. | 0.7 | 3000. | 0.44 | 70. | 0.7 | 3000. | 0.11 |
| 60. | 0.7 | 4000. | 0.42 | 70. | 0.7 | 4000. | 0.1 |
| 60. | 0.7 | 5000. | 0.39 | 70. | 0.7 | 5000. | 0.08 |
| 60. | 0.7 | 6000. | 0.36 | 70. | 0.7 | 6000. | 0.07 |
| 60. | 0.7 | 7000. | 0.33 | 70. | 0.7 | 7000. | 0.05 |
| 60. | 0.7 | 8000. | 0.3 | 70. | 0.7 | 8000. | 0.04 |
| 60. | 0.7 | 9000. | 0.28 | 70. | 0.7 | 9000. | 0.04 |

(Table 10 cont)

| DIV | TFREE | EXPORTS | SURV123 |
|---|---|---|---|
| 0. | 66. | 2000. | 0.3 |
| 0. | 66. | 3000. | 0.3 |
| 0. | 66. | 4000. | 0.3 |
| 0. | 66. | 5000. | 0.3 |
| 0. | 66. | 6000. | 0.3 |
| 0. | 66. | 7000. | 0.3 |
| 0. | 66. | 8000. | 0.3 |
| 0. | 66. | 9000. | 0.3 |
| 0. | 68. | 2000. | 0.22 |
| 0. | 68. | 3000. | 0.22 |
| 0. | 68. | 4000. | 0.22 |
| 0. | 68. | 5000. | 0.22 |
| 0. | 68. | 6000. | 0.22 |
| 0. | 68. | 7000. | 0.22 |
| 0. | 68. | 8000. | 0.22 |
| 0. | 68. | 9000. | 0.22 |
| 0. | 70. | 2000. | 0.15 |
| 0. | 70. | 3000. | 0.15 |
| 0. | 70. | 4000. | 0.15 |
| 0. | 70. | 5000. | 0.15 |
| 0. | 70. | 6000. | 0.15 |
| 0. | 70. | 7000. | 0.15 |
| 0. | 70. | 8000. | 0.15 |
| 0. | 70. | 9000. | 0.15 |
| .3 | 66. | 2000. | 0.27 |
| .3 | 66. | 3000. | 0.27 |
| .3 | 66. | 4000. | 0.26 |
| .3 | 66. | 5000. | 0.25 |
| .3 | 66. | 6000. | 0.24 |
| .3 | 66. | 7000. | 0.23 |
| .3 | 66. | 8000. | 0.22 |
| .3 | 66. | 9000. | 0.22 |
| .3 | 68. | 2000. | 0.2 |
| .3 | 68. | 3000. | 0.19 |
| .3 | 68. | 4000. | 0.18 |
| .3 | 68. | 5000. | 0.18 |
| 0.3 | 68. | 6000. | 0.17 |
| 0.3 | 68. | 7000. | 0.16 |
| 0.3 | 68. | 8000. | 0.16 |
| 0.3 | 68. | 9000. | 0.15 |
| 0.3 | 70. | 2000. | 0.14 |
| 0.3 | 70. | 3000. | 0.13 |
| 0.3 | 70. | 4000. | 0.13 |
| 0.3 | 70. | 5000. | 0.12 |
| 0.3 | 70. | 6000. | 0.11 |
| 0.3 | 70. | 7000. | 0.11 |
| 0.3 | 70. | 8000. | 0.1 |
| 0.3 | 70. | 9000. | 0.1 |
| 0.7 | 66. | 2000. | 0.23 |
| 0.7 | 66. | 3000. | 0.22 |
| 0.7 | 66. | 4000. | 0.2 |
| 0.7 | 66. | 5000. | 0.18 |
| 0.7 | 66. | 6000. | 0.16 |
| 0.7 | 66. | 7000. | 0.14 |
| 0.7 | 66. | 8000. | 0.12 |
| 0.7 | 66. | 9000. | 0.1 |
| 0.7 | 68. | 2000. | 0.18 |
| 0.7 | 68. | 3000. | 0.16 |
| 0.7 | 68. | 4000. | 0.14 |
| 0.7 | 68. | 5000. | 0.12 |
| 0.7 | 68. | 6000. | 0.11 |
| 0.7 | 68. | 7000. | 0.09 |
| 0.7 | 68. | 8000. | 0.08 |
| 0.7 | 68. | 9000. | 0.07 |
| 0.7 | 70. | 2000. | 0.12 |
| 0.7 | 70. | 3000. | 0.11 |
| 0.7 | 70. | 4000. | 0.1 |
| 0.7 | 70. | 5000. | 0.08 |
| 0.7 | 70. | 6000. | 0.07 |
| 0.7 | 70. | 7000. | 0.05 |
| 0.7 | 70. | 8000. | 0.04 |
| 0.7 | 70. | 9000. | 0.04 |

Table 11. Summary of equations and factors used to construct the models for simulating the survival of chinook salmon smolts between Sacramento and Chipps Island.

| Reach | Factors Used To Estimate Mortality | Equation Used To Estimate Mortality For Reach |
|---|---|---|
| Sacramento to Walnut Grove | Average Daily Water Temp °F at Freeport on Release Day | $M_1$ = [(-2.858) + (0.04851 * Ave Water Temp, °F, at Freeport, CA)] |
| Walnut Grove to Chipps Is via Mokelumne River System | Average Daily Water Temp °F at Freeport on Release Day | $M_2$ = [(-0.5809) + (0.01793 * Ave Water Temp, °F, at Freeport, CA) + (0.0000418 * SWP+CVP Exports)] |
| Walnut Grove to Chipps Is via Sacramento River System | Average Daily Water Temp °F at Freeport on Release Day | $M_3$ = [(-1.766) + (0.03489 * Ave Water Temp, °F, at Freeport, CA)] |

error estimates beyond considering the standard error of the regressions (Tables 3, 6 and 9).

Effects of Fraction Diverted

We chose a range of diversion fractions that closely represented conditions with the Delta Cross Channel gates open (0.70) versus closed (0.30).

Survivals increased as the fraction of water diverted at Walnut Grove decreased (Figure 7). The greatest survival benefit from a decrease in fraction diverted into the central delta (from about 0.3 to 0.5 survival) is at low water temperatures (60°F). At water temperatures of about 70°F, however, even a major reduction in the fraction diverted, from 0.70 to 0.30, results in a rather minor effect on survival.

Although there is no present means to eliminate diversions into the central delta, we also estimated the survival when the fraction diverted was zero. This eliminated any mortality in Reach 2 and the model predicted total survival between Sacramento and Chipps Island to be 0.64 at a temperature of 60°F. This can be compared to a model prediction of survival of 0.47 at 60°F when the fraction diverted was 0.70 and exports were low at 2000 cfs. When no water is diverted at Walnut Grove and the temperature is 70°F, the model predicted a survival of 0.15. This, in turn, could be compared to a model survival of 0.12 at 70°F, again, with exports at 2000 cfs and fraction diverted at 0.70. The above example infers that a relatively large increase in survival can be gained at lower water temperatures by eliminating high levels of diversion at Walnut Grove, but relatively very little can be gained at higher water temperatures.

Effect of Water Temperature

Survival increases as water temperature decreases and model results indicate rather large increases in survival over a 10°F decrease in temperature when the other two factors are held constant (Figure 7). Managing for such a large drop in temperature, however, is not practical. A lowering of temperature of from two to four degrees at 66°F to 70°F provides a measurable increase in survival (from about 0.05 to 0.10 survival units) (Figure 8). The survival benefits of a temperature decrease appear slightly better when the fraction diverted at Walnut Grove is less.

Effect of Exports

Survival increases as total SWP and CVP export pumping rate decreases. The greatest relative survival benefits of reduced exports are seen at lower temperatures of 60°F and at high fraction diverted (0.70) (Figure 5). A decrease in exports from 9000 down to 2000 cfs yielded an improvement in survival from about 0.3 to 0.5.

A major question remains relative to the survival benefit of eliminating exports. We have not measured survival with a total pump curtailment and the model can not be expected to predict it under those conditions.

## CONCLUSIONS

We have developed a smolt survival model based on multiple regression analyos using three environmental paramoters. These factors were justified for inclusion by their statistically significant relationships with survival, and appear biologically sound. As is true with all modeling of complex systems, other factors that also influence smolt survival could have been omitted due to data limitations or the fact that we restricted our choice to environmental parameters that had a potential to be changed through management actions.

Our modeling has been successful in helping us to gain a better understanding of the potential factors influencing survival and to identify critical assumptions and data gaps in need of further research. There is a need :

1) to test further the assumption that smolts are diverted in proportion to the amount of flow diverted at selected sites,
2) to gain further estimates of smolt survival in Steamboat and Sutter Sloughs, and then add these sloughs to the model,
3) to estimate survival from CWT smolt releases in the central delta (Reach 2) under low export rates and with positive flow in the western San Joaquin River, and
4) to evaluate further the reasons for the high unexplained mortality in the central delta.

We believe the model is a reasonable representation of several key factors influencing smolt survival in the Sacramento River portion of the delta, and while uncertainties remain in our understanding, it is a useful tool to assess the benefits of decreasing the fraction of Sacramento River that is diverted at Walnut Grove, the water temperature in the Sacramento River at Freeport, and the total exports of the SWP and CVP during the fall-run smolt downstream emigration period. The lessening of these three factors and their impacts on smolt surival can be achieved through a variety of potential structural and operational measures such as fish screens, Delta Cross Channel closures, fish guidance facilities and traps, tidal gates, increased flows, increased riparian vegetation, and decreased spring exports.

While survival benefits can potentially be achieved by each of the above measures, we believe that the most effective ones are those that keep smolts out of the central and southern portions of the delta where mortality is highest.

We expect that the model will be used for a diversity of activities in addition to our own Delta Salmon Team evaluations and subsequent testimony in the CSWRCB Bay/Delta Proceedings. Some of these other activities include environemental impact analyses of proposed projects in the delta; evaluations relative to the Article Seven Negotiations between CDWR, USBR and CDFG; and the CDWR and CDFG Four Pumps Agreement. We caution that the model represents survival under existing delta conditions and suggest that when the model is used to predict smolt survival under an altered delta environment that this concern be addressed.

The model is a definite improvement over the earlier, more general, smolt survival model which used the magnitude of flow as an index parameter to reflect the influence of flow, temperature and fraction diverted at Walnut Grove on survival. The flow-only model under-estimated survival under low temperature and low flow conditions which can occur in April and early May in low runoff years. As noted earlier, this was because we had not measured survival at low flows and low temperatures.

We have not been able to measure suvival when flows were increased and temperatures remained constant. This has prevented us from thoroughly evaluating the independent effects of flow. While we desire to define these effects, in practice this appears infeasible. We believe that as flows increase, smolt survival is greater due to both lessening water temperatures and fraction diverted and possibly flow itself.

It is important to remember, that of the simulations of survival we provided, the largest benefits in survival are seen for a 10°F decrease in temperature, in practice temperature decreases of several degrees are difficult to achieve through management changes. This limitation is due to the large influence of air temperature on water temperature. Further evaluation by the Delta Salmon Team will quantify the cost of lowering temperatures by various means.

We encourage suggestions for improvement of the smolt survival model and plan to refine it as additional data becomes available.

## REFERENCES


Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. Journal of the Fisheries Research Board of Canada, 9(6) 265-323.

Dettman, D. 1989. Estimating the emigration timing of cwt groups released in the lower Sacramento River and delta. Unpublished.

Hanson, C. 1989. Laboratory information on the effect of water temperature on juvenile chinook salmon in the Sacramento and San Joaquin Rivers: a literature review. Unpublished.

Snedecor and Cochran, 1967. Statistical methods, sixth edition. Iowa State University Press, Ames, Iowa, U.S.A.

USFWS, 1987. The needs of Chinook Salmon, *Oncorhynchus tshawytscha*, in the Sacramento-San Joaquin estuary. Exhibit 31, CSWRCB Bay/Delta Proceedings, Sacramento, CA.

USFWS, 1989. Survival and productivity of juvenile chinook salmon in the Sacramento-San Joaquin estuary. 1989 Annual Report of the Fisheries Assistance Office, Stockton, CA.

APPENDIX 1 Data set including survival/mortality indices and environmental parameters from which regresison analyses were performed. Expanded description of column heading abbreviations follow data set.

REACH 1

| CWT | RELDATES | SURV_T | SURVADJ | MORT123A | MORT3RCS | MORT2RCS | MORT23RC | MORT1RCS | SIZEno# | LENGTHmm | T@REL | TFREEMAX | TFREEAVE | QSAC_R | QSAC_S_C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66202 | 05/05/78 | 0. | 0. | 1. | 0.67 | 0.97 | 0.86 | 1. | 56. | 91. | 73. | 71.1 | 69.8 | 13200. | 13400. |
| 66205 | 06/24/79 | 0.42 | 0.23 | 0.77 | 0.63 | 0.91 | 0.82 | 0. | 98. | 75. | 68. | 69.7 | 68.6 | 11920. | 12850. |
| 66208 | 06/02/80 | 0.32 | 0.18 | 0.82 | 0.57 | 0.85 | 0.65 | 0.49 | 81. | 98. | 62. | 67.3 | 66.9 | 13400. | 13357. |
| 66211 | 06/04/80 | 0.35 | 0.19 | 0.81 | 0.54 | 0.84 | 0.7 | 0.37 | 57. | 96. | 62. | 66.6 | 66.2 | 13350. | 13600. |
| 66214 | 06/02/81 | 0.02 | 0.01 | 0.99 | 0.78 | 0.86 | 0.83 | 0.94 | 52. | 90. | 76. | 72.9 | 72.4 | 10650. | 10170. |
| 66217 | 06/04/81 | 0. | 0. | 1. | 0.83 | 0.9 | 0.88 | 1. | 55. | 90. | 76. | 75.2 | 74.3 | 9690. | 9485. |
| 66220 | 05/11/82 | 1.48 | 0.82 | 0.18 | 0.31 | 0.73 | 0.41 | 0. | 95. | 76. | 59.5 | 58.7 | 59.5 | 45200. | 44500. |
| 66218 | 05/12/82 | 1.54 | 0.86 | 0.14 | 0.3 | 0.7 | 0.39 | 0. | 71. | 78. | 59.4 | 59.5 | 59.3 | 43800. | 42650. |
| 66221 | 06/04/82 | 0.64 | 0.36 | 0.64 | 0.42 | 0.72 | 0.49 | 0.29 | 93. | 76. | 68. | 62.8 | 62.7 | 32400. | 31600. |
| 661406/7 | 05/05/88 | 0.65 | 0.36 | 0.64 | 0.45 | 0.89 | 0.74 | 0. | 68. | 77.5 | 62. | 63.5 | 63.5 | 9870. | 11123. |
| 66261/2 | 06/23/88 | 0.09 | 0.05 | 0.95 | 0.83 | 1. | 0.94 | 0.17 | 55. | 88.6 | 74. | 75.2 | 74.3 | 12000. | 12800. |
| 63110 | 06/01/89 | 0.16 | 0.09 | 0.91 | 0.59 | 0.63 | 0.75 | 0.64 | 54. | * | 67. | 68.7 | 67.5 | 13604. | 13319. |
| 63115/7 | 06/14/89 | 0.21 | 0.12 | 0.88 | 0.68 | 0.86 | 0.8 | 0.4 | 61.9 | * | 69.5 | 71.2 | 70. | 12748. | 12748. |

REACH 2

| CWT | RELDATES | SURV_T | SURVADJ | MORT23AJ | MORT3ADJ | MORT2ADJ | SIZEno# | LENGTHmm | T@REL | TFREEMAX | TFREEAVE | QSAC_R | DIV_WO | QWEST_CI | QOUT_CI | EXPORTS | TIDE | CCO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66224 | 05/18/83 | 1.06 | 0.59 | 0.41 | 0.34 | 0.65 | 87. | 79. | 60. | 60.3 | 60.1 | 69400. | 0.227 | 35241. | 77531. | 3730. | 1 | close |
| 66227 | 06/11/84 | 0.61 | 0.34 | 0.66 | 0.42 | 0.81 | 74. | 82. | 66. | 66.2 | 65.5 | 16200. | 0.616 | 1085. | 8051. | 5595. | 8 | open |
| 66238/41 | 05/10/85 | 0.34 | 0.19 | 0.81 | 0.57 | 0.94 | 78. | 78. | 64. | 61.7 | 61.3 | 13500. | 0.643 | -60. | 6727. | 6517. | 1 | open |
| 66243 | 05/28/86 | 0.35 | 0.19 | 0.81 | 0.62 | 0.92 | 80. | 81. | 73. | 72.5 | 71.6 | 14000. | 0.637 | 6923. | 13401. | 5281. | 1 | open |
| 66253/4 | 04/28/87 | 0.67 | 0.37 | 0.63 | 0.53 | 0.77 | 74. | 81. | 66.5 | 68. | 67.3 | 11800. | 0.412 | 869. | 5898. | 5518. | 2 | close |
| 66255/7 | 05/01/87 | 0.4 | 0.22 | 0.78 | 0.51 | 1. | 71. | 79. | 66.5 | 68.2 | 67.5 | 11200. | 0.548 | 558. | 4315. | 5438. | 1 | open |
| 661402/3 | 05/03/88 | 0.7 | 0.39 | 0.61 | 0.48 | 0.81 | 61. | 76. | 62. | 64.4 | 63.5 | 7670. | 0.387 | -2381. | 6384. | 7497. | 3 | close |
| 661404/5 | 05/06/88 | 0.76 | 0.42 | 0.58 | 0.29 | 0.82 | 64.5 | 78. | 61. | 63.5 | 62.1 | 11600. | 0.547 | -2957. | 5854. | 8020. | 1 | open |
| 66259/60 | 06/21/88 | 0.17 | 0.09 | 0.91 | 0.78 | 1. | 57. | 80. | 73. | 72.5 | 72. | 11400. | 0.412 | -2569. | 3117. | 6454. | 5 | close |
| 66250 | 05/24/88 | 0.02 | 0.01 | 0.99 | 0.81 | 1. | 59. | 89. | 76. | 75.2 | 74.3 | 13000. | 0.535 | -1477. | 2423. | 8094. | 2 | open |
| 63111 | 05/02/89 | 0.84 | 0.47 | 0.53 | 0.34 | 0.63 | 60.7 | * | 60.5 | 61.5 | 60.8 | 12578. | 0.654 | -299. | 7578. | 4224. | 6 | open |
| 63104 | 06/02/89 | 0.35 | 0.2 | 0.8 | 0.73 | 0.84 | 44. | * | 69. | 69.8 | 68.7 | 13151. | 0.847 | -2581. | 8140. | 4911. | 3 | open |
| 65805/3 | 06/15/89 | 0.21 | 0.12 | 0.88 | 0.91 | 0.87 | 54.1 | * | 71. | 71.6 | 70.9 | 11461. | 0.871 | -1262. | 6698. | 4564. | 8 | open |

REACH 3

| CWT | RELDATES | SURV_T | SURVADJ | MORT3ADJ | SIZEno# | LENGTHmm | T@REL | TFREEMAX | TFREEAVE | QSAC_R | QRIO_RV | QWEST_CI | QOUT_CI | EXPORTS | TIDE | CCO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66223 | 05/20/83 | 1.18 | 0.66 | 0.34 | 77. | 81. | 61. | 63. | 62.5 | 52400. | 42969. | 35026. | 77042. | 4150. | 5 | close |
| 66228 | 06/13/84 | 1.05 | 0.58 | 0.42 | 88. | 77. | 66. | 67.3 | 66.8 | 13900. | 8395. | 1108. | 8083. | 5497. | 3 | open |
| 66235 | 05/11/85 | 0.77 | 0.43 | 0.57 | 78. | 78. | 66. | 61.7 | 61.3 | 14000. | 7051. | -147. | 6898. | 6690. | 5 | open |
| 66248 | 05/30/86 | 0.68 | 0.38 | 0.62 | 85. | 81. | 74. | 72.5 | 72. | 13700. | 6870. | 6984. | 13439. | 5612. | 5 | open |
| 66255 | 04/29/87 | 0.85 | 0.47 | 0.53 | 76. | 79. | 67. | 68.2 | 67.4 | 11600. | 6451. | 1046. | 5619. | 5524. | 3 | close |
| 66258 | 05/02/87 | 0.88 | 0.49 | 0.51 | 73. | 80.3 | 64. | 64.4 | 67.5 | 10900. | 5046. | 511. | 4367. | 5147. | 1 | open |
| 63101 | 05/04/88 | 0.94 | 0.52 | 0.48 | 54. | 88. | 63. | 64.4 | 63.9 | 7970. | 6029. | 285. | 8032. | 7025. | 3 | close |
| 63102 | 05/07/88 | 1.28 | 0.71 | 0.29 | 53. | 87. | 61. | 60.8 | 59.9 | 12100. | 7322. | -271. | 8146. | 7959. | 1 | open |
| 66263 | 06/22/88 | 0.4 | 0.22 | 0.78 | 55. | 90. | 75. | 74.3 | 73.4 | 11100. | 7357. | -2589. | 3117. | 6500. | 6 | close |
| 63103 | 06/25/88 | 0.34 | 0.19 | 0.81 | 52. | 94. | 74. | 73.4 | 72.9 | 13400. | 5586. | -1736. | 2491. | 6253. | 8 | open |
| 63112 | 05/03/89 | 1.18 | 0.66 | 0.34 | 64.8 | * | 62. | 63.1 | 62.1 | 11178. | 4280. | -247. | 7594. | 3942. | 3 | open |
| 63107 | 06/02/89 | 0.48 | 0.27 | 0.73 | 46. | * | 67. | 69.8 | 68.7 | 13151. | 7647. | -1583. | 7673. | 5373. | 3 | open |
| H6114102 | 06/16/89 | 0.18 | 0.09 | 0.91 | 57.9 | * | 73. | 70.5 | 70. | 14036. | 7709. | -1243. | 5702. | 4709. | 8 | open |

(Appendix 2 continued)

Column Heading Descriptions

| Abbreviations | Expanded descriptions |
|---|---|
| CWT | Coded Wire Tag Identification |
| RELDATES | Beginning date of CWT smolt release |
| SURV_T | Survival index based on trawl recovery |
| SURVADJ | Adjusted suvival index based on trawl recovery |
| MORT123A | Adjusted mortality index of smolts released at Sacramento and recovered at Chipps Island |
| MORT23AJ | Adjusted mortality index of smolts released at "Courtland" and recovered at Chipps Island |
| MORT3ADJ | Adjusted mortality index of smolts released at Ryde and recovered at Chipps Island |
| MORT2ADJ | Adjusted mortality index of smolts traveling through Reach 2 |
| MORT3RCS | Reconstructed mortality of smolts traveling through Reach 3 |
| MORT2RCS | Reconstructed mortality of smolts traveling through Reach 2 |
| MORT23RC | Reconstructed mortality of smolts traveling through Reaches 2 and 3 |
| MORT1RCS | Reconstructed mortality of smolts traveling through Reach 1 |
| SIZEno# | Mean size of CWT smolts in units of number of smolts per pound of smolts |
| LENGTHmm | Mean length of CWT smolts in millimeters |
| TWREL | Instantaneous water temperature at release site, °F |
| TFREEMAX | Maximum daily water temperature at Freeport, CA on release day, °F |
| TFREEAVE | Average daily water temperature at Freeport, CA on release day, °F |
| QSAC_R | Mean of the mean daily Sacramento River flow on release day(s), cfs |
| QSAC_S_C | Mean of the mean daily Sacramento River flow on the day(s) smolts emigrated from Sacramento to "Courtland", mm |
| DIV_WG | Mean daily fraction diverted at Walnut Grove on the day(s) smolts were at Walnut Grove |
| QRIO_RV | Mean daily Rio Vista flow on the day(s) smolts were emigrating past Rio Vista, cfs |
| QWEST_CI | Mean daily flow past Jersey Point on the day(s) smolts were emigrating past Chipps Island, cfs |
| QOUT_CI | Mean daily net delta outflow on the day(s) smolts emigrated past Chipps Island, cfs |
| EXPORTS | Mean of the mean daily CVP plus SWP export pumping rate on the day(s) smolts emigrated from Walnut Grove to Chipps Island via the central delta, cfs |
| TIDE | Tide phase index at release site |
| CCG | Status of the Delta Cross Channel Gates on the day(s) smolts emigrated past Walnut Grove |

Appendix 2. Estimates of periods to which CWT juvenile salmon were exposed to different reaches of the Sacramento River following release at Discovery or Miller Parks, "Courtland" site, or Ryde (Isleton, 1983). Based on capture of fish off Chipps Island and estimates of migration speed.

| CWT Number | Release Site | Release Location: RMA[1] Reach | Release Location: River Miles | Release Date: Begin | Release Date: End | Date at "Courtland" site: Begin | Date at "Courtland" site: End | Date at Rio Vista: Begin | Date at Rio Vista: End | Date at Chipps Island: Begin | Date at Chipps Island: End | Status Of Cross Channel Gates |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66202 | DISCPARK | 410 | 62.9 | 06/05/78 | 06/05/78 | 06/06/78 | 06/07/78 | 06/08/78 | 06/10/78 | 06/10/78 | 06/17/78 | open |
| 66205 | DISCPARK | 410 | 62.9 | 06/04/79 | 06/08/79 | 06/05/79 | 06/05/79 | 06/08/79 | 06/14/79 | 06/10/79 | 06/18/79 | open |
| 66208 | DISCPARK | 410 | 62.9 | 06/02/80 | 06/03/80 | 06/04/80 | 06/04/80 | 06/05/80 | 06/16/80 | 06/06/80 | 06/20/80 | op/cl |
| 66211 | DISCPARK | 410 | 62.9 | 06/04/80 | 06/05/80 | 06/06/80 | 06/06/80 | 06/09/80 | 06/15/80 | 06/10/80 | 06/18/80 | close |
| 66214 | DISCPARK | 410 | 62.9 | 06/02/81 | 06/03/81 | 06/04/81 | 06/05/81 | 06/05/81 | 06/08/81 | 06/08/81 | 06/17/81 | open |
| 66217 | DISCPARK | 410 | 62.9 | 06/04/81 | 06/05/81 | 06/06/81 | 06/07/81 | 06/08/81 | 06/11/81 | 06/10/81 | 06/21/81 | open |
| 66220 | DISCPARK | 410 | 62.9 | 05/11/82 | 05/11/82 | 05/12/82 | 05/12/82 | 05/14/82 | 05/27/82 | 05/15/82 | 06/02/82 | open |
| 66218 | DISCPARK | 410 | 62.9 | 05/12/82 | 05/12/82 | 05/13/82 | 05/13/82 | 05/14/82 | 05/18/82 | 05/15/82 | 05/21/82 | close |
| 66221 | DISCPARK | 410 | 62.9 | 06/04/82 | 06/04/82 | 06/05/82 | 06/05/82 | 06/07/82 | 06/12/82 | 06/09/82 | 06/15/82 | close |
| B61406/7 | MILLERPARK | 410 | 62.9 | 05/05/88 | 05/05/88 | 05/07/88 | 05/07/88 | 05/08/88 | 05/14/88 | 05/09/88 | 05/16/88 | open |
| 66261/2 | MILLERPARK | 410 | 62.9 | 06/23/88 | 06/23/88 | 06/24/88 | 06/25/88 | 06/25/88 | 07/02/88 | 06/26/88 | 07/04/88 | open |
| 63110 | MILLERPARK | 410 | 62.9 | 06/01/89 | 06/01/89 | 06/02/89 | 06/03/89 | 06/04/89 | 06/10/89 | 06/05/89 | 06/08/89 | open |
| 63115/7 | MILLERPARK | 410 | 62.9 | 06/14/89 | 06/14/89 | 06/15/89 | 06/16/89 | 06/17/89 | 06/24/89 | 06/17/89 | 06/25/89 | open |
| 66224 | COURTLAND | 420 | 33.8 | 05/16/83 | 05/16/83 | 05/16/83 | 05/16/83 | 05/18/83 | 05/23/83 | 05/20/83 | 05/30/83 | close |
| 66227 | COURTLAND | 420 | 33.8 | 06/11/84 | 06/11/84 | 06/11/84 | 06/12/84 | 06/14/84 | 06/17/84 | 06/16/84 | 06/21/84 | open |
| 66238/41 | COURTLAND | 420 | 33.8 | 05/10/85 | 05/10/85 | 05/10/85 | 05/10/85 | 05/12/85 | 05/18/85 | 05/14/85 | 05/22/85 | open |
| 66243 | COURTLAND | 420 | 33.8 | 05/28/86 | 05/28/86 | 05/28/86 | 05/28/86 | 05/30/86 | 06/03/86 | 06/01/86 | 06/09/86 | open |
| 66253/4 | COURTLAND | 420 | 33.8 | 04/28/87 | 04/28/87 | 04/28/87 | 04/28/87 | 04/30/87 | 05/04/87 | 05/01/87 | 05/08/87 | close |
| 66256/7 | COURTLAND | 420 | 33.8 | 05/01/87 | 05/01/87 | 05/01/87 | 05/01/87 | 05/03/87 | 05/08/87 | 05/04/87 | 05/13/87 | open |
| B61402/3 | COURTLAND | 420 | 33.8 | 05/03/88 | 05/03/88 | 05/03/88 | 05/03/88 | 05/06/88 | 05/12/88 | 05/08/88 | 05/16/88 | close |
| B61404/5 | COURTLAND | 420 | 33.8 | 05/06/88 | 05/06/88 | 05/06/88 | 05/06/88 | 05/08/88 | 05/14/88 | 05/09/88 | 05/17/88 | open |
| 66259/60 | COURTLAND | 420 | 33.8 | 06/21/88 | 06/21/88 | 06/21/88 | 06/21/88 | 06/22/88 | 06/25/88 | 06/23/88 | 06/28/88 | close |
| 66250 | COURTLAND | 420 | 33.8 | 06/24/88 | 06/24/88 | 06/24/88 | 06/24/88 | 06/26/88 | 06/29/88 | 06/27/88 | 07/02/88 | open |
| 63111 | COURTLAND | 420 | 38.3 | 05/02/89 | 05/02/89 | 05/02/89 | 05/02/89 | 05/04/89 | 05/09/89 | 05/05/89 | 05/16/89 | open |
| 63108 | COURTLAND | 420 | 38.3 | 06/02/89 | 06/02/89 | 06/02/89 | 06/02/89 | 06/04/89 | 06/07/89 | 06/05/89 | 06/09/89 | open |
| 65805/3 | COURTLAND | 420 | 38.3 | 06/15/89 | 06/15/89 | 06/15/89 | 06/15/89 | 06/17/89 | 06/22/89 | 06/17/89 | 06/22/89 | open |
| 66223 | ISLETON | 428 | 20.4 | 05/20/83 | 05/20/83 | NA | NA | 05/20/83 | 05/23/83 | 05/22/83 | 05/30/83 | close |
| 66229 | RYDE | 424 | 27.0 | 06/13/84 | 06/13/84 | NA | NA | 06/14/84 | 06/16/84 | 06/16/84 | 06/20/84 | open |
| 66235 | RYDE | 424 | 27.0 | 05/11/85 | 05/11/85 | NA | NA | 05/12/85 | 05/15/85 | 05/14/85 | 05/19/85 | open |
| 66248 | RYDE | 424 | 27.0 | 05/30/86 | 05/30/86 | NA | NA | 05/31/86 | 06/04/86 | 06/02/86 | 06/09/86 | open |
| 66255 | RYDE | 424 | 27.0 | 04/29/87 | 04/29/87 | NA | NA | 04/30/87 | 05/03/87 | 05/02/87 | 05/06/87 | close |
| 66258 | RYDE | 424 | 27.0 | 05/02/87 | 05/02/87 | NA | NA | 05/03/87 | 05/08/87 | 05/05/87 | 05/10/87 | open |
| 63101 | RYDE | 424 | 27.0 | 05/04/88 | 05/04/88 | NA | NA | 05/03/88 | 05/07/88 | 05/07/88 | 05/11/88 | close |
| 63102 | RYDE | 424 | 27.0 | 05/07/88 | 05/07/88 | NA | NA | 05/08/88 | 05/09/88 | 05/09/88 | 05/12/88 | [illegible] |
| 68263 | RYDE | 424 | 27.0 | 06/22/88 | 06/22/88 | NA | NA | 06/22/88 | 06/25/88 | 06/23/88 | 06/28/88 | close |
| 63103 | RYDE | 424 | 27.0 | 06/25/88 | 06/25/88 | NA | NA | 06/25/88 | 06/27/88 | 06/26/88 | 06/29/88 | open |
| 63112 | RYDE | 424 | 27.0 | 05/03/89 | 05/03/89 | NA | NA | 05/03/89 | 05/07/89 | 05/06/89 | 05/15/89 | [illegible] |
| 63107 | RYDE | 424 | 27.0 | 06/02/89 | 06/02/89 | NA | NA | 06/02/89 | 06/06/89 | 06/05/89 | 06/14/89 | open |
| H6114102 | RYDE | 424 | 27.0 | 06/16/89 | 06/16/89 | NA | NA | 06/16/89 | 06/20/89 | 06/19/89 | 06/26/89 | open |

[1] - DWR/RMA Delta Hydrodynamic Model.

Appendix 3. Statistical information on which environmental parameters were chosen.

| TERM | COEFFICIENT | t-STAT | R-SQUARED | F-TEST |
|---|---|---|---|---|
| I. Reach 1 | | | | |
| A. Water temperature only | | | | |
| Intercept | -2.858 | -2.355 | | |
| Temp Freeport | 0.0485 | 2.698 | | |
| | | | 0.398 | 7.280 |
| B. Number smolts per pound smolts only | | | | |
| Intercept | 1.420 | 3.924 | | |
| Size no/# | -0.015 | -2.876 | | |
| | | | 0.429 | 8.272 |
| C. Water temperature and number smolts per pound smolts | | | | |
| Intercept | -0.857 | -0.504 | | |
| Temp Freeport | 0.029 | 1.370 | | |
| Size no/# | -0.00991 | -1.588 | | |
| | | | 0.519 | 5.403 |
| II. Reach 2 | | | | |
| A. Water temperature only | | | | |
| Intercept | -0.336 | -0.903 | | |
| Temp Freeport | 0.018 | 3.197 | | |
| | | | 0.482 | 10.224 |
| B. SWP+CVP exports only | | | | |
| Intercept | 0.616 | 3.891 | | |
| Exports | 0.0000412 | 1.510 | | |
| | | | 0.172 | 2.281 |
| C. Intercept | -0.581 | -1.737 | | |
| Temp Freeport | 0.01793 | 3.779 | | |
| Exports | 0.0000418 | 2.279 | | |
| | | | 0.659 | 9.658 |
| III. Reach 3 | | | | |
| A. Water Temperature at Freeport only | | | | |
| Intercept | -1.767 | -3.440 | | |
| Temp Freeport | 0.035 | 4.547 | | |
| | | | 0.653 | 20.677 |
| B. Tide Phase Index only | | | | |
| Intercept | 0.298 | 3.591 | | |
| Tide | 0.064 | 3.607 | | |
| | | | 0.542 | 13.011 |
| C. Water temperature at Freeport and Tide Phase Index | | | | |
| Intercept | -1.248 | -2.520 | | |
| Temp Freeport | 0.025 | 3.147 | | |
| Tide | 0.036 | 2.255 | | |
| | | | 0.770 | 16.723 |