187

THE EFFECTS OF STREAMFLOW, WATER QUALITY, AND DELTA EXPORTS ON FALL-RUN CHINOOK SALMON ESCAPEMENT IN THE SAN JOAQUIN RIVER DRAINAGE FROM 1952 TO 1992

Prepared for

Stanislaus River Council
1506 Seventeenth Street
Sacramento, California 95814
(916) 448-0326

Prepared by

Carl Mesick Consultants
1018 Cedar Street
San Carlos, California 94070
(415) 598-9108

October 1994

INTRODUCTION

In testimony to the State Water Resources Control Board, the California Department of Fish and Game presented the results of regression analyses between fall-run chinook salmon (*Oncorhynchus tshawytscha*) escapement and streamflows in the San Joaquin River at Vernalis to demonstrate the need for increased San Joaquin River outflow to protect salmon smolts migrating through the Delta (DFG Exhibit 25). Based on data collected from 1955 to 1989, the Department of Fish and Game reported that streamflows in the San Joaquin River at Vernalis during smolt outmigration explained approximately 46% of the variation ($r = 0.68$, $p = 0.01$) in the number of adult chinook salmon that returned to spawn two and one-half years later.

This report summarizes the analyses conducted by Carl Mesick Consultants (CMC). Although similar to the Department of Fish and Game analyses, CMC's analyses were expanded to accomplish three goals. The first goal was to improve the analyses by (1) accounting for the mixture of different ages of fish that constitute the escapement estimates, (2) using a multiple regression analysis to account for the combined effects of different habitat conditions (e.g., salmon stock, streamflow, water quality, ocean conditions, and exports), and (3) evaluating several different periods during outmigration (e.g., individual monthly averages versus averages of conditions from April through July). The second goal was to compare the importance of habitat conditions in the Stanislaus River to those in the San Joaquin River at Vernalis for smolt survival. The third goal was to evaluate the effects of fall habitat conditions in the San Joaquin River at Vernalis and in the Stanislaus River on escapement.

METHODS

The regression analysis incorporated fish abundance estimates provided by the Department of Fish and Game (DFG), as well as data on streamflow, water temperature, state and federal delta exports, turbidity, and dissolved oxygen levels contained in both the Department of Water Resources' database, which is called CDEC, and the State Water Resources Control Board's database, which is called STORET. The habitat data were collected in the vicinity of Knights Ferry and Ripon in the Stanislaus River, Vernalis in the mainstem San Joaquin River, and at Chipps Island in the Delta. The regression analyses were run with both monthly averages of the habitat data and with indices that reflected habitat conditions that occurred over a period of several months. Table 1 presents the habitat variables used in the regression analysis, the location of the sampling station, the range in years that data were collected, and the source of the data.

The fish abundance data provided by DFG was used to estimate two population variables that correspond to the habitat conditions that occurred when the juvenile fish were rearing in the tributaries as fry and migrating through the Delta as smolts during spring, and a third population variable that corresponds to the conditions present during fall when the fish returned to spawn. The two population variables corresponding to spring habitat conditions were (1) STOCK, which is the number of adult (three-year-old fish) that spawned during the previous fall and (2) PRODUCTION, which is the number of two- and three-year-old chinook salmon that were produced during the same spring period (they belong to the same cohort) and returned to the rivers to spawn. Two-year-old fish return to spawn 1.5 years after the spring rearing period when they were smolts and three-year-old fish return 2.5 years after the spring rearing period when they were smolts. The population variable that corresponds to the fall conditions, when the two- and three-year-old fish return to the rivers to spawn is called ESCAPEMENT.

The number of two-year-old fish, which are called grilse, and the number of three-year-old fish, which are called adults, from 1952 to 1966 and in 1992 were provided by Mr. Frank Fisher, Associate Fishery Biologist, Department of Fish and Game, Red Bluff, California. The estimates from 1967 to 1991 are reported in the DFG February 1994 report "Central Valley Anadromous Sport Fish Annual Run-Size Harvest, and Population Estimates, 1967 through 1991". Since Mr. Fisher indicated that few if any of the fish in the adult estimates were four-year-olds and so all the estimates for adult fish were assumed to consist of only three-year-old fish. A full data set was not available for either the Merced River or the mainstem San Joaquin between Friant Dam and the Merced River, and so the San Joaquin River Basin chinook salmon estimates were computed by summing the estimates for the Stanislaus and Tuolumne rivers.

A habitat variable was included in the analyses to reflect the influence of El Nino conditions in the ocean, which have been shown to influence chinook salmon production in Alaska (Hare and Francis 1992). Hare and Francis (1992) have speculated that the warm surface temperatures off the coast of Alaska that occur during El Nino events reduce the salmon's vulnerability to predators (principally marine mammals) while improving feeding conditions. Although El Nino events have the opposite effect on chinook salmon off the California coast, conditions that reflect the El Nino events should provide a useful indication of ocean conditions as they affect salmon survival off the California coast. The index used to reflect the El Nino events is the North Pacific Index (NPI), which is the average sea level pressure over the North Pacific from 30 to 65°N, 140°E to 60°W from November through March; the values used as the NPI are departures from the 1992 year mean of 1009.39 mb. In addition to the annual NPI values, a three year average of the NPI during the years that salmon spent in the ocean was also tested; this variable was called NPIMEAN. NPI values are averaged over time to also account for the lag between atmospheric conditions and sea surface temperatures (Trenberth and Hurrell 1992).

Separate regression analyses were conducted for the Stanislaus River and the San Joaquin River Basin using the Statistix 4.0 software program. The first step in the analyses was to compute a Pearson correlation matrix to determine for each habitat variable which months were highly correlated with fish production. Then a seasonal variable was computed to reflect the average, minimum, and maximum levels throughout the critical months for each habitat variable. Based on these analyses, the seasonal habitat variables for the Stanislaus River reflected conditions from March through May for all years. However two sets of seasonal habitat variables for the Vernalis and Chipps Island data were evaluated: one for the April and May period and the other for the April through June period. Seasonal variables for the fall period to evaluate the ESCAPEMENT variable included both September and October as the critical months during fall for adult salmon for all habitat variables. Other habitat variables were used to evaluate the ESCAPEMENT variable that reflected the percentage of streamflow at Ripon and Vernalis compared to those at Chipps Island.

The second step was to conduct stepwise regression analyses between the PRODUCTION variables for the Stanislaus River and the San Joaquin River Basin and the habitat variables.

These analyses were also conducted with two different periods of data, because when the water quality variables were included in the analysis, none of the data collected prior to 1968 could be evaluated due to statistical protocol. Statistical protocol requires that for a year's set of data to be evaluated, all habitat variables included in the analysis must contain values (i.e., no missing data). Therefore, when water quality data on dissolved oxygen, turbidity, and water temperature were evaluated, the lack of water quality data prior to 1968 precluded the evaluation of the streamflow, Delta export, and ocean condition data prior to 1968. To avoid this problem, the stepwise regression analyses were repeated without the water quality data to permit an evaluation of the data collected from 1952 to 1992.

Regression analyses are appropriate to detect correlations between the habitat variables and fish production, because no potentially confounding effects from density-dependent mortality on the stock-production relationship were detected. Density-dependent mortality would occur if an excessive number of adults returned to spawn that caused egg mortality or otherwise disrupted spawning for most of the fish. If density-dependent effects were occurring, then a plot of stock (number of spawning adults) versus production (number of surviving offspring) would show that production is highest at mid-levels of stock and consistently low at high levels of stock. This is not the case for either the Tuolumne River (Figure 1) or for the Stanislaus River (Figure 2). Although the plot for the Tuolumne River (Figure 1) indicates that the highest levels of production occurred at relatively low levels of stock, the high levels of production are probably a result of high streamflows rather than low levels of stock. The highest levels of production in the Tuolumne River occurred during 1956, 1958, 1967, 1969, and 1983, which were all wet years for the San Joaquin River Basin when streamflows were relatively high (Figure 3).

RESULTS AND DISCUSSION

Two sets of regression analyses were conducted, one to evaluate rearing conditions for fry and smolts passing through the Delta during spring and the other to evaluate habitat conditions that occur as adults migrate upstream in the fall.

Spring Habitat Conditions For Juvenile Salmon

The results of the stepwise multiple regression analyses indicate that the streamflow in the San Joaquin River at Vernalis during spring is the habitat variable tested that explains the most variation in the number of chinook salmon that return to spawn in the Stanislaus and Tuolumne rivers. The streamflows at Vernalis were positively correlated with the San Joaquin PRODUCTION variable, suggesting that survival of chinook salmon smolts is highest when streamflows in the vicinity of Vernalis are highest (Figure 3). The other habitat variable that was significantly correlated with the San Joaquin PRODUCTION variable was maximum total Delta exports during spring. There was a weak negative correlation between Delta exports primarily during June and the San Joaquin PRODUCTION variable (Figure 4).

The final San Joaquin PRODUCTION model indicates that streamflows at Vernalis during spring (average flows for April through June) and maximum total Delta exports during spring (April through June) explain 73% of the variation in the number of fish returning to spawn; the adjusted multiple coefficient of determination (adj-R^2) for the final model was 0.73. The coefficient of determination (R^2) for streamflows at Vernalis was 0.63 (probability level = 0.0000) whereas the R^2 for maximum total Delta exports between April and June was 0.11 (p = 0.000). Therefore the influence of Delta exports are much less than those for streamflows at Vernalis. The regression equation for the San Joaquin PRODUCTION model is:

$$\text{SJPRODUCTION} = 1.81\ \text{VERNFLOW} - 0.0455\ \text{EXPORTS} + 17{,}840.9$$

where VERNFLOW = Average of the Monthly Flows at Vernalis, April through June
EXPORTS = Maximum Monthly Total Delta Exports from April through June

This equation suggests that by changing the average spring flows at Vernalis by one unit that the number of adult salmon that return to spawn will change by 1.8 units. For example, to double the number of salmon that returned to spawn from 1967 to 1991, the average monthly streamflows at Vernalis from April through June would have to be increased from 6,802 cfs to about 9,500 cfs. The average monthly flows (cfs) at Vernalis from 1965 to 1989 were as follows (Spring is defined as April through June):

Water Year Type	April	May	June	July	Spring
Critical	1,687	1,450	1,240	1,007	1,459
Dry	1,868	1,434	1,106	1,202	1,469
Below Normal	1,471	1,348	1,446	753	1,422
Above Normal	3,417	2,773	2,458	1,412	2,883
Wet	16,556	14,657	11,538	5,516	14,250
All Combined	7,923	6,934	5,549	2,886	6,802

From 1965 to 1989, there were 10 wet years, 4 above normal years, 2 below normal years, 4 dry years, and 5 critical years.

When habitat variables were used in the regression analysis that reflected conditions in April and May only, the adj-R^2 for the above model decreased to 0.67, which suggests that conditions during June were important to juvenile salmon survival for the period between 1952 and 1992. This is supported by the fact that smolts from the American River have been collected in the Delta during June in wet years (Dick Daniels, DFG). The regression analyses for the 1952 to 1992 period also suggest that streamflows at Vernalis are more important for the survival of chinook salmon smolts than the El Nino effects in the ocean (NPI and NPIMEAN variables), the number of adult salmon that return to spawn, and streamflow at Chipps Island, which includes flow from the Sacramento, Mokelumne and Cosumnes rivers.

For the period from 1968 to 1992, the adj-R^2 was 0.80 for the final model, which included positive correlations with both the average monthly flows at Vernalis from April through June ($R^2 = 0.76$, $p = 0.0000$) and the number of adult salmon present during the previous fall (the STOCK variable; $R^2 = 0.06$, $p = 0.035$). The adj-R^2 for this model decreased to 0.66 when the habitat variables were changed to reflect conditions in April and May, omitting June. Whether or not the spring habitat variables included June conditions, these analyses suggest that streamflows at Vernalis are more important for the survival of chinook salmon smolts than turbidity, water temperature, or dissolved oxygen concentrations at either Vernalis or Chipps Island.

The results of the stepwise multiple regression analyses for the Stanislaus River also indicated that streamflow in the San Joaquin River at Vernalis during spring is the most important habitat variable tested for explaining the variation in the production of chinook salmon. The streamflows at Vernalis were positively correlated with the Stanislaus PRODUCTION variable, suggesting that survival of chinook salmon smolts is highest when streamflows in the vicinity of Vernalis are highest (Figure 5). The other habitat variable that was significantly correlated with the Stanislaus River PRODUCTION variable was STOCK, which is the number of adults that returned to spawn during the previous fall; there was a weak positive correlation between the Stanislaus STOCK and Stanislaus PRODUCTION variables (Figure 2). What is most interesting about this analysis is that the flows at Vernalis were more important for salmon survival than were flows in the Stanislaus River at either Knights Ferry or Ripon. This suggests that the limiting factor for juvenile salmon in the San Joaquin River Basin does not occur in the tributaries, but downstream of Vernalis and upstream of Chipps Island. In addition the regression analyses suggest that total Delta exports and the effects of entrainment and impingement of smolts at the intakes of the pumping facilities are not a major problem for survival of juvenile salmon. Although water quality at Vernalis and Chipps Island was not correlated with salmon production, and therefore not a problem, very little water quality data in the Vicinity of the turning basin in the Stockton ship channel, particularly during spring, were found. However, the available data indicates that dissolved oxygen levels were less than 4 ppm and as low as 0.2 ppm during late-summer and fall on several occasions in the vicinity of the turning basin between 1965 and 1979. These levels are probably lethal to salmon and it is likely that high flows at Vernalis minimize the occurrence of lethal levels of dissolved oxygen. Another possibility is that high streamflows dilute the negative effects of agricultural runoff. Turbidity levels at Vernalis are negatively correlated with streamflows at Vernalis. One possible explanation for this correlation is that high flows dilute agricultural runoff, which includes nutrients that stimulate algae production and thus increases turbidity. High levels of algae may lead to low dissolved oxygen levels at night when algae consume oxygen. The dissolved oxygen data used in this analysis were daytime measurements and would not reflect potentially low levels at night. It is also likely that high flows also improve the suitability of water temperatures and other water quality factors that cumulatively result in high survival rates for salmon smolts passing through the Delta.

Fall Habitat Conditions For Adults Returning To Spawn

The previous analysis indicated that 75 to 80% of the variation in the number of two- and three-year-old salmon that return to spawn can be explained by the habitat conditions present when juveniles were rearing the in river and outmigrating through the Delta. Additional regression analyses suggest that dissolved oxygen levels at Chipps Island during September explain about 18% of the variation ($R^2 = 0.18$, $p = 0.002$) and were positively correlated with the number of two- and three-year-old salmon that return to the San Joaquin River Basin to spawn. In addition, the proportion of streamflow at Vernalis to the streamflow at Chipps Island in September explained another 26% of the variation ($R^2 = 0.26$, $p = 0.018$) and was positively correlated with San Joaquin River Basin escapement. The adj-R^2 for the final San Joaquin fall escapement model was 0.39. This suggests that the relative amount of streamflow in the San Joaquin River compared to the outflow from the Sacramento, Cosumnes, and Mokelumne rivers and high dissolved oxygen levels at Chipps Island are important for attracting adult salmon to the San Joaquin River Basin during September. A means to improve low dissolved oxygen levels at Chipps Island could not be discerned from these analyses, because there are only weak correlations between dissolved oxygen levels and streamflows, turbidity, and water temperatures at Chipps Island in September. R^2 ranged between 0.08 for water temperature and 0.14 for turbidity.

The results were similar for the Stanislaus River fish in that dissolved oxygen levels at Chipps Island during September explain about 23% ($R^2 = 0.23$, $p = 0.003$) of the variation in escapement, whereas maximum water temperatures at Knights Ferry explained another 21% ($R^2 = 0.21$, $p = 0.015$) of the variation in escapement. The adj-R^2 for the final Stanislaus River fall escapement model was 0.38. This analysis suggests that dissolved oxygen levels at Chipps Island and water temperatures at Knights Ferry were more important to the success of the upstream migration than was streamflow in the Stanislaus River, San Joaquin River, or the Delta at Chipps Island.

LITERATURE CITED

Mills, T.J. and F. Fisher. 1994. Central Valley anadromous sport fish annual run-size, harvest, and population estimates, 1967 through 1991. Inland Fisheries Technical Report, second draft, revised February 1994. Department of Fish and Game.

Hare, S.R. and R.C. Francis. 1992. Climate change and salmon production in the northeast Pacific Ocean. Canadian Journal of Fisheries and Aquatic Science, in press.

Trenberth, K.E and J.W. Hurrell. 1992. Decadal coupled atmospheric-ocean variations in the North Pacific. Paper presented at International Symposium on Climate Change and Northern Fish Populations, Oct. 13-16, 1992, Victoria, BC, Canada.

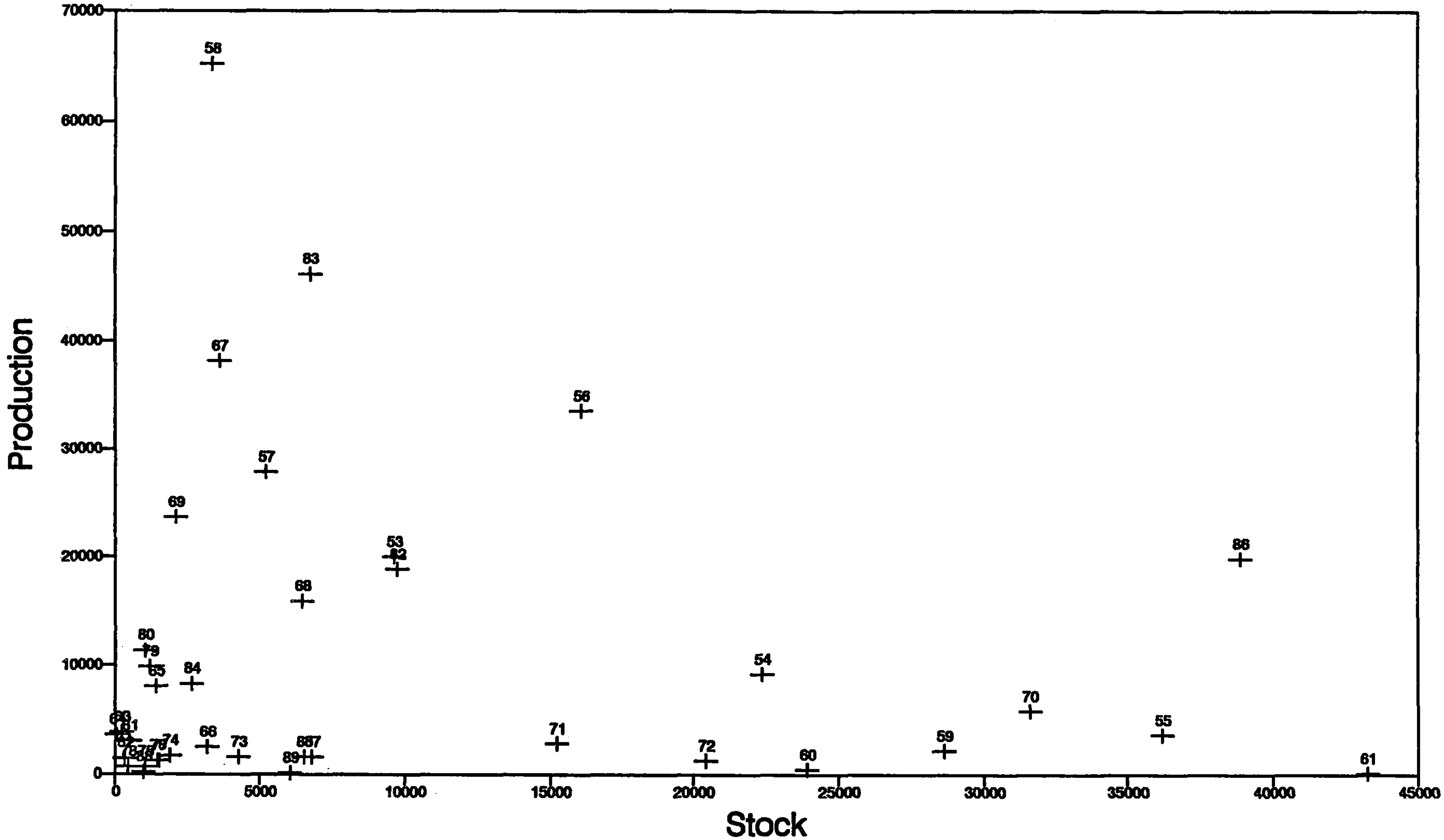

Figure 1. Number of two- and three-year-old chinook salmon of the same cohort that returned to spawn (Production) versus the number of spawners that produced those cohorts (Stock) from 1953 to 1989 in the Tuolumne River. Data points are identified according to the year when the fish in the Production cohorts were juveniles (one-year-olds).

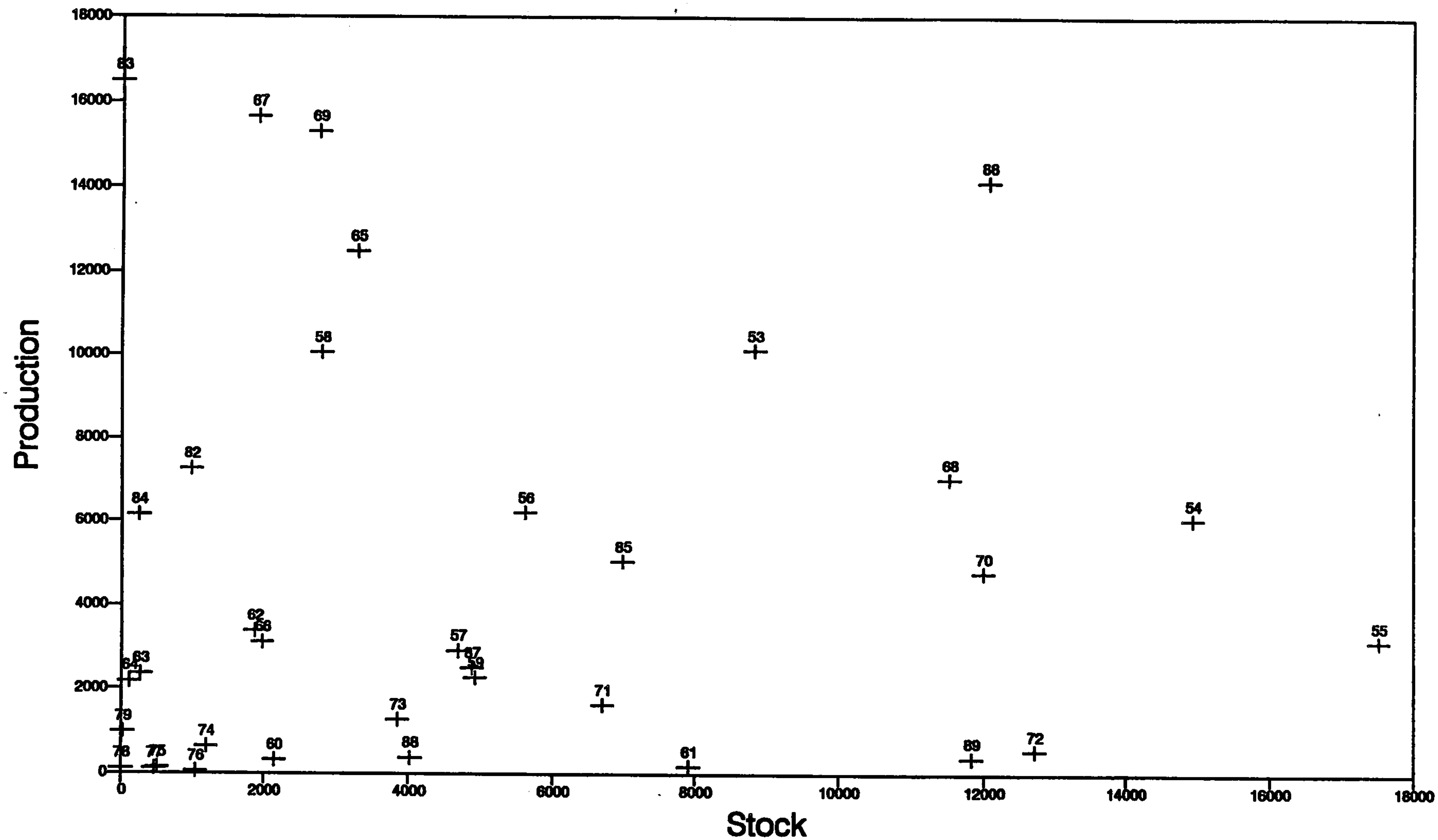

Figure 2. Number of two- and three-year-old chinook salmon of the same cohort that returned to spawn (Production) versus the number of spawners that produced those cohorts (Stock) from 1953 to 1989 in the Stanislaus River. Data points are identified according to the year when the fish in the Production cohorts were juveniles (one-year-olds).

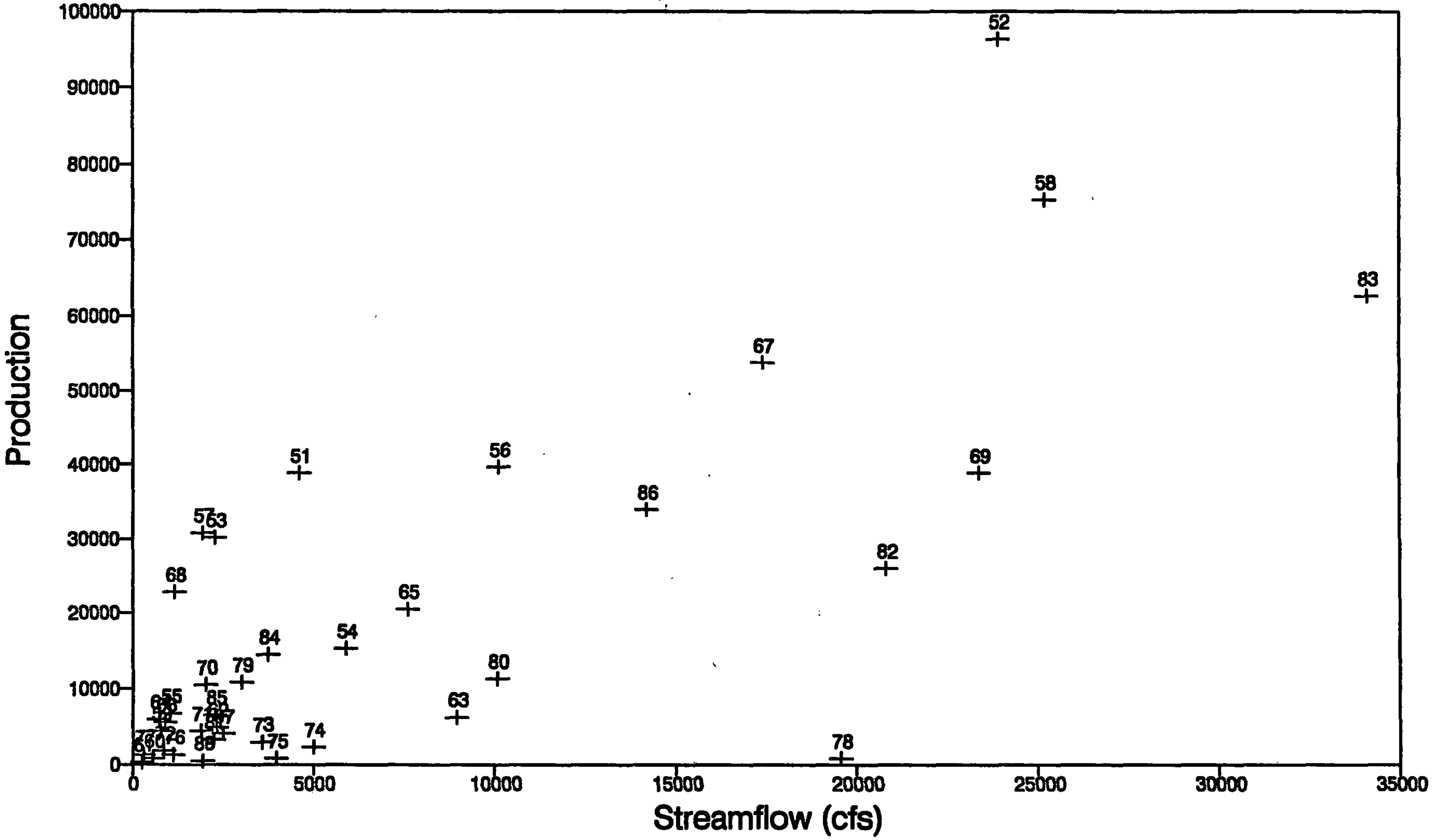

Figure 3. Number of two- and three-year-old chinook salmon of the same cohort that returned to spawn in the Stanislaus and Tuolumne rivers combined (Production) versus the average streamflow from April through June in the San Joaquin River in the vicinity of Vernalis during the year when each salmon cohort migrated through the Delta as smolts from 1951 to 1989. Data points are identified according to the year when the fish were juveniles (smolts).

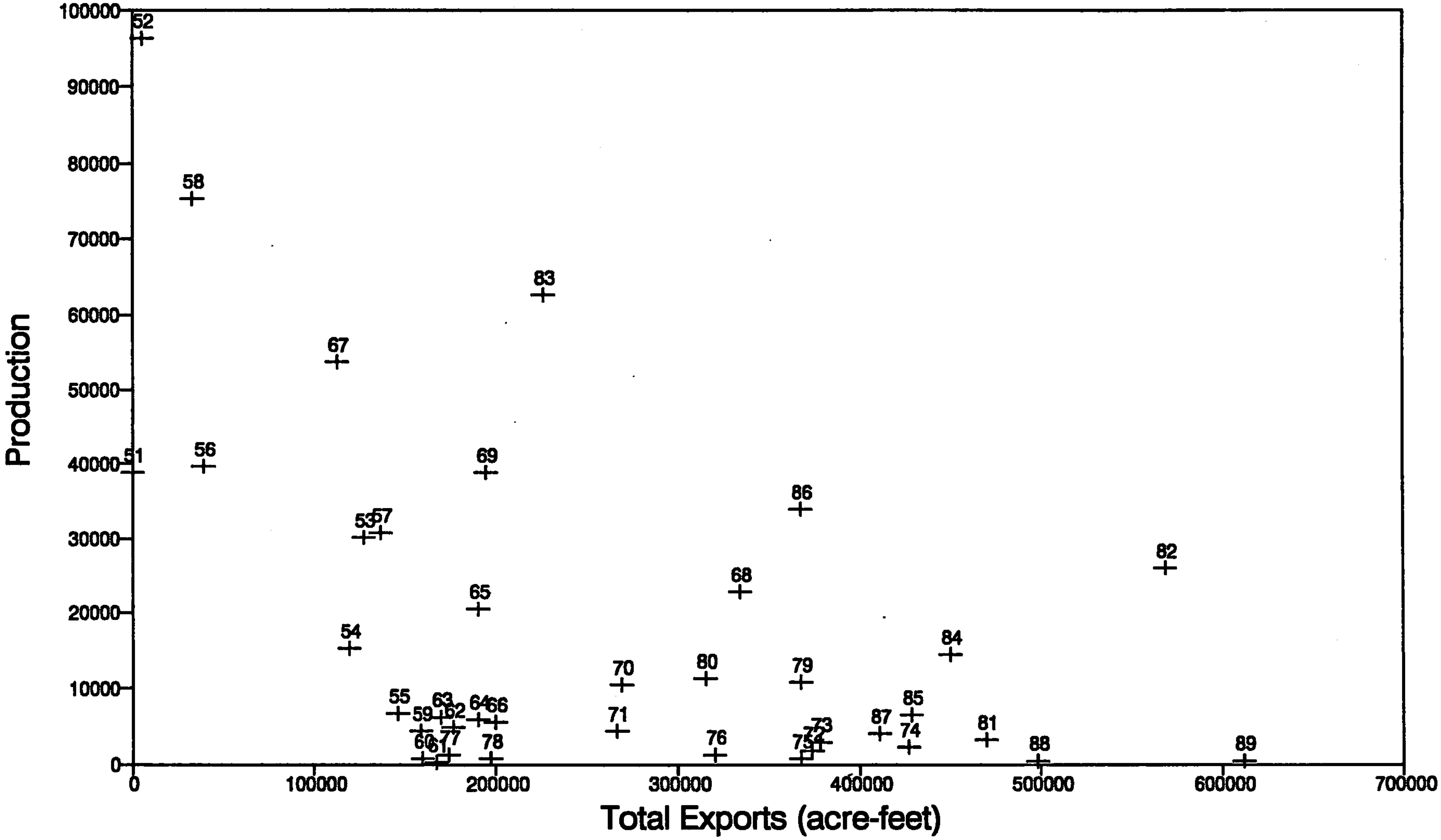

Figure 4. Number of two- and three-year-old chinook salmon of the same cohort that returned to spawn (Production) in the Stanislaus and Tuolumne rivers combined versus the maximum monthly Delta exports at the State and Federal pumping facilities combined that occurred from April through June during the year when each salmon cohort migrated through the Delta as smolts from 1951 to 1989. Data points are identified according to the year when the fish in the Production cohorts were juveniles (smolts).

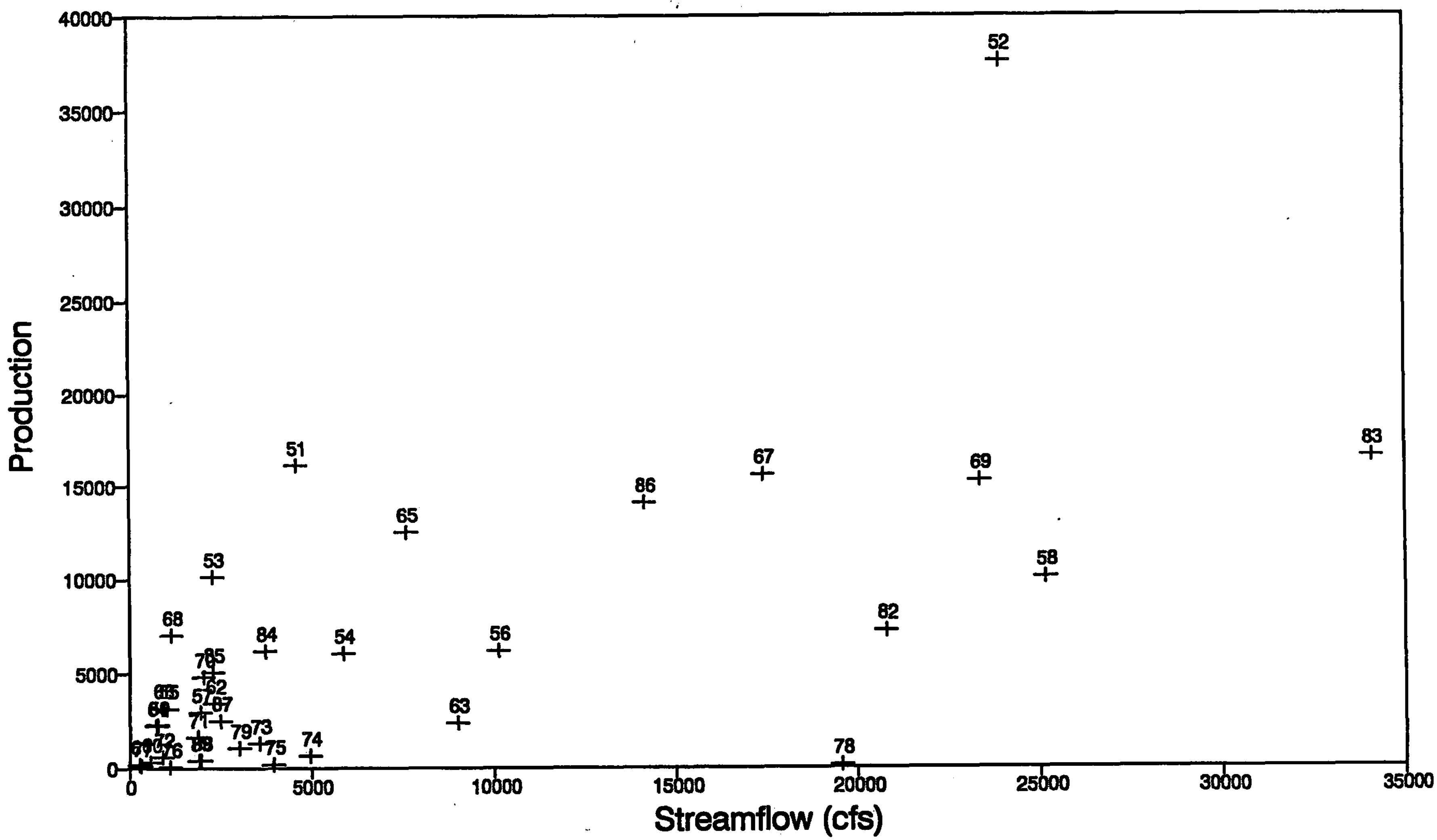

Figure 5. Number of two- and three-year-old chinook salmon of the same cohort that returned to spawn in the Stanislaus River (Production) versus the average streamflow from April through June in the San Joaquin River in the vicinity of Vernalis during the year when each salmon cohort migrated through the Delta as smolts from 1951 to 1989. Data points are identified according to the year when the fish were juveniles (smolts).

TABLE 1. HABITAT VARIABLES USED IN THE REGRESSION ANALYSIS, LOCATION OF SAMPLING STATIONS, RANGE IN YEARS THAT DATA WERE COLLECTED, AND THE SOURCE OF THE DATA.

Habitat Variable	Years	Source
North Pacific Index	1951-1992	Trenberth & Hurrell (1992)
Delta Exports	1951-1992	DWR CDEC
Streamflow		
Stanislaus River		
Knights Ferry	1957-1992	DWR CDEC
Ripon	1960-1992	DWR CDEC
San Joaquin River		
Vernalis	1951-1992	DWR CDEC
Delta		
Chipps Island	1954-1992	SWRCB STORET
Water Temperature		
Stanislaus River		
Knights Ferry	1966-1992	DWR CDEC
Ripon	1986-1989	DWR CDEC
San Joaquin River		
Vernalis	1968-1992	SWRCB STORET
Delta		
Chipps Island	1968-1992	SWRCB STORET
Dissolved Oxygen		
San Joaquin River		
Vernalis	1969-1992	SWRCB STORET
Delta		
Chipps Island	1968-1992	SWRCB STORET
Turbidity		
San Joaquin River		
Vernalis	1969-1992	SWRCB STORET
Delta		
Chipps Island	1968-1992	SWRCB STORET