# THE EFFECTS OF STREAMFLOW, WATER QUALITY, DELTA EXPORTS, OCEAN HARVEST, AND EL NINO CONDITIONS ON FALL-RUN CHINOOK SALMON ESCAPEMENT IN THE SAN JOAQUIN RIVER DRAINAGE FROM 1951 TO 1989

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28 November 1994

# INTRODUCTION

In testimony to the State Water Resources Control Board for the water rights phase of the Bay-Delta hearing proceedings, the California Department of Fish and Game (DFG) presented the results of regression analyses that showed a strong relationship between fall-run chinook salmon (*Oncorhynchus tshawytscha*) escapement and streamflows in the San Joaquin River at Vernalis (DFG Exhibit 25; June 1992). DFG 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 from 1955 to 1989. Based on these results and studies conducted with hatchery-reared salmon smolts, DFG recommended that San Joaquin River outflow be increased to protect salmon smolts migrating through the Delta.

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 harvest, 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 for smolt survival in the Stanislaus and Tuolumne rivers to those in the San Joaquin River at Vernalis and to those at Chipps Island in the Delta. The third goal was to evaluate the effects of fall habitat conditions at Chipps Island, 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, Modesto in the Tuolumne River, Vernalis in the mainstem San Joaquin River, and Chipps Island in the Delta. 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.

In addition to using the unadjusted streamflow and water quality data, other variables were used to reflect (1) the ratios of streamflow to total exports for both Vernalis and Chipps Island during the spring when the smolts were migrating and (2) the ratio of streamflow at Ripon to streamflow at Vernalis and the ratio of streamflow at Vernalis to the streamflow at Chipps Island during fall when the adults were migrating upstream. A ratio of streamflow to exports provides an acceptable independent variable for the regression analyses, because there are no substantial correlations between streamflow and total exports, which were averaged over the period from April through June, at either Vernalis (adj-$R^2$ = 0.009, p = 0.24) from 1951 to 1992 or Chipps Island (adj-$R^2$ = 0.085, p = 0.04) from 1954 to 1992. Because the relationships between the chinook salmon escapement variables and the ratio of streamflow to total exports were logarithmic, a logarithmic transformation (base 10) of the ratios were made so that the variables were appropriate for linear regression analyses. On the other hand, there are relatively strong correlations for fall streamflows between Ripon, Vernalis, and Chipps Island suggesting that correlations with ratios of fall streamflows should be viewed with caution. The correlation for the average streamflows for September and October between Ripon in the Stanislaus River and Vernalis in the San Joaquin River for the period from 1960 to 1992 has an adj-$R^2$ of 0.88 and probability level of 0.0000. The correlation for the streamflow ratio at Vernalis and Chipps Island for the period from 1954 to 1992 has an adj-$R^2$ of 0.55 and probability level of 0.0000.

The fish abundance data provided by DFG were 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 adults (three-year-old fish) that spawned during the previous fall and (2) RECRUITMENT, 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, was called ESCAPEMENT.

The number of two-year-old fish, which are called grilse or jacks, 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". Fisher indicated that few (< 5%) 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. The lack of escapement data in 1982 for the Stanislaus River precluded computing the RECRUITMENT estimate for 1980 and 1981 and the STOCK estimate for 1983 for both the Stanislaus River and the San Joaquin River Basin.

To detect the effect of ocean harvest on salmon recruitment, two variables were used that incorporated data on the number of chinook salmon caught in the commercial troll and recreational fisheries reported for the Monterey, San Francisco, and Fort Bragg areas (Pacific Fisheries Management Council 1993). The harvest data were first segregated into cohorts assuming that the percentage of the harvested two-year-old fish was the same as the average percentage of two-year-old fish that returned to spawn in the Tuolumne and Stanislaus rivers during the same year. Regression analyses were conducted with a commercial harvest variable that pertained to the 1951 to 1989 cohorts and with a combined commercial and recreational variable that pertained to the 1961 to 1989 cohorts.

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, Tuolumne River, and the San Joaquin River Basin using the Statistix 4.0 software program. The first step in the analyses was to conduct simple linear regressions with each habitat variable to determine 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 and those for the Tuolumne River at Modesto, San Joaquin River at Vernalis, and Chipps Island reflected 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.

The second step was to conduct stepwise regression analyses between the fish population variables (RECRUITMENT and ESCAPEMENT) and the seasonal habitat variables. These analyses were conducted with three different periods of data, because some of the habitat data were not available for all years (1951 to 1989) and statistical protocol dictates 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. Similarly, when the maximum stream temperature data at Vernalis were included in the analysis, none of the data prior to 1977 were evaluated. To avoid this problem, the regression analyses were conducted for the 1951 to 1989 period, 1968 to 1989 period, and the 1977 to

1989 period. Comparisons of the coefficient of determinations ($R^2$) between the habitat variables presented in Tables 2 through 4 should be made within the same periods.

## RESULTS AND DISCUSSION

Two sets of regression analyses were conducted, one to evaluate rearing conditions for fry in the tributaries and for smolts passing through the Delta during spring and the other to evaluate habitat conditions that occur as adults migrate upstream in the fall. The results of the analyses evaluating the spring rearing conditions for the San Joaquin River Basin RECRUITMENT variable are presented in Table 2, those for the Stanislaus River RECRUITMENT variable are presented in Table 3, and those for the Tuolumne River RECRUITMENT variable are presented in Table 4. These tables are located at the end of this report (pages 18 through 24). The figures showing relationships between the RECRUITMENT variables and the important habitat variables begin on page 25.

### Spring Habitat Conditions For Juvenile Salmon

The results of the stepwise multiple regression analyses indicate that the ratio of streamflow in the San Joaquin River at Vernalis to total Delta exports from April through June explains about 76% of the variation (adj-$R^2 = 0.76$, $p = 0.0000$) in the combined number of chinook salmon that return to spawn in the Stanislaus and Tuolumne rivers from 1951 to 1989 and that none of the other habitat variables were relatively important for the survival and production of San Joaquin chinook salmon. The importance of a ratio of streamflow to exports suggests that the proportion of flow diverted to the pumping facilities has had the greatest effect on salmon production in the San Joaquin system compared to streamflows in the tributaries and at Chipps Island, ocean harvest, El Nino conditions, stream temperatures, dissolved oxygen levels, and turbidity. Water diverted to the pumping facilities through the Old River leads the salmon smolts to a "dead-end" system where they are exposed to numerous predators, primarily striped bass, and impingement on the screens at the pumping facilities. The California Department of Fish and Game (1987) has estimated that between 63 and 86 percent of the salmon smolts die after they enter Clifton Court Forebay at the State pumping facilities at Tracy. Clifton Court Forebay has an abundance of striped bass and it is likely that additional mortality occurs as a result of impingement and the salvage operations that transports the surviving fish to the lower Delta. Although there are no data on smolt survival at the Federal pumping facilities, the correlations with the RECRUITMENT variables were similar for both the State and Federal facilities (Tables 2 through 4), suggesting that mortality is also high at the Federal facilities.

The importance of streamflow in the San Joaquin River Basin to the survival of salmon smolts is probably also related to the presence of predators throughout the system, unscreened diversions in both the mainstem San Joaquin and the tributaries, pesticides contained in agricultural runoff, and low dissolved oxygen levels at the turning basin in the Stockton ship channel. While striped bass are primarily found in the Delta, some occur in the tributaries and largemouth bass are abundant in the Tuolumne River. Both striped bass and largemouth bass prey on salmon fry and smolts and it is possible that high flows decrease predation rates by accelerating the passage of smolts through the system. It is also possible that 44 small, unscreened pump diversions on the Stanislaus River, 36 more on the Tuolumne River, and four major unscreened diversions on the mainstem San Joaquin River downriver from Mendota Pool also contribute to smolt mortality. In addition, pesticides contained in agricultural runoff, particularly from Mud and Salt Sloughs, may also negatively affect salmon smolt survival. Although dissolved oxygen levels were not highly correlated with salmon recruitment, and therefore not a problem, it is likely that low dissolved oxygen concentrations exist at the turning basin in the Stockton ship channel during late-spring when water temperatures are high and streamflow is low. 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 at the turning basin between 1965 and 1979 and these levels could be lethal for juvenile salmon. Although the effects of predation, unscreened diversions, agricultural runoff, and water quality at the Stockton turning basin have not been adequately studied, it is likely that high streamflows in the mainstem San Joaquin minimize their potential negative impacts.

The ratio of streamflow at Vernalis to Delta exports has the highest correlation with the RECRUITMENT variables during the month of June, compared to April and May (Tables 2 through 4) and the average ratios for the months of April through June have higher correlations than do the average ratios for either the months of April and May or May and June, and therefore indicates that the migration of salmon smolts through the Delta should be protected during the entire period from April through June. June is probably the most important month for salmon smolts in the Delta because the average ratio of streamflow to exports has been lowest (61%) in June from 1965 to 1989, compared to the ratios for April and May, which were 91% and 74% respectively. The correlations for June conditions were highest for the 1977 to 1989 period, perhaps because the ratio of streamflow to exports was usually quite low due to the prevalence of drought and increased pumping rates. Although the U.S. Fish and Wildlife Service (USFWS) has collected few smolts in the Delta during June in recent years, data presented by S.P. Cramer & Associates (1994) showed that relatively high numbers of chinook salmon smolts in the Stanislaus River were just starting their downstream migration in late-May and early-June in 1993. Furthermore, smolts from the American River have been collected in the Delta during June in wet years (Daniels, 1994). Although the USFWS believes that water temperatures are too high during June for smolt survival, there are no strong correlations for maximum stream temperatures at Vernalis or daily measurements of stream temperature at Chipps Island, particularly during June, that would suggest that this is true. In addition, there were no correlations with either turbidity or dissolved oxygen that would suggest that other water quality problems occur during June for salmon juveniles. One possible reason for the discrepancy between the USFWS's studies and the results of these analyses is that the USFWS uses tagged hatchery-reared fish for their studies, whereas these analyses utilized data on wild salmon only. Juvenile hatchery-reared salmon develop relatively quickly and are released when most are ready to adapt to salt water (smoltify) and so most probably migrate through the Delta prior to June. Conversely, wild juvenile salmon typically develop from February through June in the San Joaquin tributaries, and so many migrate through the Delta over an extended period. In addition, the juvenile hatchery-reared salmon probably suffer higher mortality rates than do wild juvenile salmon during their downstream migration (Foott 1994), and so the smolt survival indices computed by the USFWS may not be comparable to the survival rates for wild fish.

There was a weak correlation (adj-$R^2 = 0.37$) between the RECRUITMENT variables and the combined commercial and recreational ocean harvest for the Monterey, San Francisco, and Fort Bragg areas during the 1960 to 1989 period (Table 2). When the harvest variable was forced into the stepwise regression model, it increased the adj-$R^2$ from 0.56 to 0.60 and it was not significant ($p = 0.17$). This is a surprising result since the total ocean harvest for these areas from 1967 to 1991 has ranged between two to four times the number of salmon returning to spawn in the San Joaquin and Sacramento River Basins combined (DFG 1994).

Similarly, there were only weak correlations between the RECRUITMENT variables and the number of spawners (STOCK). Only the number of spawners returning to the Stanislaus River were weakly correlated with the RECRUITMENT variables for both the Stanislaus River and the San Joaquin River Basin. The number of spawners in the Stanislaus River increased the regression model with the ratio of streamflow at Vernalis to total exports from an adj-$R^2$ of 0.66 to 0.69, with a probability level of 0.15. The correlations with the number of spawners in the Tuolumne River were even weaker than those for the Stanislaus River. Although EA Engineering, Science, and Technology's analyses for the Tuolumne River indicate that the relationship between stock and recruitment is non-linear due to density-dependent factors, no density-dependent factors were observed for the Department of Fish and Game data. Density-dependent mortality would occur if an excessive number of adults returned to spawn that caused egg mortality or otherwise disrupted spawning. If density-dependent effects were occurring, then a plot of stock versus recruitment would show that recruitment would be highest at mid-levels of stock and low at high levels of stock. This is not the case for either the Stanislaus River (Figure 4) or for the Tuolumne River (Figure 5) after accounting for the effects of streamflow and exports. By evaluating the regression between the ratio of streamflow to exports versus recruitment for the Stanislaus River (Figure 2) and the Tuolumne River (Figure 3), none of the points below the regression lines (i.e., when other factors reduced recruitment) occurred when stock in either river was relatively high. The appearance of a density-dependent relationship for the Tuolumne River, where the highest levels of production occurred at relatively low levels of stock (Figure 5), can be explained by the influence of streamflow and exports rather than by density-dependent factors. All of the high levels of recruitment in the Tuolumne River occurred during 1956, 1957, 1958, 1967, 1969, and 1983, when streamflows at Vernalis were relatively high and exports were low during the spring when the fish were smolts (Figure 3); and it was simply a coincidence that the number of spawners (STOCK) that produced those smolts was low because streamflows were low and exports were high during the spring when the spawners migrated through the Delta as smolts. Although density-dependent factors do not appear to be occurring for either the Stanislaus or the Tuolumne rivers, the lack of a strong correlation between stock and recruitment suggests that there are severe limitations for either spawning or rearing habitat in those tributaries, particularly the Tuolumne River. EA Engineering, Science, and Technology has documented that the spawning gravel in the Tuolumne River contains high levels of fine particles that reduce the survival of the fish larvae by about half. It is also likely that the elimination of upstream sources of gravel for spawning due to the dams on both tributaries in combination with gravel mining operations and periodic high flows capable of mobilizing gravel have greatly reduced the availability of spawning gravels in both rivers.

The lack of a correlation with El Nino conditions for the San Joaquin River Basin may have been caused by the intensive ocean harvest of important prey species for adult salmon, such as California sardine, hake, and anchovy, that has occurred since 1950. Although La Niña conditions (opposite of El Niño conditions) prevailed from 1950 to 1970 when ocean temperatures should have been low and prey should have been abundant off the California coast, the Central Valley salmon populations were relatively small compared to previous La Nina periods. While the reason that the salmon populations failed to respond to the 1950 to 1970 La Nina conditions was partially due to the overexploitation of their ocean prey, it is also likely that the completion of Friant Dam on the mainstem San Joaquin River in 1949 and the operation of the Federal and State pumping facilities, which began in 1951 and 1968 respectively, also contributed to the problem.

Fall Habitat Conditions For Adult Salmon Returning To Spawn

Additional regression analyses suggest that dissolved oxygen levels at Chipps Island during September and the proportion of streamflow at Vernalis to total Delta outflow are weakly correlated with salmon escapement in the Stanislaus and Tuolumne rivers, whereas absolute streamflows and maximum stream temperatures have had very little or no effect on escapement. Dissolved oxygen levels at Chipps Island in September were positively correlated and explain about 18% of the variation ($R^2 = 0.18$, $p = 0.002$) in 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 increased the model's $R^2$ by 0.26 ($p = 0.018$) and was also positively correlated with San Joaquin River Basin escapement. The adj-$R^2$ for the final San Joaquin fall escapement model was 0.39. Correlations with absolute streamflows averaged for September and October were quite weak regardless of location; the correlations between the ESCAPEMENT variable and average fall streamflows at either Ripon, Vernalis, or Chipps Island had adj-$R^2$s that were less than -0.02 and probability levels greater than 0.52. 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. The $R^2$ for these correlations with dissolved oxygen levels ranged between 0.08 for water temperature and 0.14 for turbidity. Therefore, it is unlikely that increasing streamflows during the fall will substantially increase salmon escapement in the San Joaquin River Basin compared to the benefits provided by increasing streamflow and reducing exports during the spring when the juveniles begin their migration to the ocean.

Conditions Necessary To Double Recruitment

The correlations between the production of chinook salmon in the Stanislaus and Tuolumne rivers and streamflow at Vernalis and total Delta exports were both strong and statistically significant; however, it cannot be stated with confidence based on the correlations alone that it is possible to double the salmon population by increasing streamflows and reducing total exports. One limitation of correlation analyses is that they do not prove cause-effect relationships and it is possible that the observed relationships between salmon production and streamflow and exports might be coincidental if the factor(s) that actually controls salmon production is related to climatic events that also affect streamflow and exports in the same manner. On the other hand, studies conducted by the U.S. Fish and Wildlife Service and the Department of Fish and Game indicate that the survival of hatchery chinook salmon smolts is highest when streamflows at Vernalis are high and exports are low. Furthermore, the agencies studies suggest that high streamflows in the San Joaquin at Vernalis and low export rates improve the survival of salmon smolts by: (1) minimizing the amount of water, and therefore the number of smolts, diverted to the pumping facilities where the smolts are either caught on the screens or eaten by predators, (2) diluting agricultural runoff that typically contains pesticides that may kill the prey eaten by smolts and the smolts directly, (3) minimizing the number of smolts entrained in the numerous unscreened diversions in the San Joaquin River and its tributaries, (4) improving water temperatures and dissolved oxygen levels, and (5) minimizing predation rates. Therefore, because similar results were obtained with these correlation analyses with wild chinook salmon and the agencies studies with hatchery fish and because there are several potential mechanisms that account for the benefits of high streamflows and reduced exports for salmon, it is very likely that the regression equations described below could be used to compute the streamflows and exports necessary to double the number of naturally produced chinook salmon in the San Joaquin River basin and satisfy the requirements of the Central Valley Project Improvement Act (CVPIA).

The best regression equations for the San Joaquin RECRUITMENT models that would be most likely to achieve the goal of doubling the salmon populations are those that include (1) streamflow at Vernalis and total exports as separate independent variables and (2) the ratio of streamflow to total exports. The baseline period identified under the CVPIA is from 1967 to 1991 and corresponds to the spring conditions from 1965 to 1989 that were evaluated in this report. To compute examples of the conditions that should occur during the next 25 years to achieve doubling, the average streamflows and exports that occurred during the baseline period were used in the regression equations to compute the number of two- and three-year-old fish for the baseline period and then this result was doubled to solve for the new levels of streamflows and exports. The following conditions, which occurred during the baseline period, were used to solve for the conditions necessary to achieve doubling: (1) an average streamflow at Vernalis during spring of 6,802 cfs; (2) a maximum monthly exports during spring (primarily in June) of 366,246 acre-feet (about 5,970 cfs); and (3) an average ratio of streamflow at Vernalis to total exports during spring of 0.744. To check the equations accuracy, the recruitment for the San Joaquin basin that was computed by the regression equation for the baseline period was compared to an average of 13,689 fish based on DFG's estimates. To compute the streamflows necessary to achieve doubling by water year type, it was assumed that the same combination of water types that occurred during the baseline period, which included 10 wet years, 4 above normal years, 2 below normal years, 4 dry years, and 5 critical years, would be repeated during the next 25 years.

The regression equation for the San Joaquin RECRUITMENT model that includes streamflow at Vernalis and total Delta exports, which has an adj-$R^2$ of 0.68, is as follows:

$$\text{San Joaquin RECRUITMENT} = 1.82\ \text{VERNFLOW} - 0.0509\ \text{EXPORTS} + 18{,}417.3$$

where

VERNFLOW = Average of the Monthly Flows at Vernalis, April through June; and

EXPORTS = Maximum Monthly Total Delta Exports from April through June

The following table presents one possible scenario of changes in streamflows at Vernalis and total maximum exports during spring that would double the number of salmon. Based on the above equation, doubling could be achieved by reducing maximum total exports from April through June from the baseline period average of 366,246 acre-feet per month to 200,000 acre-feet per month (about 3,250 cfs) and by increasing the average flows at Vernalis from 6,802 cfs to 9,000 cfs. A similar table was not computed for exports alone, since the correlation between salmon recruitment and total exports was relatively weak compared to the correlation with streamflows at Vernalis. The computed recruitment for the San Joaquin River basin is 12,144 fish, which compares to 13,689 fish based on DFG's estimates. The average monthly flows (cfs) at Vernalis from 1965 to 1989 (Baseline) and one possible set of streamflows likely to double the number of salmon (Doubling) are as follows (Spring is defined as April through June):

| | Baseline | | | | Doubling | | | |
|---|---|---|---|---|---|---|---|---|
| Water Year Type | April | May | June | Spring | April | May | June | Spring |
| Critical | 1,687 | 1,450 | 1,240 | 1,459 | 3,500 | 3,000 | 2,500 | 3,000 |
| Dry | 1,868 | 1,434 | 1,106 | 1,469 | 5,500 | 5,000 | 3,750 | 4,750 |
| Below Normal | 1,471 | 1,348 | 1,446 | 1,422 | 7,500 | 7,000 | 5,500 | 6,667 |
| Above Normal | 3,417 | 2,773 | 2,458 | 2,883 | 9,500 | 9,000 | 7,750 | 8,750 |
| Wet | 16,556 | 14,657 | 11,538 | 14,250 | 16,556 | 14,657 | 11,538 | 14,250 |
| All Combined | 7,923 | 6,934 | 5,549 | 6,802 | 10,322 | 9,262 | 7,395 | 8,993 |

To ensure that the new streamflows at Vernalis will be sufficient to achieve the doubling goal, the results of the regression analyses suggest that it will be necessary to regulate the amount of exports relative to streamflow levels in the Delta. This could be done by using the following regression equation for the San Joaquin RECRUITMENT model that includes the log of the ratio of streamflow at Vernalis to total Delta exports and has an adj-$R^2$ of 0.76:

San Joaquin RECRUITMENT = 26,013 LOG (FLOW/EXP) + 17,981

where

FLOW/EXP = Average of the ratio of monthly flows at Vernalis to total Delta exports during spring

The following table presents an example using the above equation whereby the ratio of streamflow at Vernalis to the average total exports (cfs/cfs) during spring (April through June) could be increased from the baseline average of 0.74 (Baseline) to an average of 2.72 (Doubling) that would be needed for the next 25 years to double the number of salmon. The computed recruitment for the San Joaquin River Basin was 14,634, which compares to 13,689 fish based on the DFG estimates.

| | Baseline | | | | Doubling | | | |
|---|---|---|---|---|---|---|---|---|
| Water Year Type | April | May | June | Spring | April | May | June | Spring |
| Critical | 0.246 | 0.247 | 0.270 | 0.254 | 2.818 | 2.239 | 1.778 | 2.239 |
| Dry | 0.267 | 0.235 | 0.203 | 0.233 | 3.162 | 2.512 | 1.950 | 2.493 |
| Below Normal | 0.384 | 0.324 | 0.247 | 0.313 | 3.311 | 2.570 | 1.995 | 2.570 |
| Above Normal | 0.636 | 0.501 | 0.415 | 0.510 | 3.548 | 2.630 | 1.995 | 2.651 |
| Wet | 3.887 | 2.793 | 2.009 | 2.794 | 3.981 | 3.162 | 2.512 | 3.162 |
| All Combined | 0.908 | 0.740 | 0.612 | 0.744 | 3.464 | 2.716 | 2.130 | 2.716 |

Management Alternatives

In biological terms, the most conservative means of protecting the San Joaquin River salmon populations is to increase streamflows in the San Joaquin River, its tributaries, and the Delta, restrict exports, and monitor the salmon population to ensure that these actions were achieving the desired result. However, given the economic consequence of relying only on increases in streamflow at Vernalis or reductions in total exports, it may be possible to reduce or eliminate the problems that directly impact salmon smolts migrating through the Delta. This would require minimizing problems associated with (1) the state and federal pumping facilities, where mortality is high due to impingement and predation, (2) unscreened diversions that occur throughout the basin, (3) predation by striped bass and largemouth bass in the tributaries, Delta, and Bay, and (4) unsuitable water quality, including temperature, dissolved oxygen, and pesticides. The primary problem for this approach is that there is a greater risk that the biological objective of doubling the salmon population will not be achieved in comparison to the strategy of increasing streamflows and reducing exports. First of all, there is inadequate information to accurately determine whether some or all of the four previously discussed problems need to be corrected to achieve the doubling goal. Second, it is highly possible that there are other unknown problems in the Delta that would be corrected by increased streamflows or reduced exports, but otherwise might continue to limit the salmon populations. And finally, it is impossible to accurately determine the level of streamflow in the San Joaquin River and export restrictions that would be necessary to achieve the doubling goal if management alternatives were implemented to directly alleviate the problems. Due to these uncertainties, the implementation of any or all of the following management alternatives should be accompanied with increases in streamflow and restrictions in exports as well as extensive monitoring of the response of the salmon population.

Minimizing the number of salmon smolts that migrate towards the state and federal pumping facilities might be achieved by using a series of barriers with gates to create two separate pathways for streamflow through the Delta: one for salmon smolt migration and the other carrying water to the pumping facilities. Because salmon smolts typically migrate only at night and remain relatively stationary during the day, it may be possible to divert almost all of the flow of water and migrating smolts away from the pumping facilities and predator concentrations during the night into a single channel through the Delta, whereas pumping and diversions operations could occur during the daylight hours through the normal channels leading to the pumping facilities without causing significant mortality of smolts. Although pumping would occur during the day, sufficient streamflow would have to be kept in the smolt migration channel to maintain suitable water quality, particularly dissolved oxygen levels at the Stockton turning basin, water temperature, and pesticide levels, at all times. This might be easier to achieve, particularly during dry and critical years, if the streamflow was consolidated in one channel for smolt migration. Barriers with gates may be necessary in the Old River, because approximately 60% of the San Joaquin River flows through these channels even when there is no pumping at the state and federal facilities (DWR Bulletin 76), and it is likely that mortality would be high for smolts diverted into this channel due to predation by striped bass and to a lesser degree by impingement at the facilities screens. It also may be necessary to restrict the flow of water from the lower Delta to minimize mortality of Delta smelt at the pumping facilities. Several alternatives based on barriers and gates have already been proposed to protect the passage of salmon smolts and it is possible that a combination of these alternatives would minimize the impacts associated with the pumping facilities. A map of the Sacramento-San Joaquin Delta indicating the location of the Delta Cross Channel, the proposed Old River Barrier, and the pumping facilities is shown in Figure 6.

Another management alternative would be to try to concentrate the migration of salmon smolts during intermittent releases of short-duration pulse flows that would protect the smolts with high flows throughout the spring period, conserve the use of water, and allow relatively high levels of exports during the periods between the pulse flows. For this alternative to be successful, the San Joaquin smolts must migrate quickly through the lower San Joaquin River and upper Delta to the areas where Sacramento River streamflows improve habitat conditions before the pulse flows cease. However, there is conflicting information as to whether smolt survival is highest when they can grow and migrate slowly through the lower San Joaquin River and upper Delta or whether they can migrate quickly through the Delta to the Bay without reducing their chances for survival. On one side of the issue, the correlations for individual populations in both the Stanislaus (Table 3) and Tuolumne rivers (Table 4) suggest that smolt survival is highest when they migrate slowly through the system, particularly when streamflows are high. For both populations, the correlations with streamflow are highest in the tributaries in March and April, highest at Vernalis in May and June, and highest at Chipps Island in June. Although these patterns of correlations provide weak evidence that the prime rearing areas for smolts moves slowly from the tributaries in March and April, to the upper Delta in May and June, and finally to the lower Delta by June, they suggest that intermittent short-duration pulse flows may not provide the rearing habitat in the upper Delta necessary for high levels of salmon production.

On the other side of the issue, field studies conducted by S.P Cramer & Associates, Inc. (SPCA; 1994) in the Stanislaus River in 1993 indicated that two two-week periods when flows were increased from the baseline flows of about 200 cfs to 1,500 cfs beginning in late-April resulted in a tripling of the smolt migration rate that lasted for only one day. Thereafter, the migration rate returned to approximately the same levels that occurred prior to the pulse flow although the pulse flows were maintained. SPCA also presented data indicating that juvenile salmon migration rates are directly related to the size of the fish and that pulse flows primarily trigger the migration response in those fish large enough to adapt to salt water. Therefore, short-duration pulse flows may increase smolt survival, if the smolts quickly migrate through the San Joaquin River to the lower Delta where Sacramento River flows improve their chances for survival, so that there would be sufficient time to complete a baseflow-pulse flow cycle before the next group of smolts begins to migrate. The benefit provided by short-term pulse flows may be greatest during dry and critical years when the outmigration period may last two to three months and the availability of water for releases is scarce. Other considerations include: (1) the effect of intermittent pulse flows on the fish and invertebrate species in the Delta and (2) whether agricultural runoff could be stored and then released only during the pulse flows to achieve the desired dilution effect.

In conclusion, the effectiveness of the previously described management alternatives to achieve the doubling goal for the salmon population will be difficult to predict and so restoration plans should be viewed as experimental, include intensive monitoring programs, and rely primarily on streamflow and export restrictions until the benefits of the other alternatives have been verified.

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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 |
| Tuolumne River | | |
| Modesto | 1957-1992 | 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 |

TABLE 2 ADJUSTED-$R^2$ AND PROBABILITY LEVEL FOR CORRELATIONS WITH THE SAN JOAQUIN RECRUITMENT VARIABLE FROM 1951 TO 1989, 1968 TO 1989, AND 1977 TO 1989

| Variable | Adj-$R^2$/p 1951-1989 | 1968-1989 | 1977-1989 |
|---|---|---|---|
| Log Streamflow at Vernalis/Total Exports | | | |
| April | 0.71/0.00 | 0.44/0.00 | 0.49/0.01 |
| May | 0.71/0.00 | 0.42/0.00 | 0.41/0.02 |
| June | 0.75/0.00 | 0.48/0.00 | 0.73/0.00 |
| Apr-Jun Average | 0.76/0.00 | 0.48/0.00 | 0.54/0.00 |
| Log Streamflow at Vernalis/Export at Banks | | | |
| April | -- | 0.46/0.00 | 0.56/0.01 |
| May | -- | 0.43/0.00 | 0.48/0.01 |
| June | -- | 0.31/0.01 | 0.63/0.00 |
| Log Streamflow at Vernalis/Export at Tracy | | | |
| April | 0.68/0.00 | 0.42/0.00 | 0.46/0.01 |
| May | 0.69/0.00 | 0.39/0.00 | 0.38/0.03 |
| June | 0.71/0.00 | 0.46/0.00 | 0.78/0.00 |
| Log Streamflow at Chipps Island/Total Exports | | | |
| April | 0.48/0.00 | 0.23/0.02 | 0.39/0.02 |
| May | 0.50/0.00 | 0.34/0.00 | 0.40/0.02 |
| June | 0.62/0.00 | 0.34/0.00 | 0.48/0.01 |
| Apr-Jun Average | 0.58/0.00 | 0.36/0.00 | 0.51/0.00 |
| Monthly Streamflow | | | |
| Vernalis | | | |
| April | 0.48/0.00 | -- | -- |
| May | 0.63/0.00 | -- | -- |
| June | 0.64/0.00 | -- | -- |
| Apr-Jun Average | 0.57/0.00 | -- | -- |
| Chipps Island | | | |
| April | 0.43/0.00 | -- | -- |
| May | 0.65/0.00 | -- | -- |
| June | 0.71/0.00 | -- | -- |
| Apr-Jun Average | 0.62/0.00 | -- | -- |
| Total Exports | | | |
| April | 0.17/0.01 | -- | -- |
| May | 0.28/0.00 | -- | -- |
| June | 0.29/0.00 | -- | -- |

TABLE 2 (CONTINUED)

| Variable | Adj-$R^2$/p 1951-1989 | 1968-1989 | 1977-1989 |
|---|---|---|---|
| **Maximum Stream Temperature** | | | |
| Vernalis | | | |
| April | -- | -- | 0.04/0.21 |
| May | -- | -- | -0.01/0.38 |
| June | -- | -- | 0.05/0.19 |
| Spring Max | -- | -- | -0.01/0.39 |
| **Point-In-Time Measurements Of Stream Temperature** | | | |
| Chipps Island | | | |
| April | -- | 0.18/0.05 | -- |
| May | -- | 0.23/0.02 | -- |
| June | -- | -0.02/0.43 | -- |
| Spring Max | -- | 0.22/0.02 | -- |
| **Dissolved Oxygen** | | | |
| Vernalis | | | |
| April | -- | 0.08/0.13 | -- |
| May | -- | 0.00/0.32 | -- |
| June | -- | 0.03/0.21 | -- |
| Chipps Island | | | |
| April | -- | 0.04/0.22 | -- |
| May | -- | 0.00/0.31 | -- |
| June | -- | -0.01/0.39 | -- |
| **Turbidity** | | | |
| Vernalis | | | |
| April | -- | 0.05/0.20 | -- |
| May | -- | 0.03/0.22 | -- |
| June | -- | 0.01/0.29 | -- |
| Chipps Island | | | |
| April | -- | -0.04/0.54 | -- |
| May | -- | -0.05/0.82 | -- |
| June | -- | -0.06/0.93 | -- |
| **North Pacific Index (El Nino Index)** | | | |
| Yearly | -0.03/0.95 | -- | -- |
| Three Year Mean | -0.02/0.71 | -- | -- |
| **Harvest At Monterey, San Francisco, and Fort Bragg** | | | |
| 2-yr Commercial | 0.04/0.13 | -- | -- |
| 2-yr Comm & Rec | 0.37/0.00 | -- | -- |

TABLE 3 ADJUSTED-$R^2$ AND PROBABILITY LEVEL FOR CORRELATIONS WITH THE STANISLAUS RIVER RECRUITMENT VARIABLE FROM 1951 TO 1989, 1968 TO 1989, AND 1977 TO 1989

| Variable | Adj-$R^2$/p | | |
|---|---|---|---|
| | 1951-1989 | 1968-1989 | 1977-1989 |
| **Log Streamflow at Vernalis/Total Exports** | | | |
| April | 0.55/0.00 | 0.42/0.00 | 0.42/0.02 |
| May | 0.58/0.00 | 0.39/0.00 | 0.29/0.05 |
| June | 0.62/0.00 | 0.47/0.00 | 0.55/0.01 |
| Apr-Jun Average | 0.61/0.00 | 0.46/0.00 | 0.42/0.02 |
| **Log Streamflow at Vernalis/Export at Banks** | | | |
| April | -- | 0.35/0.00 | 0.40/0.02 |
| May | -- | 0.36/0.00 | 0.32/0.04 |
| June | -- | 0.29/0.01 | 0.44/0.02 |
| **Log Streamflow at Vernalis/Export at Tracy** | | | |
| April | 0.54/0.00 | 0.41/0.00 | 0.41/0.02 |
| May | 0.57/0.00 | 0.38/0.00 | 0.29/0.05 |
| June | 0.60/0.00 | 0.46/0.00 | 0.61/0.00 |
| **Log Streamflow at Chipps Island/Total Exports** | | | |
| April | 0.25/0.00 | 0.17/0.04 | 0.24/0.07 |
| May | 0.24/0.00 | 0.25/0.01 | 0.20/0.10 |
| June | 0.34/0.00 | 0.27/0.01 | 0.28/0.05 |
| Apr-Jun Average | 0.30/0.00 | 0.27/0.01 | 0.29/0.05 |
| **Monthly Streamflow** | | | |
| Ripon | | | |
| March | 0.37/0.00 | -- | -- |
| April | 0.38/0.00 | -- | -- |
| May | 0.26/0.00 | -- | -- |
| June | 0.32/0.00 | -- | -- |
| Mar-May Average | 0.41/0.00 | -- | -- |
| Vernalis | | | |
| April | 0.33/0.00 | -- | -- |
| May | 0.47/0.00 | -- | -- |
| June | 0.53/0.00 | -- | -- |
| Apr-Jun Average | 0.41/0.00 | -- | -- |
| Chipps Island | | | |
| April | 0.32/0.00 | -- | -- |
| May | 0.43/0.00 | -- | -- |
| June | 0.51/0.00 | -- | -- |
| Apr-Jun Average | 0.44/0.00 | -- | -- |
| **Total Exports** | | | |
| April | 0.13/0.02 | -- | -- |
| May | 0.19/0.00 | -- | -- |
| June | 0.22/0.00 | -- | -- |

TABLE 3 (CONTINUED)

| Variable | Adj-$R^2$/p 1951-1989 | 1968-1989 | 1977-1989 |
|---|---|---|---|
| Maximum Stream Temperature | | | |
| Knights Ferry | | | |
| April | -- | 0.24/0.01 | -- |
| May | -- | 0.17/0.04 | -- |
| June | -- | 0.16/0.04 | -- |
| Spring Max | -- | 0.21/0.02 | -- |
| Vernalis | | | |
| April | -- | -- | -0.01/0.39 |
| May | -- | -- | -0.03/0.49 |
| June | -- | -- | 0.01/0.29 |
| Spring Max | -- | -- | -0.04/0.53 |
| Point-In-Time Measurements Of Stream Temperature | | | |
| Chipps Island | | | |
| April | -- | 0.07/0.15 | -- |
| May | -- | 0.10/0.10 | -- |
| June | -- | -0.02/0.44 | -- |
| Spring Max | -- | 0.10/0.10 | -- |
| Dissolved Oxygen | | | |
| Vernalis | | | |
| April | -- | 0.04/0.21 | -- |
| May | -- | 0.02/0.25 | -- |
| June | -- | 0.04/0.20 | -- |
| Chipps Island | | | |
| April | -- | -0.02/0.42 | -- |
| May | -- | 0.02/0.26 | -- |
| June | -- | -0.00/0.35 | -- |
| Turbidity | | | |
| Vernalis | | | |
| April | -- | -0.02/0.40 | -- |
| May | -- | -0.02/0.41 | -- |
| June | -- | 0.02/0.26 | -- |
| Chipps Island | | | |
| April | -- | -0.01/0.40 | -- |
| May | -- | -0.05/0.84 | -- |
| June | -- | -0.06/0.96 | -- |
| North Pacific Index (El Nino Index) | | | |
| Yearly | -0.03/0.90 | -- | -- |
| Three Year Mean | -0.03/0.85 | -- | -- |
| Harvest At Monterey, San Francisco, and Fort Bragg | | | |
| 2-yr Commercial | 0.07/0.07 | -- | -- |
| 2-yr Comm & Rec | 0.37/0.00 | -- | -- |

TABLE 4 ADJUSTED-$R^2$ AND PROBABILITY LEVEL FOR CORRELATIONS WITH THE TUOLUMNE RIVER RECRUITMENT VARIABLE FROM 1951 TO 1989, 1968 TO 1989, AND 1977 TO 1989

| | Adj-$R^2$/p | | |
|---|---|---|---|
| Variable | 1951-1989 | 1968-1989 | 1977-1989 |
| **Log Streamflow at Vernalis/Total Exports** | | | |
| April | 0.68/0.00 | 0.43/0.00 | 0.49/0.00 |
| May | 0.67/0.00 | 0.41/0.00 | 0.43/0.01 |
| June | 0.70/0.00 | 0.46/0.00 | 0.76/0.00 |
| Apr-Jun Average | 0.72/0.00 | 0.46/0.00 | 0.56/0.00 |
| **Log Streamflow at Vernalis/Export at Banks** | | | |
| April | -- | 0.49/0.00 | 0.59/0.00 |
| May | -- | 0.43/0.00 | 0.50/0.00 |
| June | -- | 0.26/0.01 | 0.49/0.00 |
| **Log Streamflow at Vernalis/Export at Tracy** | | | |
| April | 0.65/0.00 | 0.41/0.00 | 0.46/0.01 |
| May | 0.65/0.00 | 0.38/0.00 | 0.40/0.01 |
| June | 0.66/0.00 | 0.44/0.00 | 0.76/0.00 |
| **Log Streamflow at Chipps Island/Total Exports** | | | |
| April | 0.49/0.00 | 0.25/0.01 | 0.45/0.01 |
| May | 0.52/0.00 | 0.37/0.00 | 0.46/0.01 |
| June | 0.64/0.00 | 0.35/0.00 | 0.54/0.00 |
| Apr-Jun Average | 0.60/0.00 | 0.38/0.00 | 0.57/0.00 |
| **Monthly Streamflow** | | | |
| Modesto | | | |
| April | 0.65/0.00 | -- | -- |
| May | 0.54/0.00 | -- | -- |
| June | 0.53/0.00 | -- | -- |
| Apr-Jun Average | 0.63/0.00 | -- | -- |
| Vernalis | | | |
| April | 0.48/0.00 | -- | -- |
| May | 0.61/0.00 | -- | -- |
| June | 0.61/0.00 | -- | -- |
| Apr-Jun Average | 0.56/0.00 | -- | -- |
| Chipps Island | | | |
| April | 0.41/0.00 | -- | -- |
| May | 0.64/0.00 | -- | -- |
| June | 0.68/0.00 | -- | -- |
| Apr-Jun Average | 0.60/0.00 | -- | -- |
| **Total Exports** | | | |
| April | 0.18/0.00 | -- | -- |
| May | 0.27/0.00 | -- | -- |
| June | 0.27/0.00 | -- | -- |

TABLE 4 (CONTINUED)

| Variable | | Adj-$R^2$/p | |
|---|---|---|---|
| | 1951-1989 | 1968-1989 | 1977-1989 |
| Variable | | Adj-$R^2$/p | |
| | 1951-1989 | 1968-1989 | 1977-1989 |
| **Maximum Stream Temperature** | | | |
| Vernalis | | | |
| April | -- | -- | 0.09/0.12 |
| May | -- | -- | 0.02/0.27 |
| June | -- | -- | 0.08/0.14 |
| Spring Max | -- | -- | 0.02/0.26 |
| **Point-In-Time Measurements Of Stream Temperature** | | | |
| Chipps Island | | | |
| April | -- | 0.21/0.02 | -- |
| May | -- | 0.29/0.01 | -- |
| June | -- | -0.00/0.35 | -- |
| Spring Max | -- | 0.29/0.01 | -- |
| **Dissolved Oxygen** | | | |
| Vernalis | | | |
| April | -- | 0.09/0.11 | -- |
| May | -- | -0.01/0.39 | -- |
| June | -- | 0.03/0.21 | -- |
| Chipps Island | | | |
| April | -- | 0.05/0.17 | -- |
| May | -- | -0.01/0.37 | -- |
| June | -- | -0.02/0.43 | -- |
| **Turbidity** | | | |
| Vernalis | | | |
| April | -- | 0.11/0.09 | -- |
| May | -- | 0.06/0.14 | -- |
| June | -- | 0.01/0.30 | -- |
| Chipps Island | | | |
| April | -- | -0.04/0.57 | -- |
| May | -- | -0.04/0.68 | -- |
| June | -- | -0.05/0.85 | -- |
| **North Pacific Index (El Nino Index)** | | | |
| Yearly | -0.03/0.96 | -- | -- |
| Three Year Mean | -0.03/0.83 | -- | -- |
| **Harvest At Monterey, San Francisco, and Fort Bragg** | | | |
| 2-yr Commercial | 0.02/0.17 | -- | -- |
| 2-yr Comm & Rec | 0.33/0.00 | -- | -- |

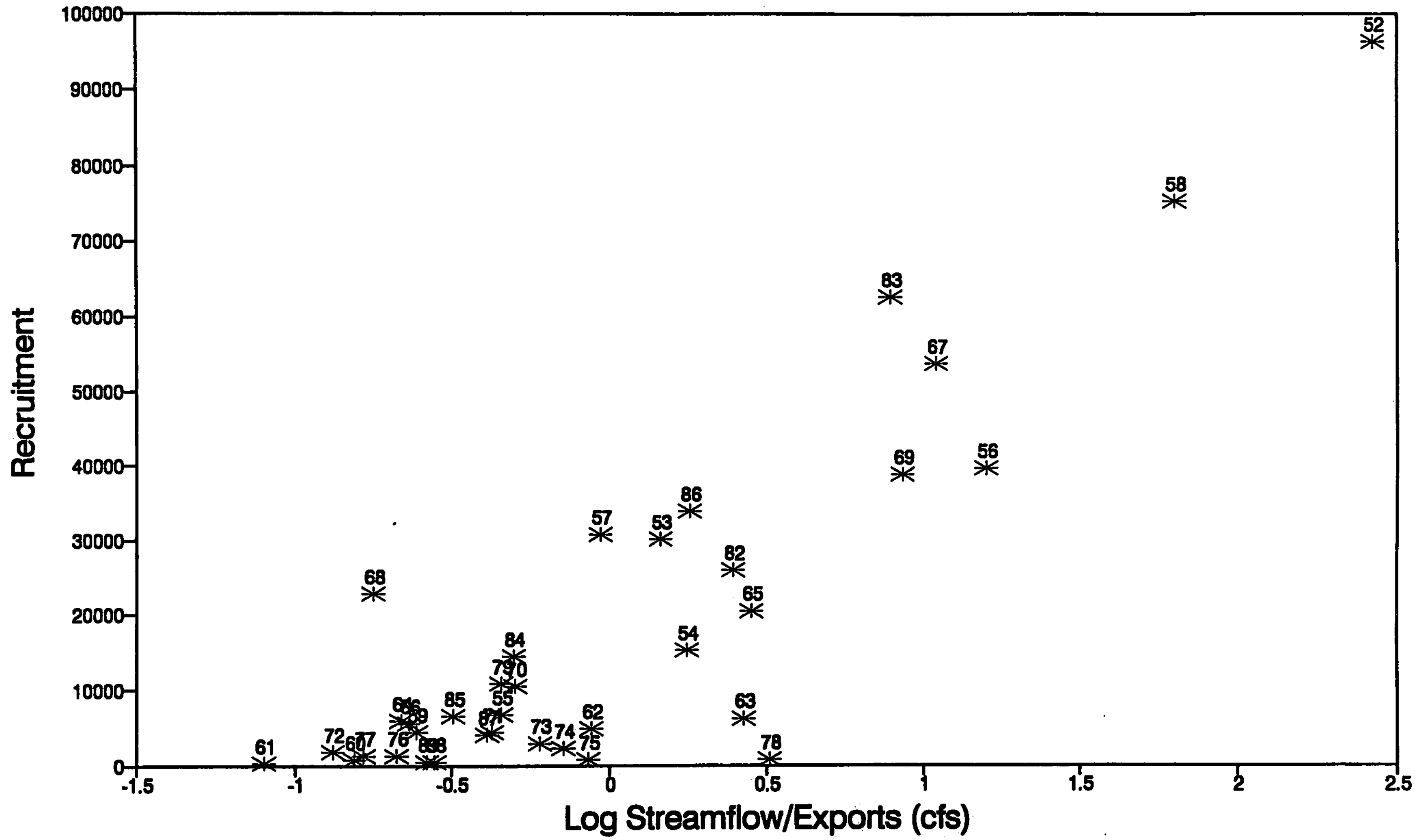


Figure 1. Number of two- and three-year-old chinook salmon of the same cohort that returned to spawn in the Stanislaus and Tuolumne rivers combined (Recruitment) versus the log of the ratio of streamflow in the San Joaquin River in the vicinity of Vernalis to total Delta exports at the State and Federal pumping facilities from April through June during the year when each salmon cohort migrated through the Delta as smolts from 1951 to 1989. When the log of the ratio of streamflow to exports equals zero, then total exports equal the streamflow at Vernalis. Data points are identified according to the year when the fish were juveniles (smolts).

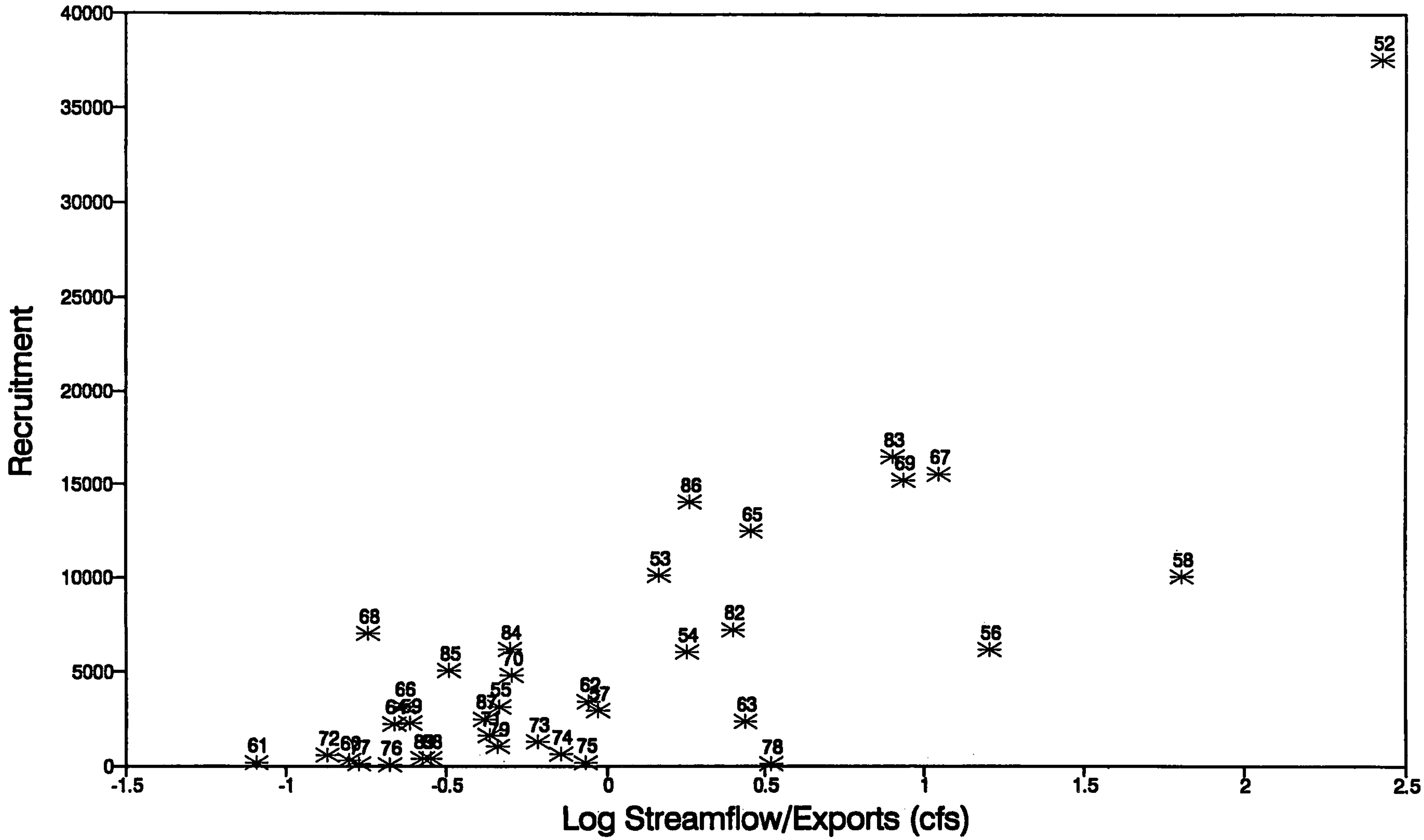


Figure 2. Number of two- and three-year-old chinook salmon of the same cohort that returned to spawn in the Stanislaus River (Recruitment) versus the log of the ratio of streamflow in the San Joaquin River in the vicinity of Vernalis to total Delta exports at the State and Federal pumping facilities from April through June during the year when each salmon cohort migrated through the Delta as smolts from 1951 to 1989. When the log of the ratio of streamflow to exports equals zero, then total exports equal the streamflow at Vernalis. Data points are identified according to the year when the fish were juveniles (smolts).

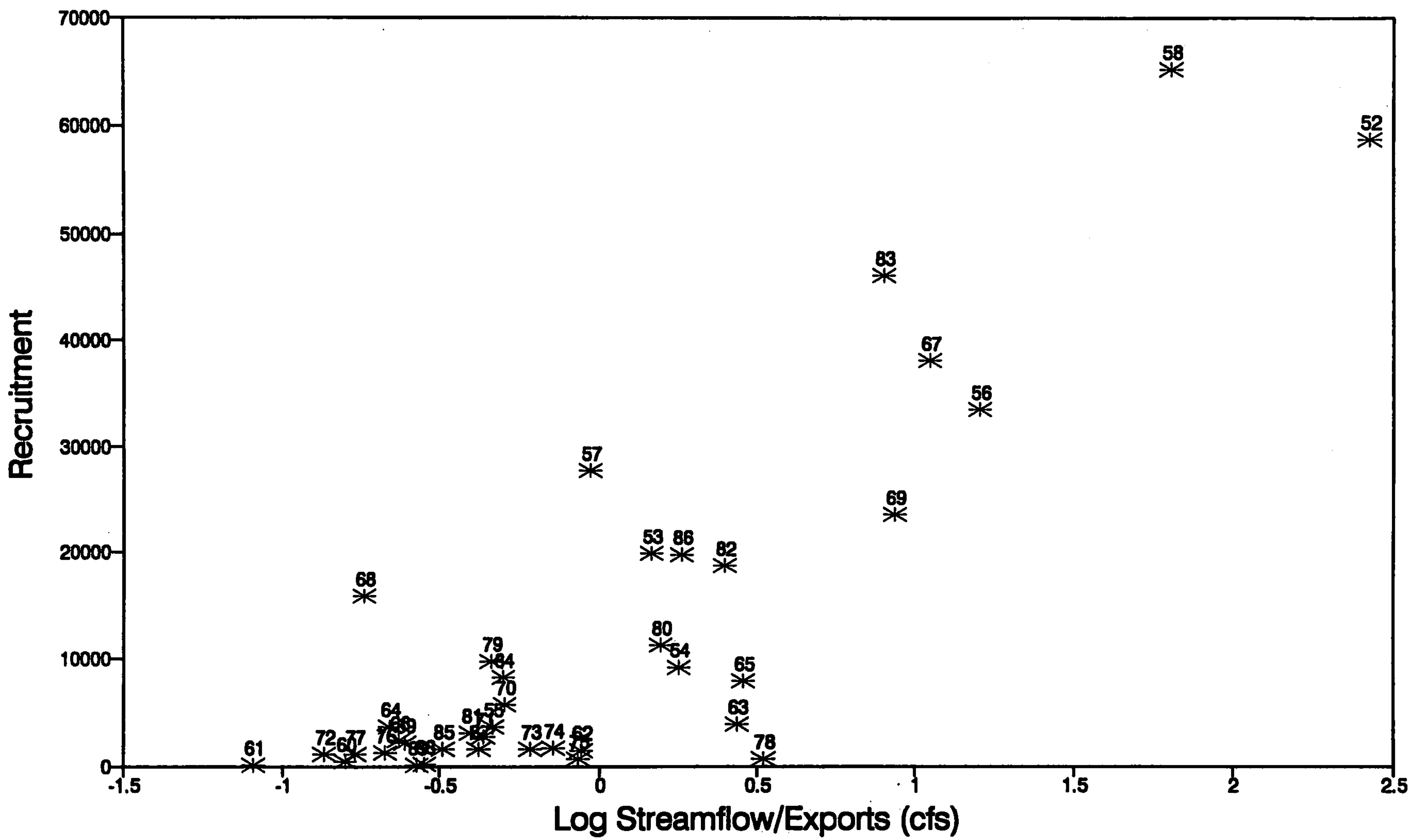


Figure 3. Number of two- and three-year-old chinook salmon of the same cohort that returned to spawn in the Tuolumne River (Recruitment) versus the log of the ratio of streamflow in the San Joaquin River in the vicinity of Vernalis to total Delta exports at the State and Federal pumping facilities from April through June during the year when each salmon cohort migrated through the Delta as smolts from 1951 to 1989. When the log of the ratio of streamflow to exports equals zero, then total exports equal the streamflow at Vernalis. Data points are identified according to the year when the fish were juveniles (smolts).

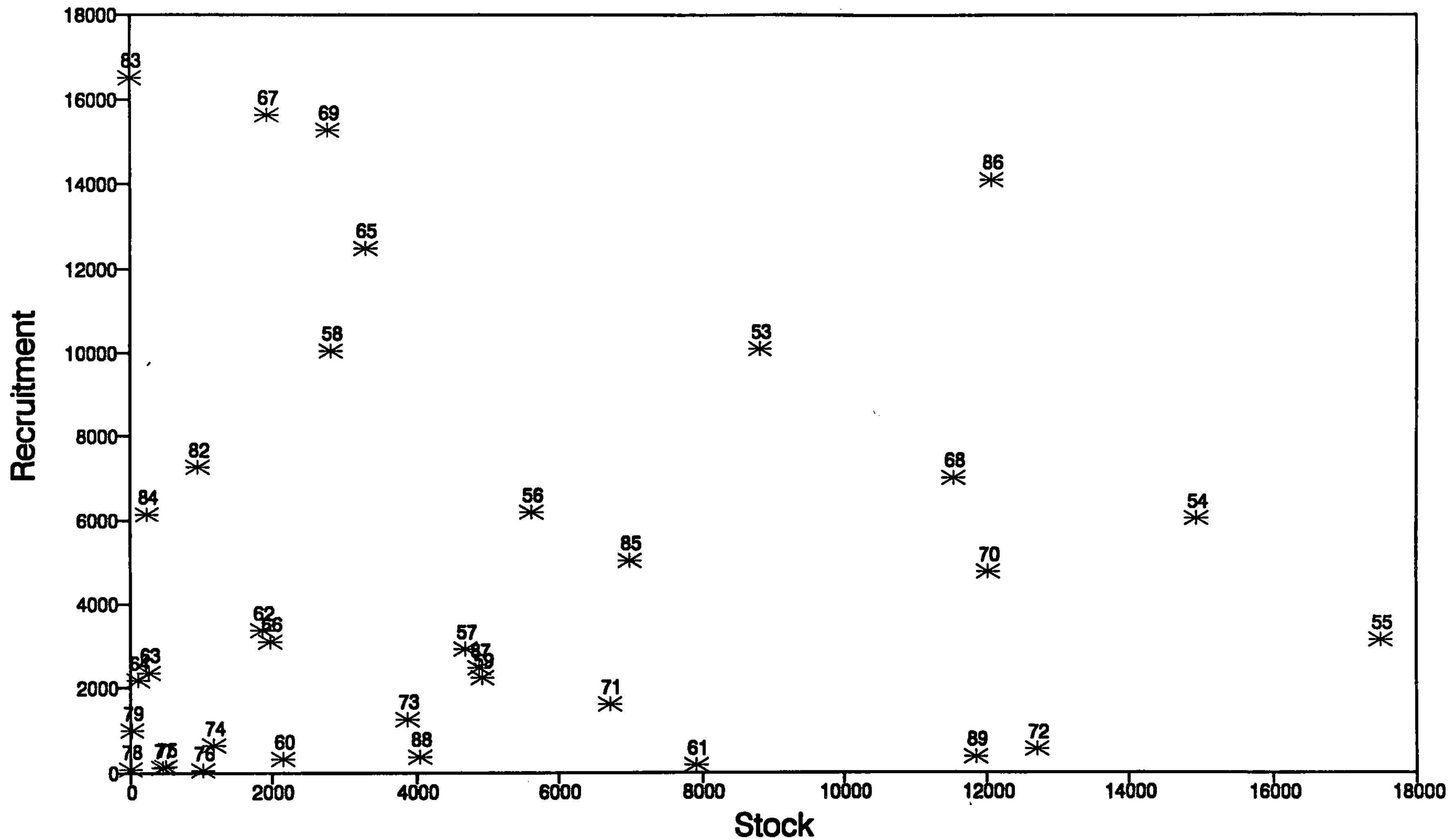


Figure 4. Number of two- and three-year-old chinook salmon of the same cohort that returned to spawn (Recruitment) versus the number of spawners that produced those cohorts (Stock) from 1953 to 1989 in the Stanislaus River. Data points are identified according to the year when the fish in the Production cohorts were juveniles (one-year-olds).

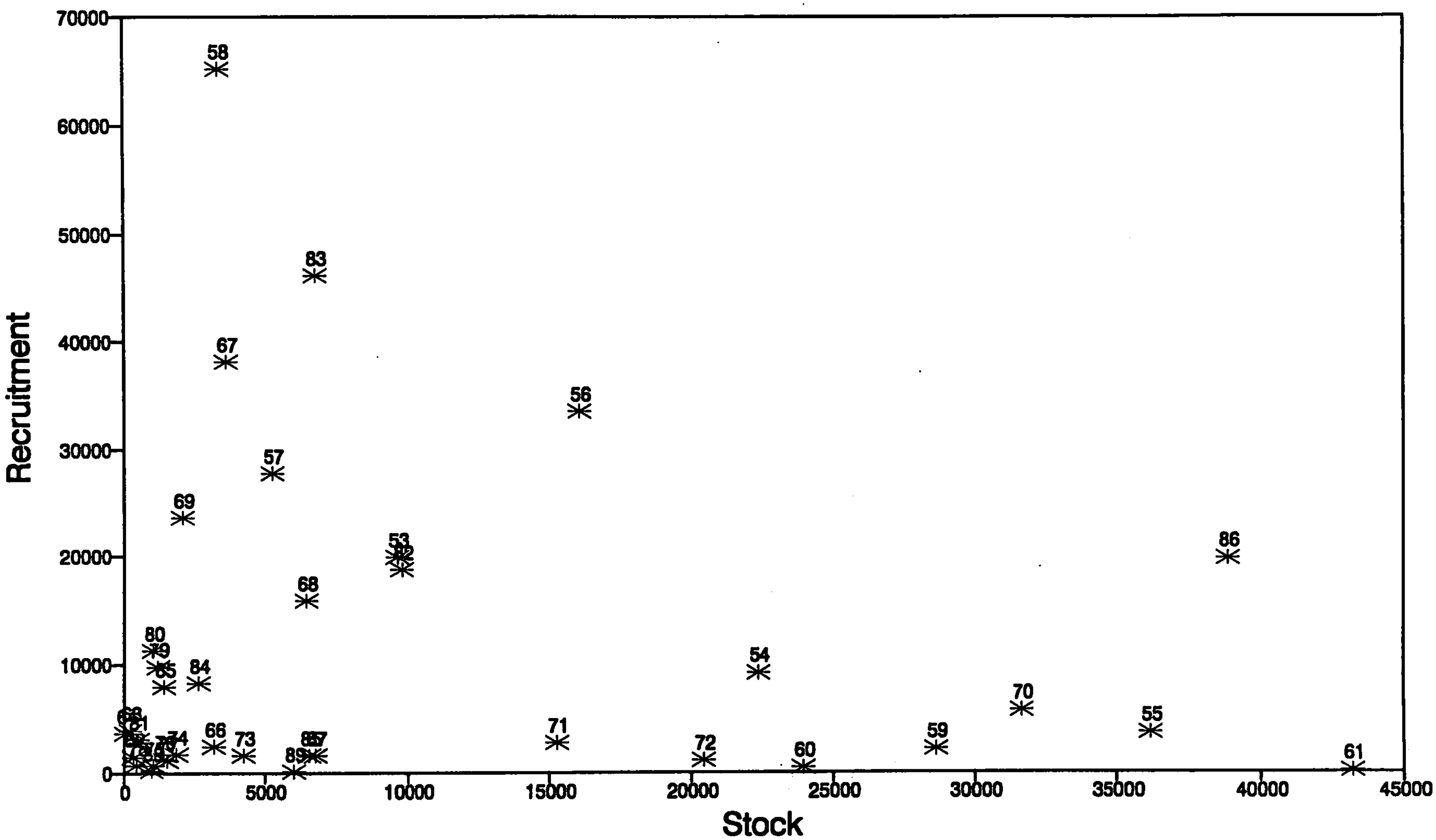


Figure 5. Number of two- and three-year-old chinook salmon of the same cohort that returned to spawn (Recruitment) versus the number of spawners that produced those cohorts (Stock) from 1953 to 1989 in the Tuolumne River. Data points are identified according to the year when the fish in the Production cohorts were juveniles (one-year-olds).

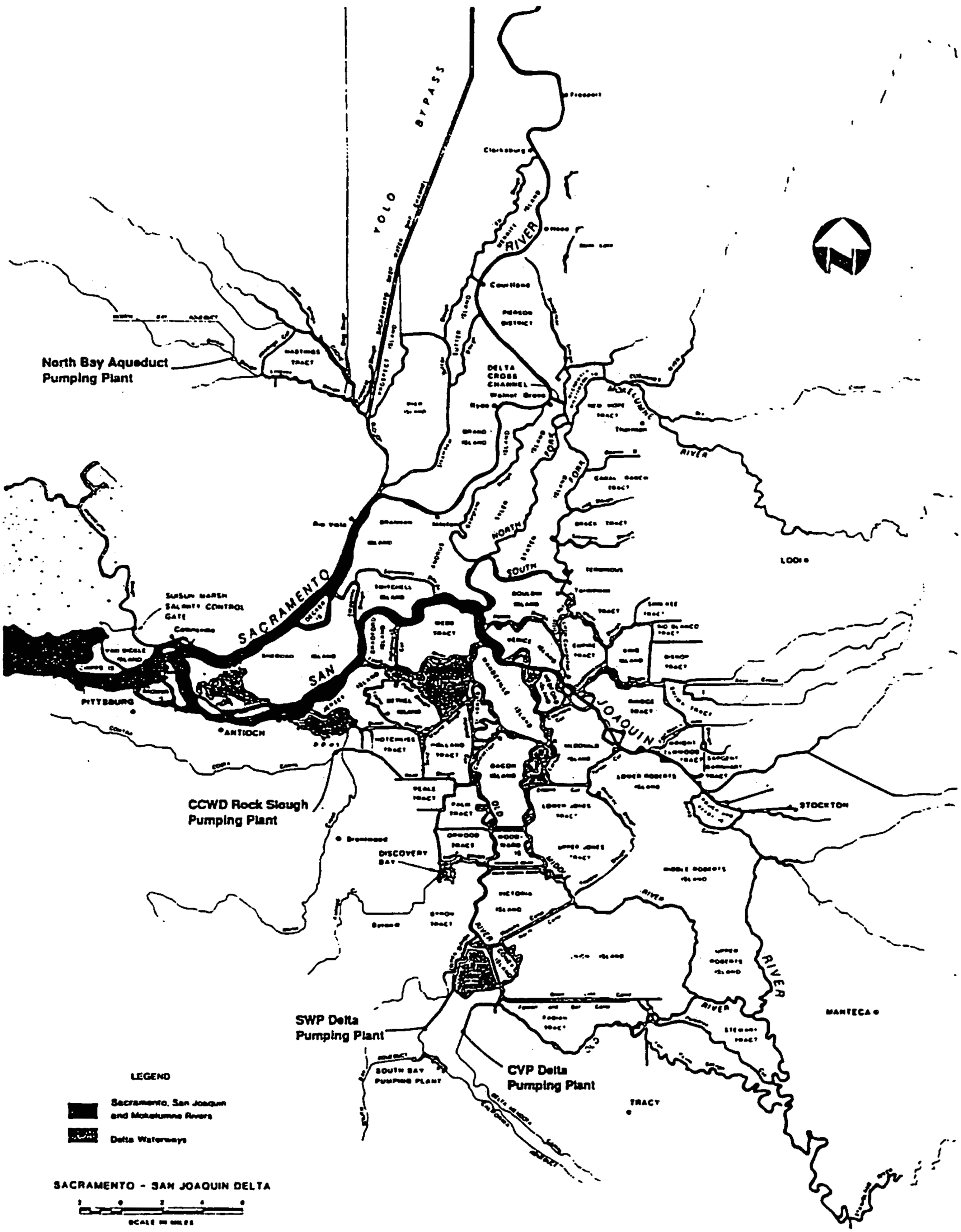


Figure 6. The Sacramento-San Joaquin Delta showing the location of the Delta Cross Channel and the State and Federal pumping facilities. Reproduced with permission from the U.S. Fish and Wildlife Service.

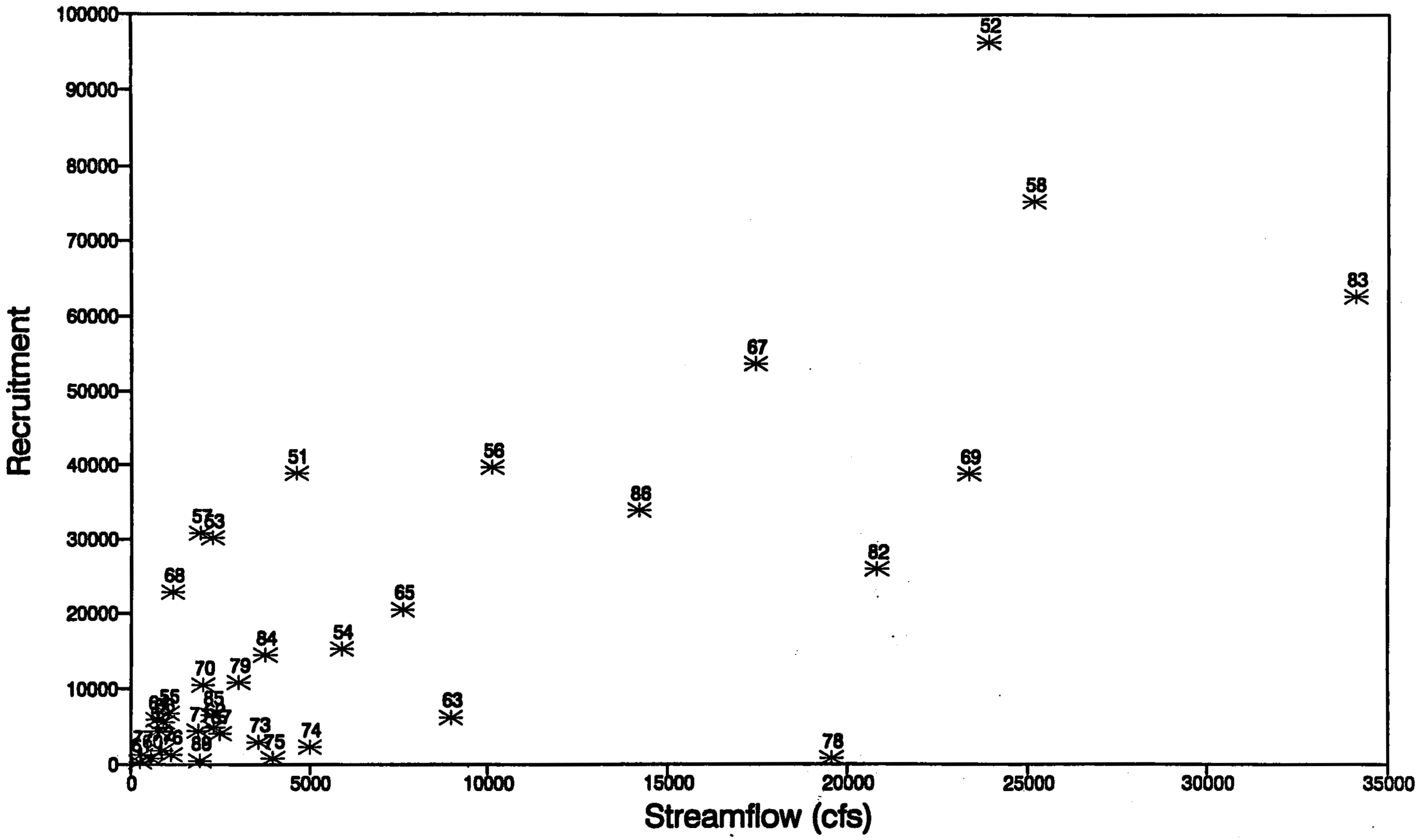


Figure 7. Number of two- and three-year-old chinook salmon of the same cohort that returned to spawn in the Stanislaus and Tuolumne rivers combined (Recruitment) versus the average streamflow from April through June in the San Joaquin River in the vicinity of Vernalis during the year when each salmon cohort migrated through the Delta as smolts from 1951 to 1989. Data points are identified according to the year when the fish were smolts.

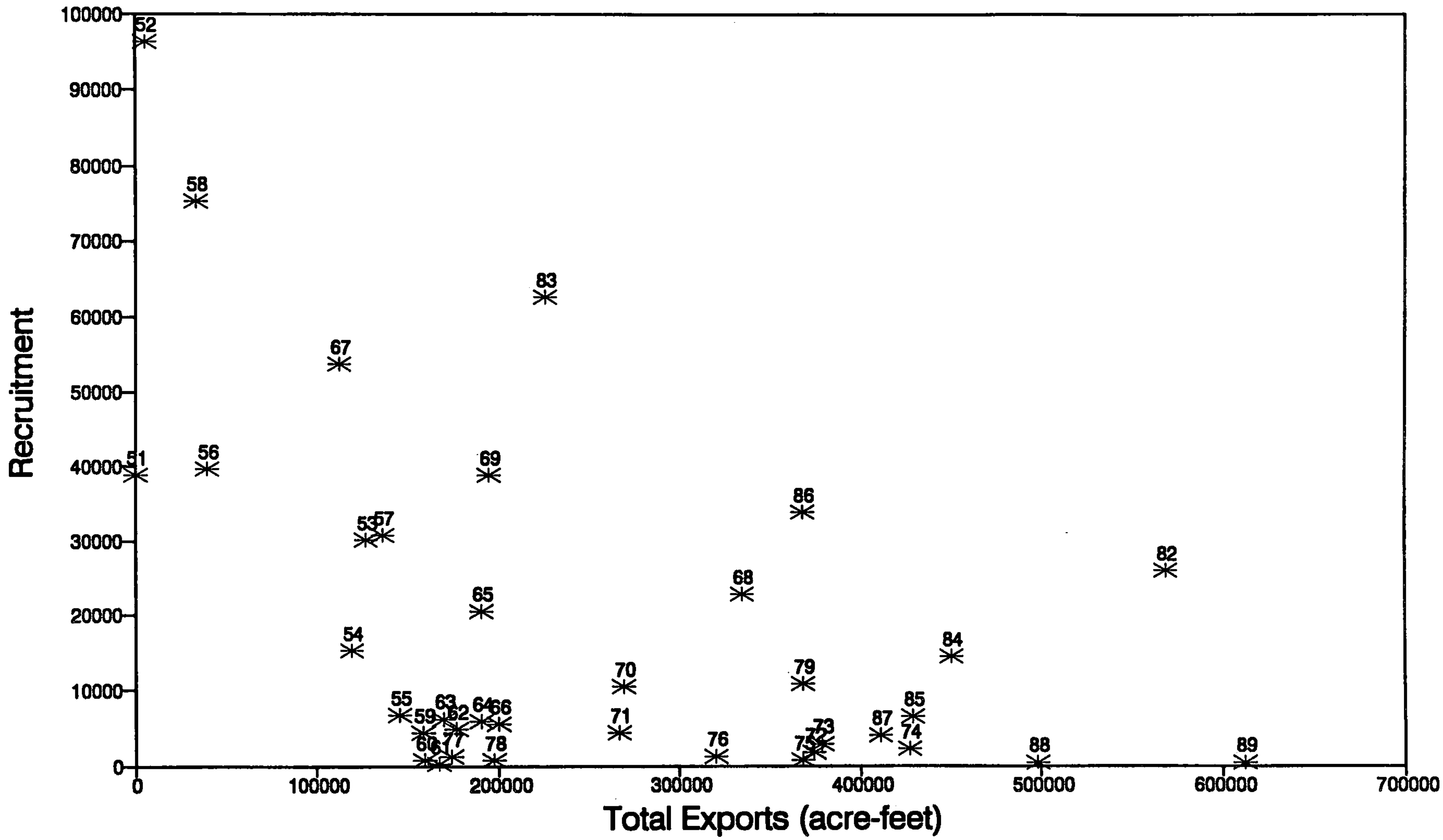


Figure 8. Number of two- and three-year-old chinook salmon of the same cohort that returned to spawn in the Stanislaus and Tuolumne rivers combined (Recruitment) versus the maximum monthly Delta exports at the State and Federal pumping facilities combined that occurred from April through June during 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 were smolts.