WRINT-DFG-Exhibit 2

# A RE-EXAMINATION OF FACTORS AFFECTING STRIPED BASS ABUNDANCE IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

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## Executive Summary

Over the past three decades, the striped bass population of the Sacramento-San Joaquin Estuary has experienced a severe decline. The population of about 3 million adult bass in the early 1960's has eroded to less than 600,000 naturally produced fish in 1990. Concurrently, young-of-the-year striped bass abundance suffered an erratic but persistent decline from high index levels sometimes exceeding 100 in the mid-1960's to the all time low of only 4.3 in 1990. Since 1977, average abundance of young striped bass has been less than one-third of previous average levels.

Substantial effort has gone into evaluating factors responsible for the decline in striped bass abundance. This effort has centered on the concept that for the population to decline, there must be a decrease in its birth and/or increase in its death rates. In brief, our explanation of the striped bass decline is that there has been an increase in death rate (decrease in the survival rate) predominately during the first year of life and caused mainly by increased losses of fish entrained in water exports by the State and Federal Water Projects. This has led to a lower adult striped bass population which is producing fewer eggs (lower birth rate) and that, in turn, is producing fewer young fish and subsequently even fewer adults.

More specifically regarding the decline in young bass abundance, during Phase I of these hearings we explained that since 1977, based on the abundance index at the 38-mm stage, young striped bass abundance has consistently fallen below expectations based on the relationship between their abundance, outflows and water diversion rates from 1959-1976. This relationship is the basis for the striped bass outflow standards and water export limitations mandated in Decision 1485. Given this lower production of young bass and its implication that Decision 1485 standards and limitations are inadequate, it is important to determine why young bass are now less abundant. Fundamentally, young bass abundance

could have declined for one of three reasons: 1) the mechanism(s) causing the relationship between abundance, outflow and water diversions have changed, resulting in lower survival at any given combination of outflow and diversion rates, 2) mechanisms and striped bass response have not changed (survival of young bass still varies as predicted), but the decline is solely due to the reduced numbers of eggs being spawned, and 3) some combination of 1) and 2).

The only potential reason for the decline in young striped bass abundance consistent with the population data is that egg production has declined substantially (see first paragraph). Survival between the egg and 38-mm stage has not declined relative to outflows and water exports. Since 1977, survival has varied, depending on outflows and water exports, in the same manner as before 1977. The resultant explanation is that the decline of young bass at any given outflow/diversion combination can only be attributable to fewer eggs produced by fewer adults.

Lower recruitment of new 3-year old fish has been the major cause of the declining abundance of adults. This lower recruitment accounts for about three-quarters of the adult bass decline while the estimated annual survival rate of the adults themselves accounts for the remaining quarter. Evidence in WRINT-DFG-Exhibit 3 reveals that recruitment has been reduced by losses of young bass to water diversions both before and after the 38-mm stage.

Significant evidence, critical to the current State Water Resources Control Board deliberations is that substantially increased losses of fish occurred when exports increased due to initiation of the State Water Project and the San Luis Project during the 1970's. After an appropriate lag period, the adult striped bass population declined and it has subsequently failed to rebound. The process described above (lower recruitment, fewer adults, fewer eggs, fewer young, lower recruitment, etc.) has led to the historic low population estimate of only 590,000 naturally produced (total adults minus hatchery stocked fish) adult fish in 1990, and strong incrimination of water project operations as the root cause of the striped bass population decline.

We do not want to imply that other factors such as toxicity or illegal fishing are not potentially significant mortality sources that warrant evaluation, enforcement and correction. Such factors will continue to cause striped bass mortality as in the past and may account for some of the annual variability in the abundance measures unexplained by our model. The evidence, however, is that effects of these other factors have not changed in the persistent manner and magnitude required to account for the major downward trend in striped bass abundance.

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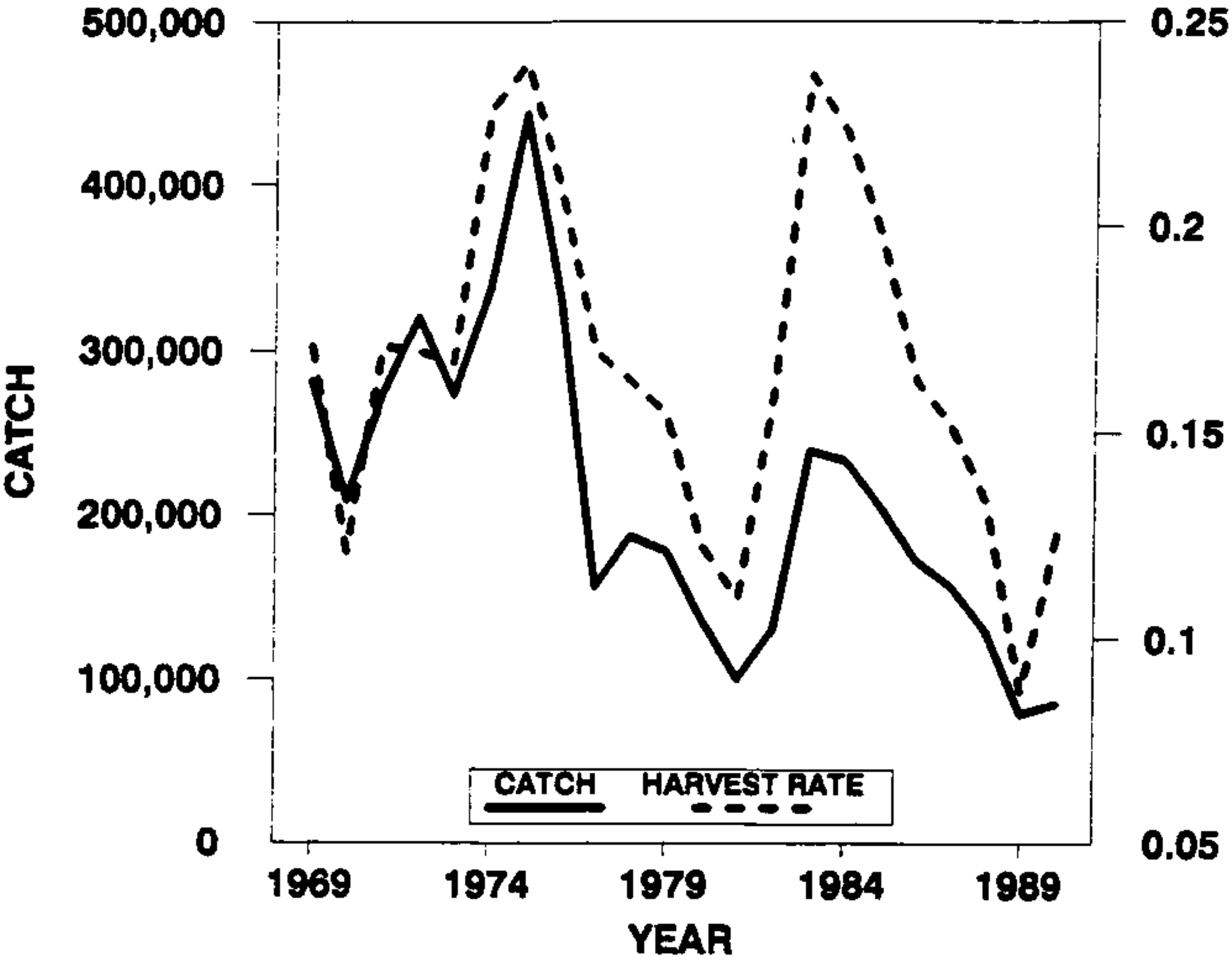

Figure 1. Trend in recreational catch and harvest rate of striped bass in the Sacramento-San Joaquin Estuary, 1969-1990

Angler surveys indicated that about 1.5 million angler days were expended fishing for striped bass in the early 1970's. Such information is not available for more recent years.

The annual recreational value of the striped bass fishery has been estimated to exceed 45 million dollars (Meyer Resources 1985).

## Status of the Striped Bass Population and Its Fishery.

Based on mark-recapture population estimates, the number of legal sized (18" or larger) adult striped bass fell to a record low of approximately 680,000 fish in 1990 (Figure 2). This estimate includes approximately 90,000 fish that were raised in hatcheries and stocked into the estuary as yearlings 2 or more years earlier. Thus, the 1990 estimate for naturally produced fish is only about 590,000 fish. The preliminary abundance estimates of 1.2 million total adult striped bass and 960,000 naturally produced adult bass in 1991 are considerably greater than those for 1990, but the 1991 estimates are not as reliable because the estimates for age 3 fish, the most numerous age group, make up about one-half of the total estimates and they are based on an inadequate recapture sample of only two tags during the entire fall creel census. This recapture sample has resulted in a statistical confidence interval of ± 98 percent around the age 3 population estimate for 1991--a much wider interval than on any other estimate (Figure 3). Age 3 fish are the 1988 year class which, when young, provided the second lowest abundance index (4.6) of the record which extends back to 1959. Thus, based on the available information, it is not rational to conclude that a population recovery is in progress. Unless proven otherwise by additional data that will be obtained over the next several years, a more reasonable conclusion is that the 1991 population is at about the same level as the 1990 population.

These current estimates of the adult striped bass population represent a decline from about 1 million bass in the 1980's and 1.7 million bass in the late-1960's and early 1970's when the mark-recapture estimates were initiated. Data from the fishery indicate that the population was probably about 3 million fish in the early-1960's.

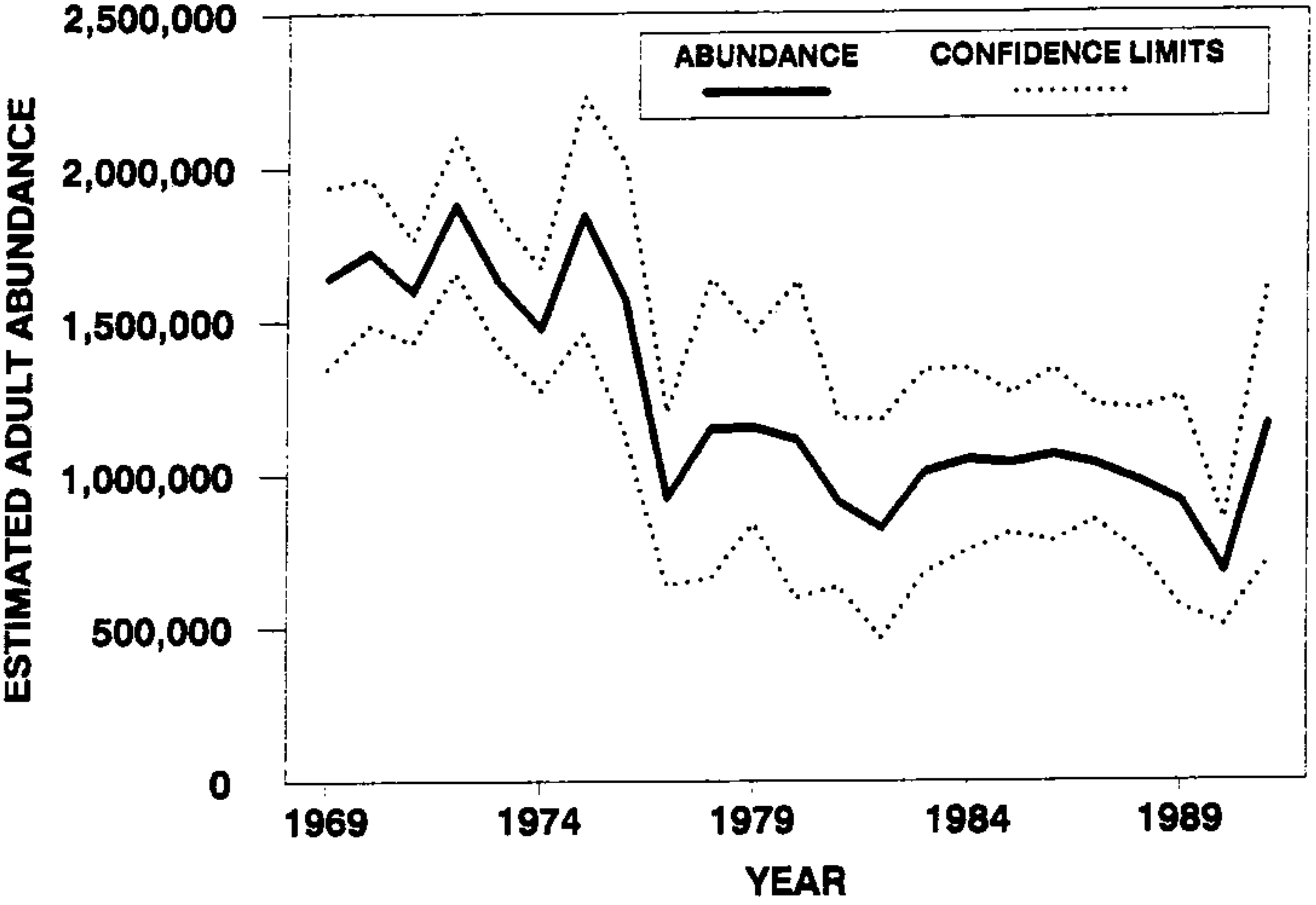

Figure 2. Trend in mark-recapture estimates of adult striped bass abundance in the Sacramento-San Joaquin Estuary, 1969-1991.

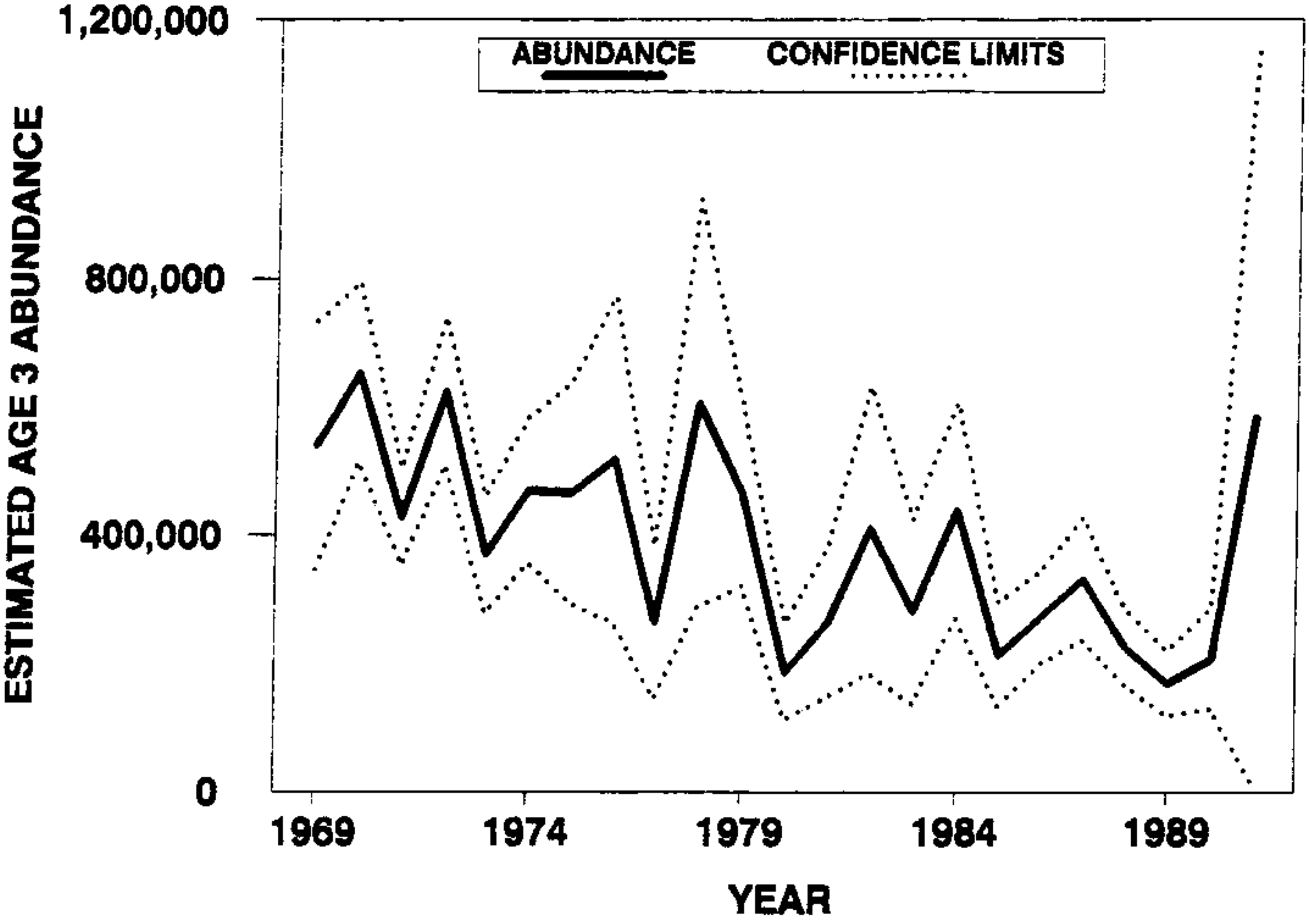

Figure 3. Trend in mark-recapture estimates of age 3 striped bass abundance in the Sacramento-San Joaquin Estuary, 1969-1991.

The adult striped bass population decline primarily reflects a decline in the number of new fish reaching the legal size. Estimates of the abundance of 3-year old fish, which are the youngest and most numerous component of the adult population, have been declining and were at record lows in 1990 (Figure 3). The unreliable preliminary estimate for age 3 fish in 1991 is an aberration in the declining trend, and as already discussed, should not be given credence.

The lower recruitment of 3-year old fish accounts for 76 percent of the adult bass decline (Table 1) when the estimated annual survival rate (Figure 4) is assumed for adults. The remaining 24 percent of the decline is then due to the changes in estimated survival of the adults themselves.

There also has been an irregular but steady decline in production of young striped bass that extends back to the mid-1960's (Figure 5). As measured by the DFG's annual summer tow net survey which was initiated in 1959, the peak abundance of young bass occurred in 1965 when the index was 117.2. The four lowest indices of record have occurred from 1988 to 1991 when the average index was 4.9. The record low was an index of 4.3 in 1990. Since 1977, the average abundance index for young bass has been 19.4. From 1959 to 1976, the average was 66.6.

The declining striped bass population has resulted in a substantial decline in take by anglers which harvest about 10 to 24 percent of the population in most years (Figure 1). Such harvest rates are considered safe for healthy striped bass populations and compare with rates which exceeded 40% on Atlantic Coast populations for many years (National Marine Fisheries Service and U.S. Fish and Wildlife Service 1984).

Based on multiplying abundance estimates by harvest rate, catch ranged from about 200,000 to more than 400,000 fish in the early to mid-1970's. Subsequently annual catch has ranged from about 100,000 to 200,000 fish with the estimates for 1989 and 1990 at the low end of this range. Assuming a population of 3 million bass and the estimated harvest

Table 1. Relative contribution of decreases in recruitment and adult survival to the decline of adult striped bass abundance in the Sacramento-San Joaquin Estuary. Adult bass abundance was simulated from 1969 to 1991 by 1) holding recruitment fixed at 1 million age 3 fish and allowing annual survival rate to vary in the manner observed over this period and 2) holding survival rate constant at 0.55 and allowing recruitment to vary in the manner observed over this period. Predicted rates of decrease are the slopes of regressions of abundance on year from these simulations.

| Recruitment | Adult Survival | Predicted Rate of Decrease (number/year) | Percent of Total Rate of Decrease |
|---|---|---|---|
| Fixed @ 1 million[1] | Estimated | -16874 | 24% |
| Estimated | Fixed @ 0.55[2] | -53588 | 76% |
| | Total | -70462 | 100% |

[1] One million is the average estimated number of age 3 recruits from 1969 to 1976 when adult striped bass abundance averaged 1.7 million.

[2] Estimated annual survival rate of 0.55 is the average from 1969 to 1976 when adult striped bass abundance averaged 1.7 million.

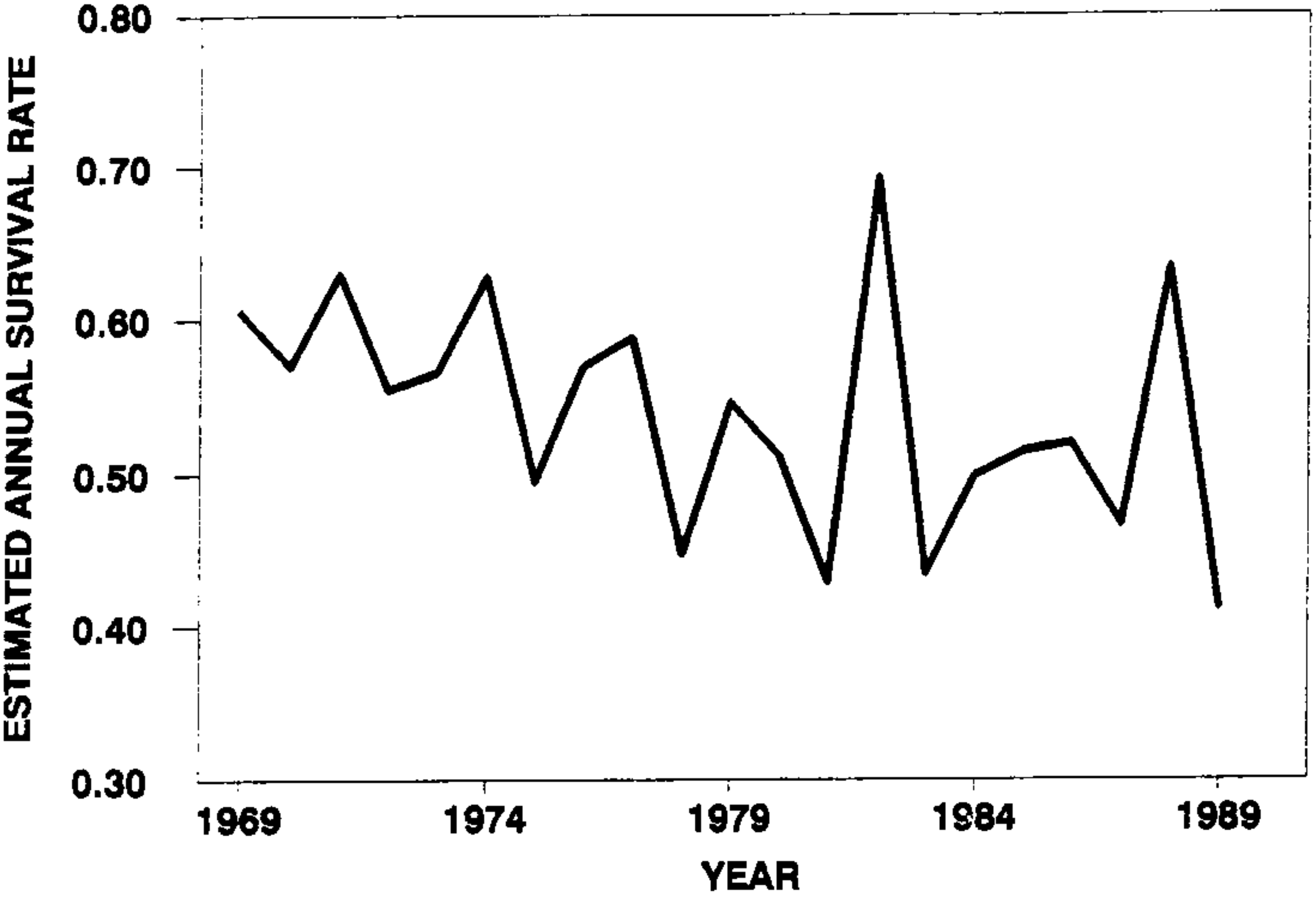

Figure 4. Trend in estimated survival of adult striped bass in the Sacramento-San Joaquin Estuary.

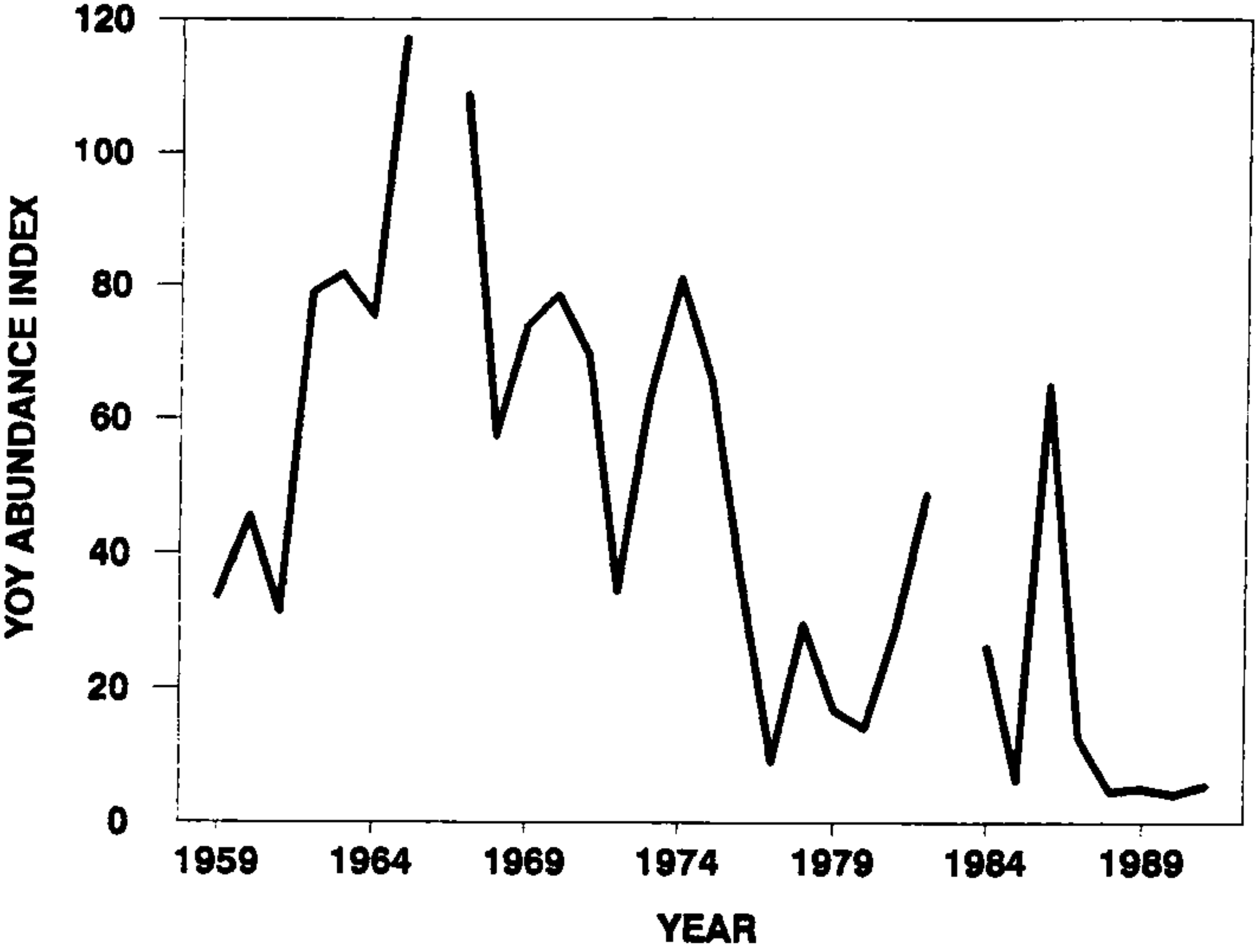

Figure 5. Trend in young striped bass abundance in the Sacramento-San Joaquin Estuary when mean length is 38 mm. Abundance index is based on catches of young bass during an annual tow net survey from 1959-1991.

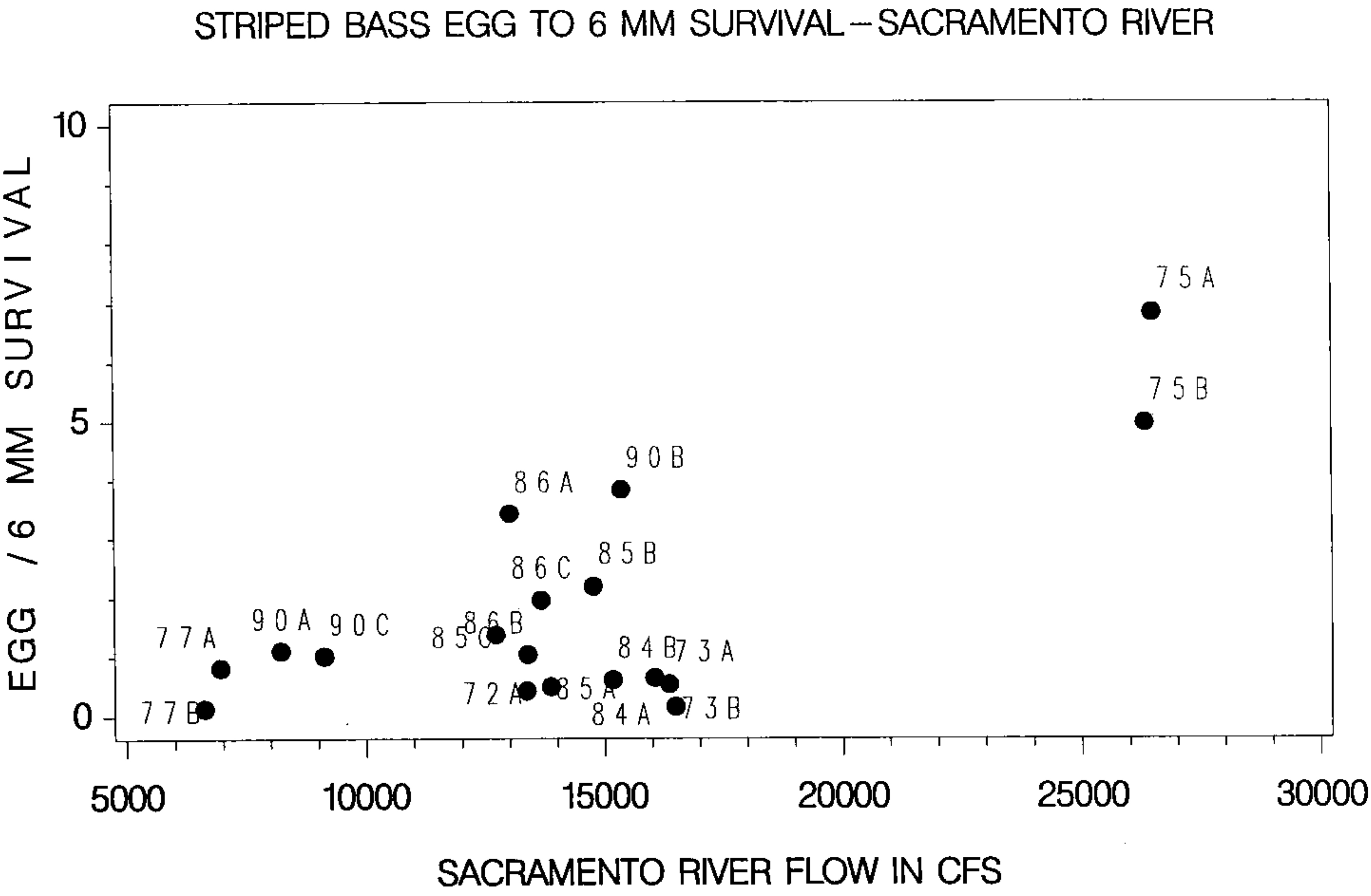

Figure 6. Survival of striped bass from egg to 6 mm larva stage in relation to Sacramento River flow at Sacramento. Survival index is based on egg abundance in the river above Sacramento and the abundance of 6 mm larvae downstream to Collinsville.

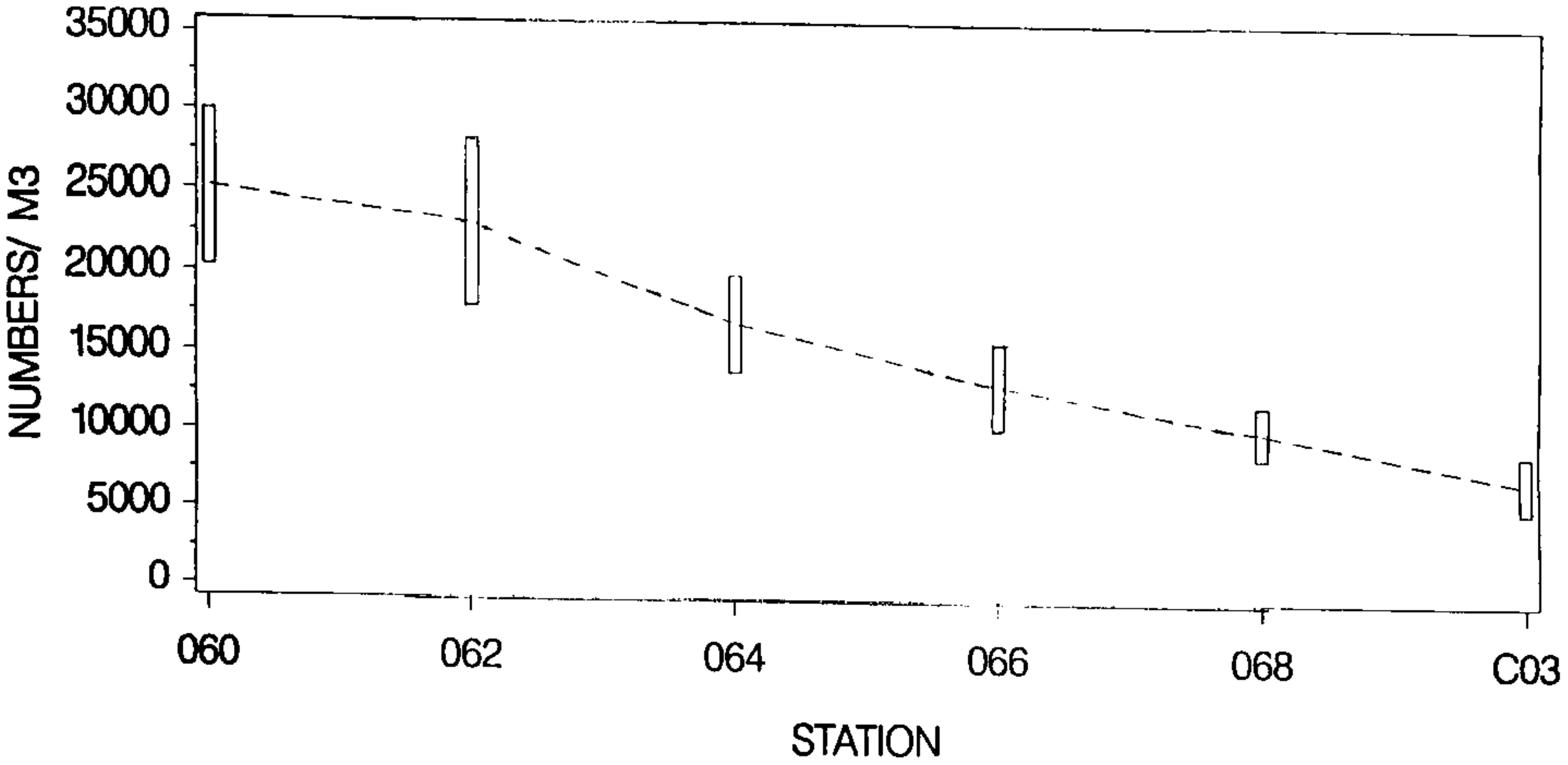

Figure 7. The mean concentration of crustacean zooplankton sampled in the Sacramento River above and below Rio Vista by the Neomysis-zooplankton survey. Only years when station C03 was sampled were included. These years are: 1973, 1974, 1978-1981, 1984, 1988-1990. Station C03 is located near Hood. Stations 60 and 68 are located in the reach from Collinsville to Rio Vista with station 68 at Rio Vista. The bars represent 2 standard errors around the mean concentration.

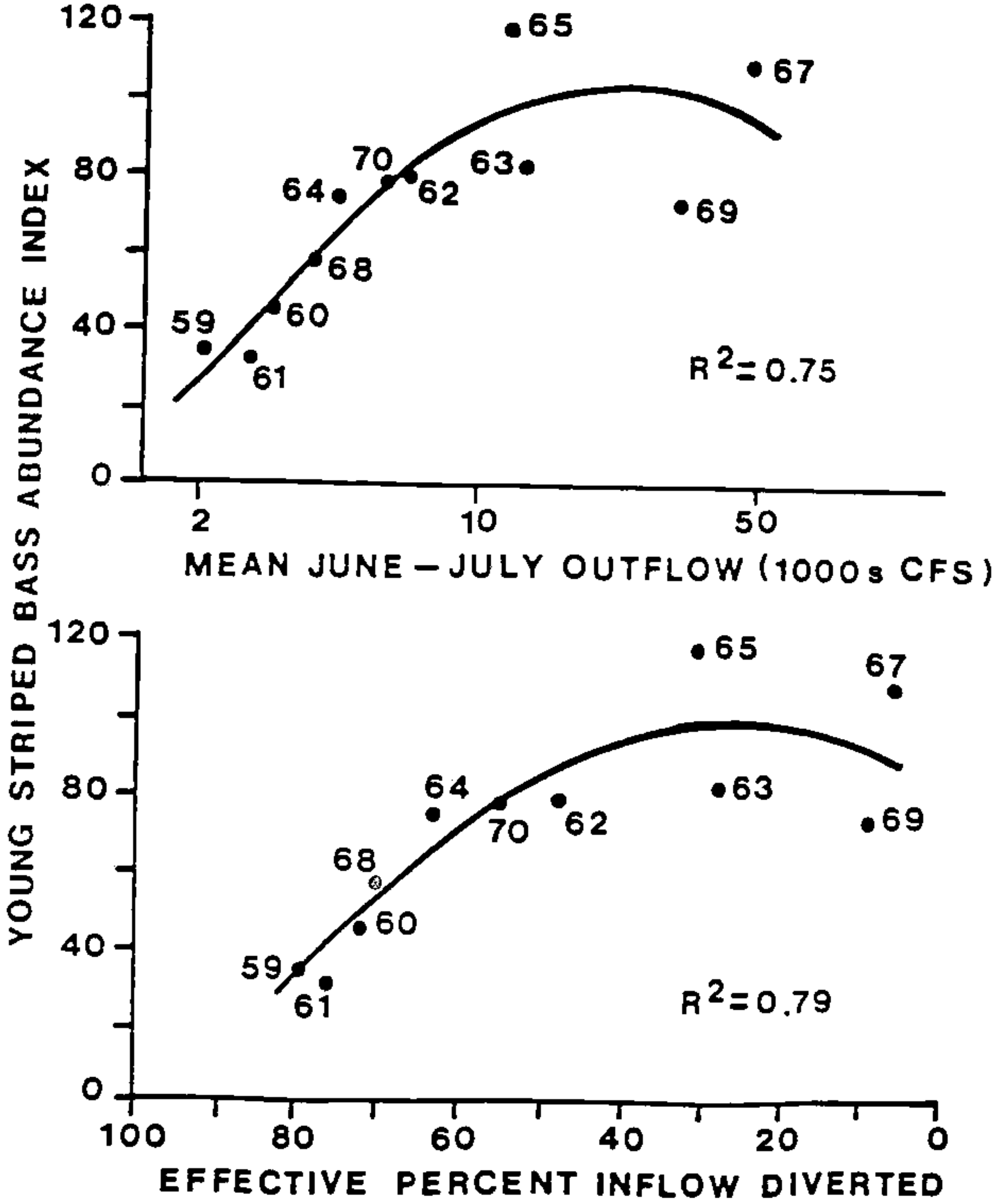

Figure 10. Relationship between total abundance of young striped bass in the Sacramento-San Joaquin Estuary and Delta outflow and diversions from 1959-1979. In years when outflow was high and percent of river inflow diverted was low, the striped bass index was high; conversely, when outflows were low and the percent diverted was high, the young striped bass index was low. Effective percent inflow diverted is the portion of Delta inflow diverted for internal use and exports, except that the portion of the San Joaquin River inflow not reaching the western/central Delta is not included in the calculations.

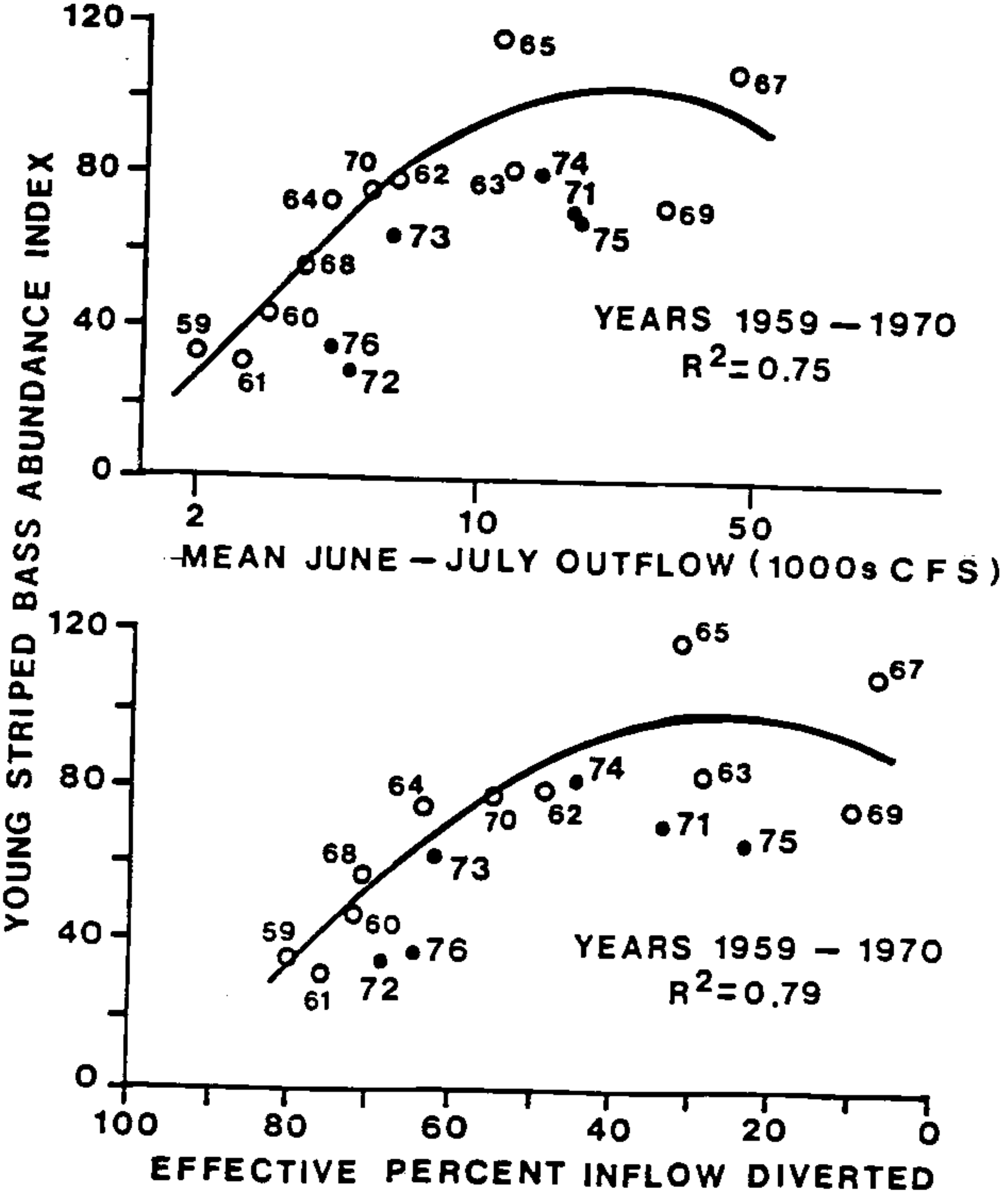

Figure 11. Relationship between total abundance of young striped bass in the Sacramento-San Joaquin Estuary and Delta outflow and diversions, 1959-1976. Curves are fits to 1959-1970 data. In the early to mid-1970s, young bass abundance was consistently lower than expected based on the 1959-1970 relationships of abundance with outflow and abundance with percent diverted. This decline in abundance occurred primarily in the Delta portion of the estuary. Effective percent inflow diverted is the portion of Delta inflow diverted for internal use and exports, except that the portion of the San Joaquin River inflow not reaching the western/central Delta is not included in the calculations.

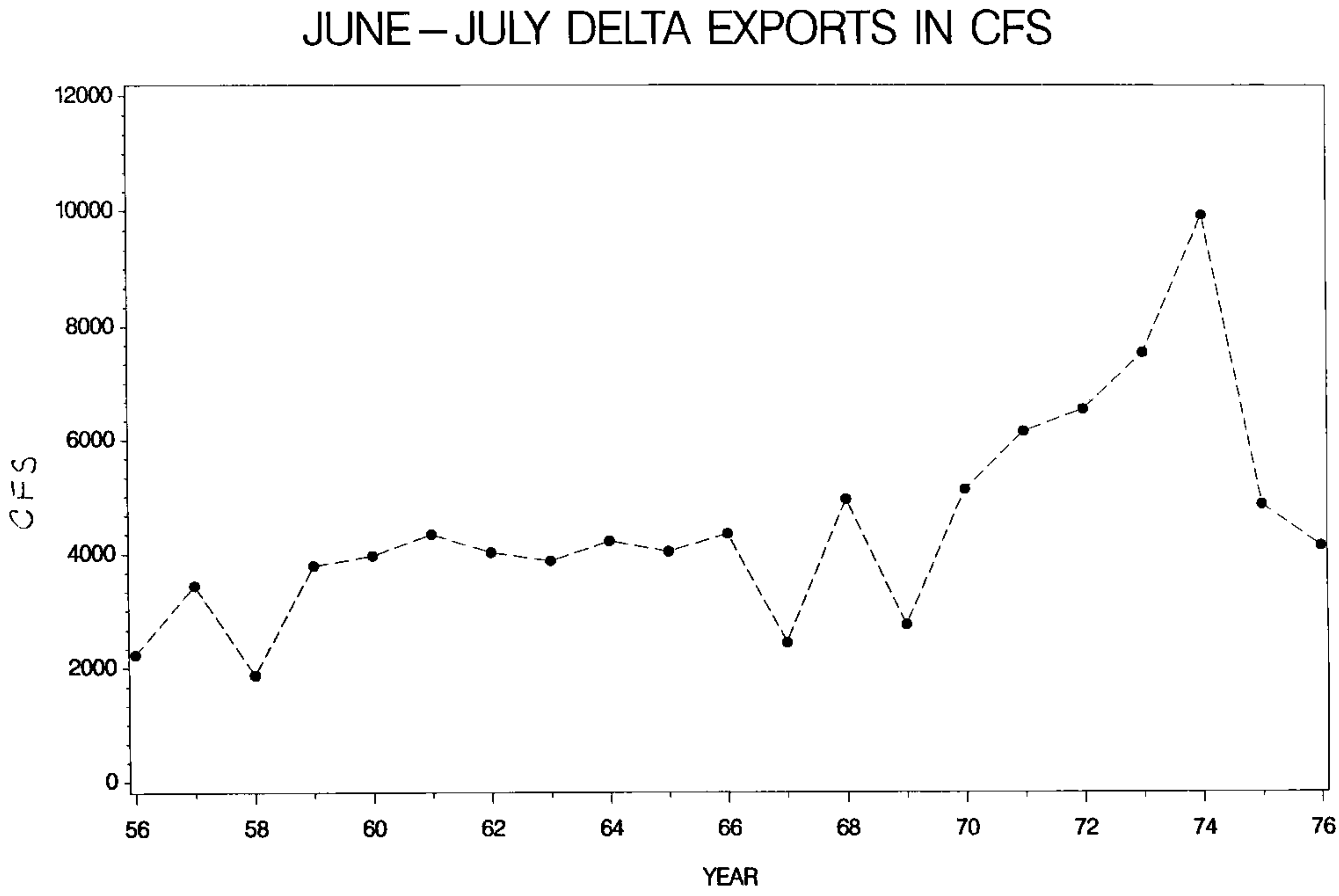

Figure 12. Mean total June-July CVP and SWP Delta water exports in cfs from 1956-1976.

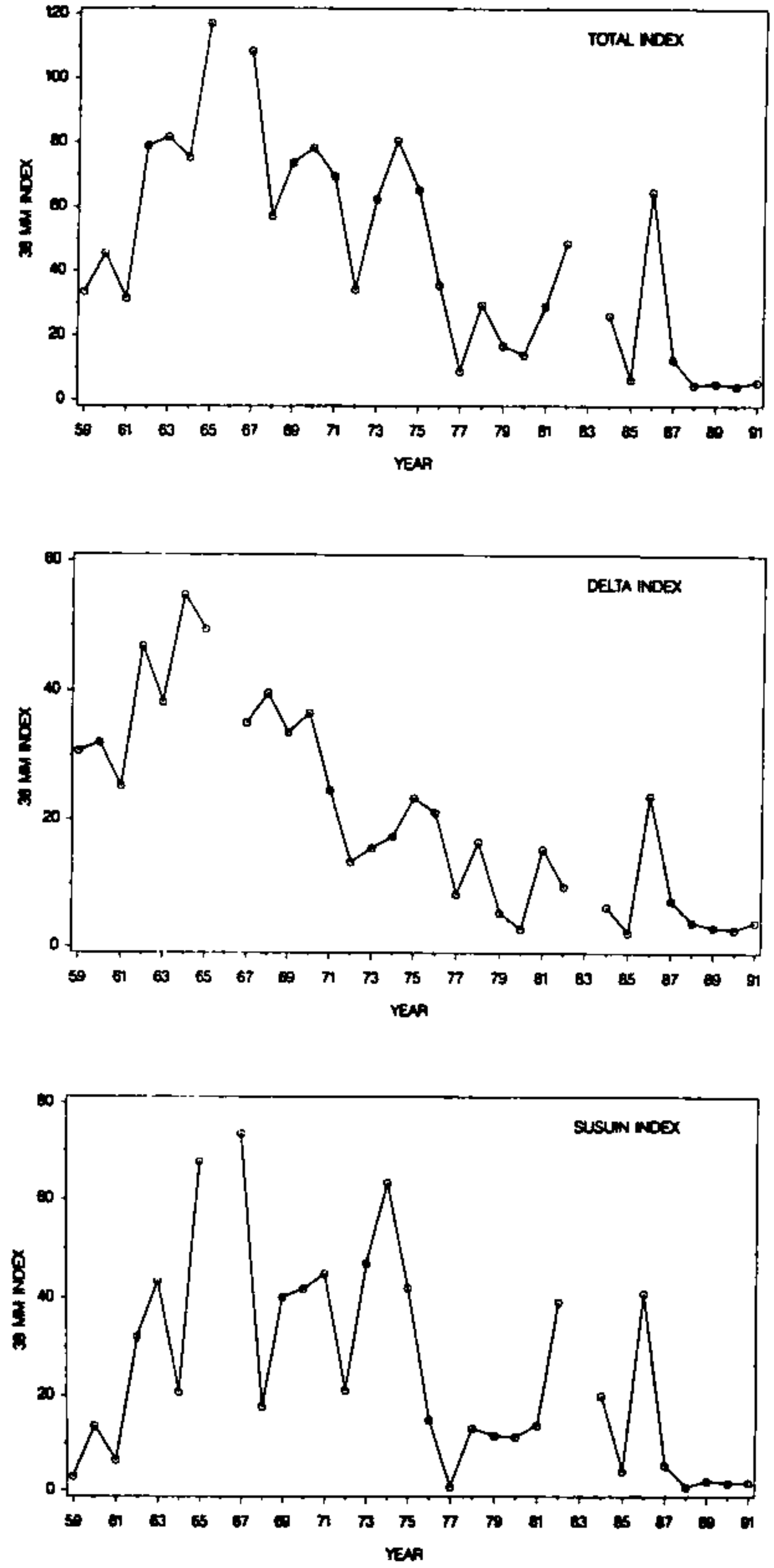

Figure 13. Annual index of young striped bass abundance by area. There has been an unsteady but persistent decline in young bass from the mid 1960s to the present. Lowest abundances have occurred in 5 of the last 7 years. The most pronounced decline is in the Delta, but the it is also clearly visible in Suisun Bay despite greater year to year fluctuations there. No sampling was conducted in 1966, and in 1983 the index was omitted because extremely high flows moved fish downstream of the area efficiently sampled by the townet survey.

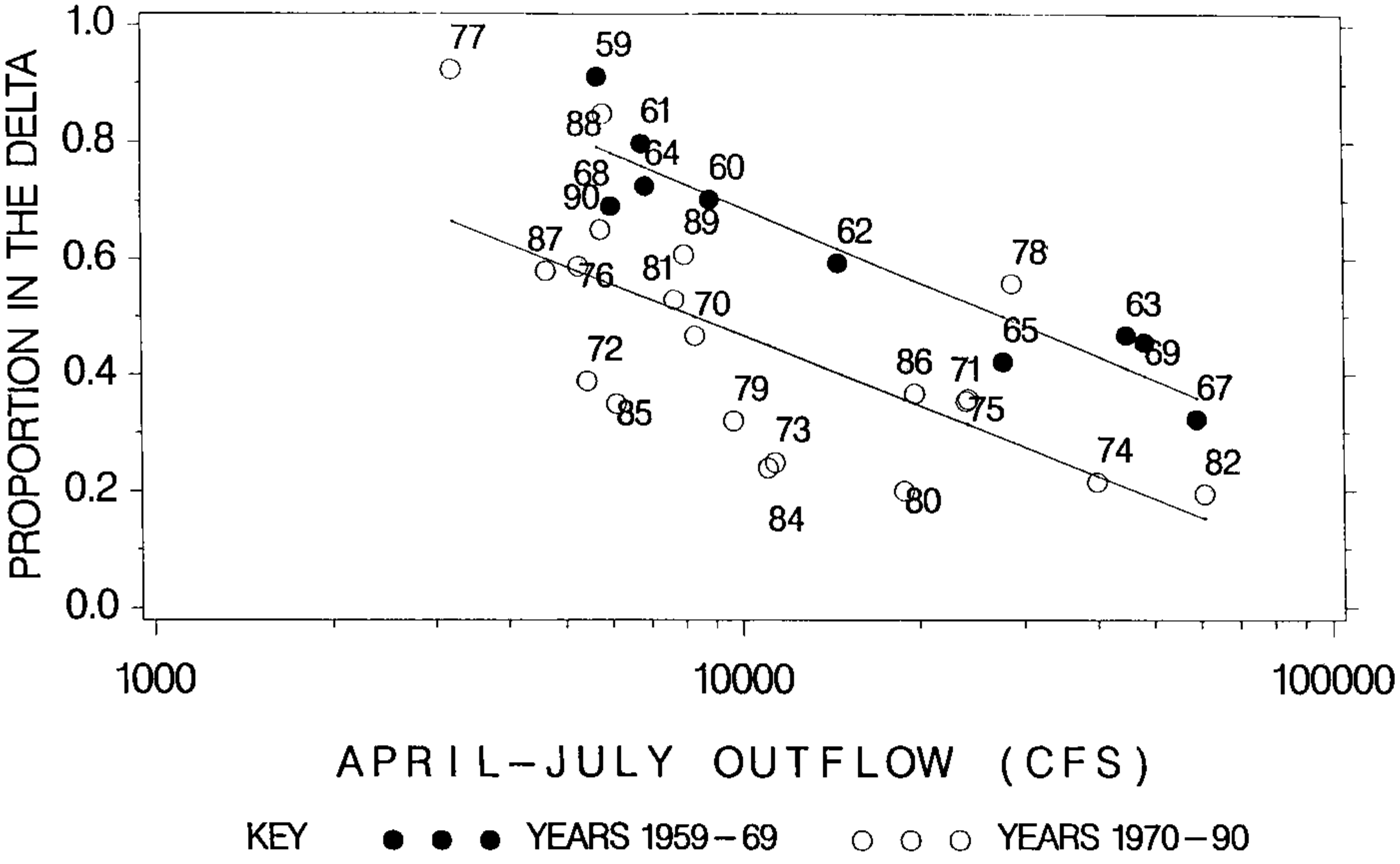

Figure 14. The proportion of striped bass 38-mm index located in the Delta in relation to the mean April to July Delta outflow.

Table 4. Coefficient of Determination ($R^2$) for multiple regressions of the fraction of the young striped bass population residing in the Delta against water diversion rates and log Delta outflow, 1959-1990.

| Months | $R^2$ |
|---|---|
| April-July | 0.65 |
| May-July | 0.73 |

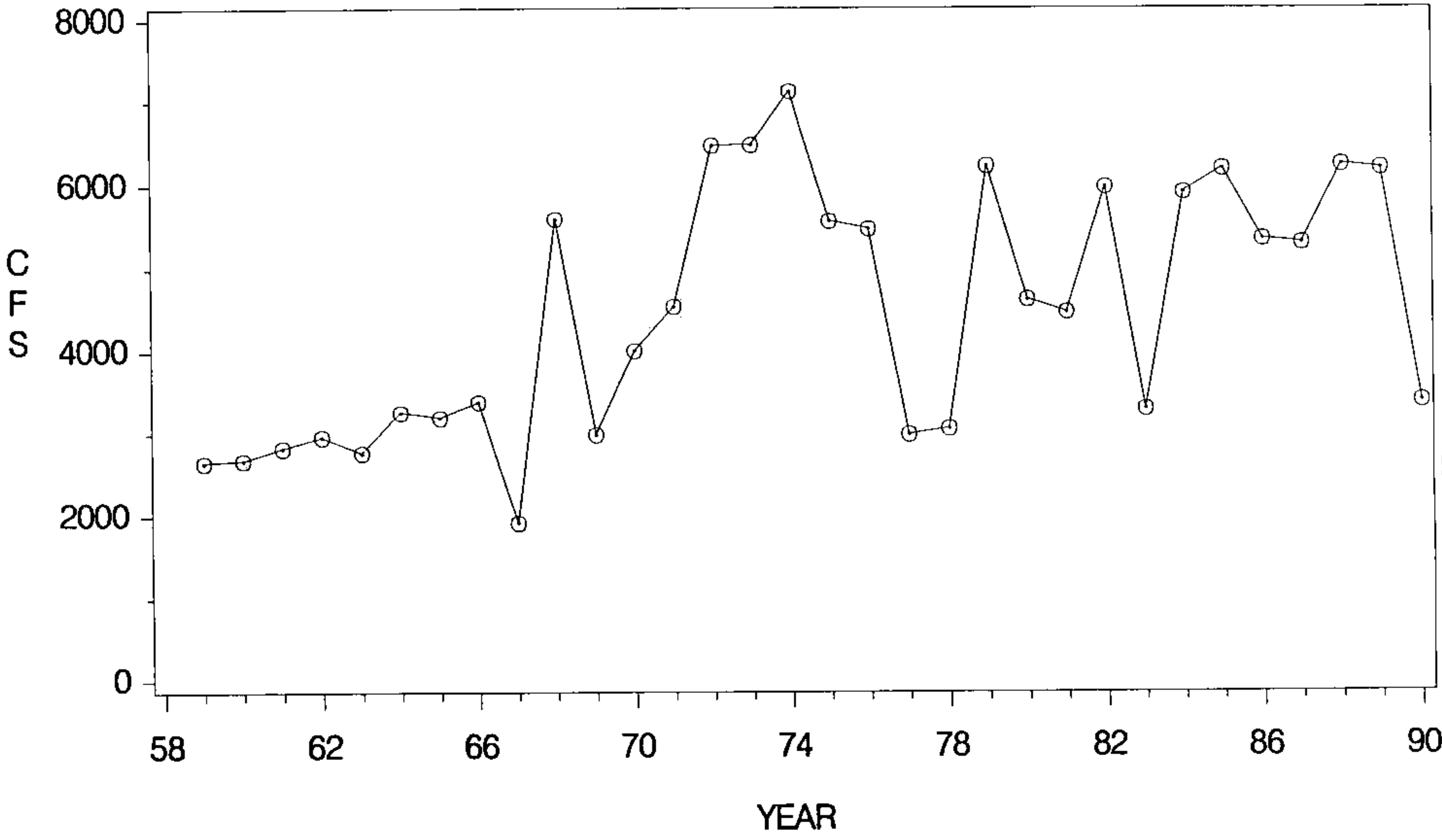

Figure 15. Total Delta water exports for May in cfs from 1959-1990.

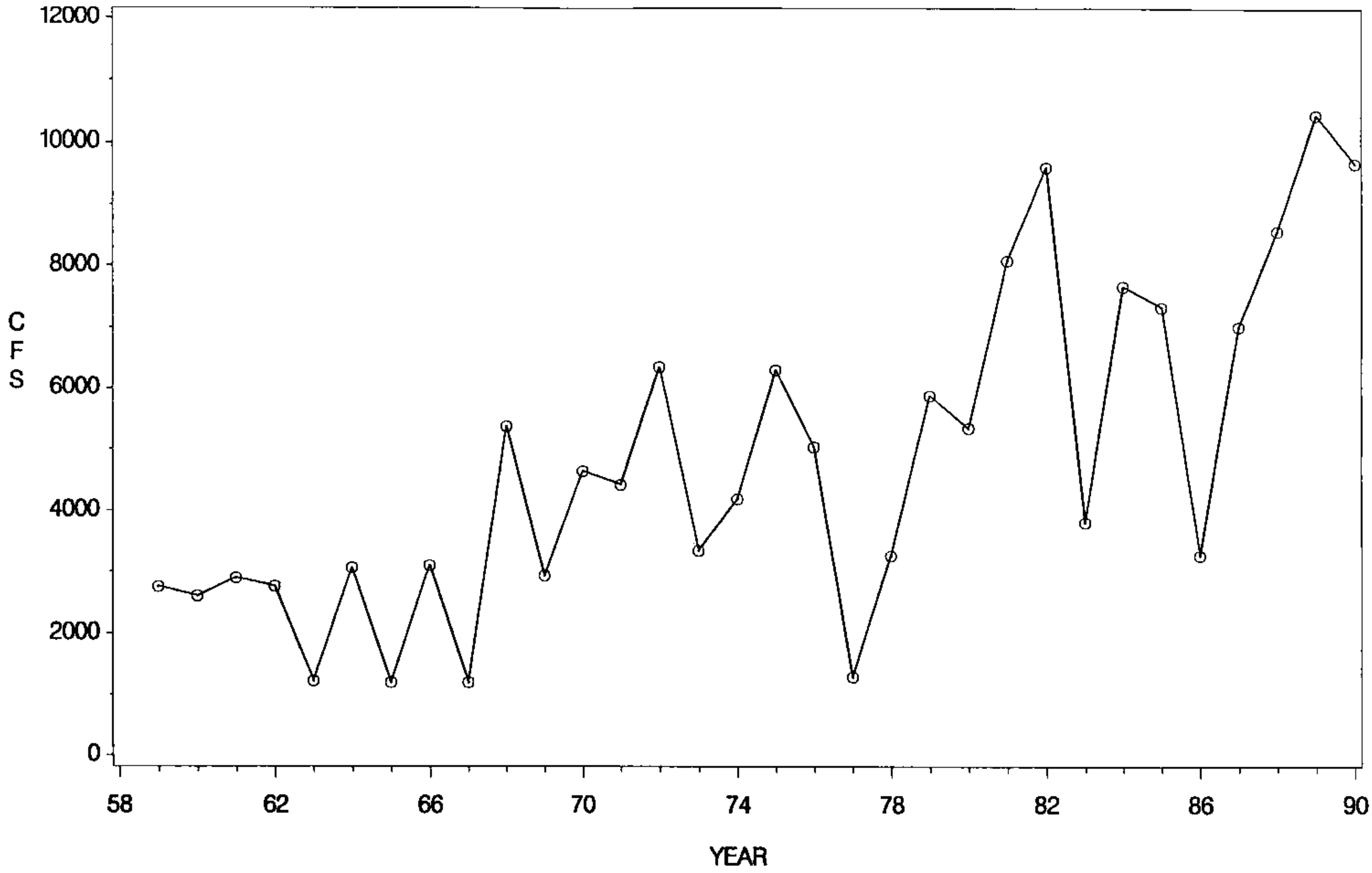

Figure 16. Total Delta water exports for April in cfs from 1959-1990.

Table 6. Percent of Delta striped bass spawning occurring in April based on catch of live striped bass eggs during striped bass spawning surveys in the San Joaquin River. Only years in which surveys began before April 22 are included.

| Year | Percent catch in April | Survey Starting Date | Number of April Samples | Number of Total Samples |
|---|---|---|---|---|
| 1968 | 14.0 | April 4 | 224 | 688 |
| 1977 | 13.8 | April 11 | 160 | 480 |
| 1984 | 16.4 | April 16 | 128 | 495 |
| 1985 | 27.4 | April 16 | 160 | 544 |
| 1986 | 30.8 | April 12 | 111 | 504 |
| 1988 | 46.5 | April 12 | 68 | 359 |
| 1989 | 32.5 | April 12 | 76 | 307 |
| 1990 | 22.7 | April 12 | 114 | 498 |

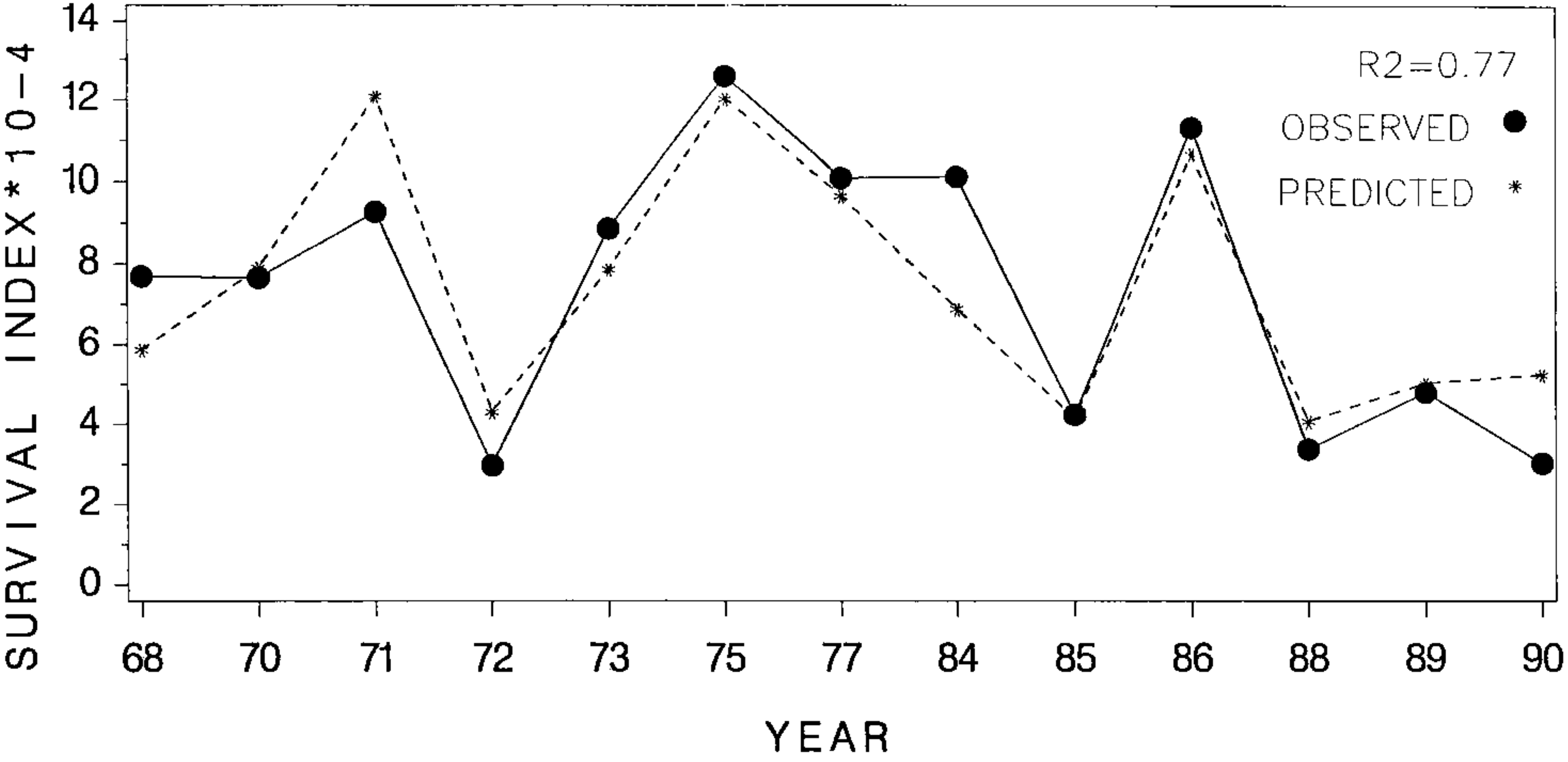

Figure 17. Relationship between observed striped bass survival index and the survival index for the interval 9 mm to 38 mm predicted from outflows and water diversions. The predicted survival index is based on the regression model: survival = 0.001116 + 0.001047 log10 April-July Delta outflow -0.001206 log 10 April-July Delta water exports.

Table 7. R-square values for the 9-38 mm striped bass survival index regressed on combinations of April-July Delta outflow and diversions from 1968 to 1990. The table values include the periods starting with the month at the top through the month on the left.

| | April | May | June | July |
|---|---|---|---|---|
| April | 0.629 | | | |
| May | 0.684 | 0.450 | | |
| June | 0.735 | 0.488 | 0.487 | |
| July | 0.716 | 0.525 | 0.508 | 0.369 |

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Table 8. Regression equations used to predict striped bass abundance at 38mm or the survival index between 9mm and 38mm. Equations are for the time periods producing the highest $R^2$ value.

| | | | |
|---|---|---|---|
| 1959-1970 | | | |
| June-July | Total striped bass abundance index | = | 110.99 - 0.816 (percent of effective inflow diverted) |
| June-July | Total striped bass abundance index | = | -1151.7 + 577.5 ($\log_{10}$ outflow) |
| 1959-1976 | | | |
| May-June | Delta striped bass abundance index | = | -507.22 - 0.0553 (diversions) + 282.37 log (outflow) - 34.05 $(\log \text{outflow})^2$ |
| June-July | Suisun striped bass abundance index | = | -670.44 + 314.93 (log outflow) - 33.97 $(\log \text{outflow})^2$ |
| 1977-1990 | | | |
| April-July | Delta striped bass abundance index | = | -308.7 - 0.00227 (diversions) + 156.09 ($\log_{10}$ outflow) - 17.80 $(\text{log10 outflow})^2$ |
| April-July | Suisun striped bass abundance index | = | -107.96 + 30.08 ($\log_{10}$ outflow) |
| 1968-1990 | | | |
| April-July | Survival index between 38mm and 9mm | = | -0.00180 - 0.00000121 (diversions) +0.0092 ($\log_{10}$ outflow) |

Specifically, the diversion terms have negative coefficients and the outflow terms have positive coefficients. The signs on the coefficients are not forced positive or negative by the biologists evaluating the data. The signs and coefficients are determined by the best fit of the dependent variable (young bass abundance or survival) to the independent variables (diversions and outflow).

The negative coefficients on diversions mean that increasing water diversions have a negative effect on young bass abundance. This result is consistent with more fish being removed from the population as diversions increase. The positive coefficients on outflows are consistent with the concept that more flow reduces the impact of diversions by transporting fish away so a smaller portion of the population becomes entrained. Higher flows also may benefit survival of young bass through several other mechanisms including: 1) expanding the nursery area which occurs when more fish are transported downstream, 2) transporting fish to downstream areas with greater food productivity, 3) increasing nutrient input to the estuarine nursery areas, and 4) dilution of toxicity.

To summarize our point regarding the form of the regression models, we reiterate that these models are consistent with intuitive reasoning regarding the way in which striped bass abundance would respond to water diversions in general. Secondly the population decline that has occurred since water exports increased in the early 1970's is consistent with expectations based on these regressions.

4. The magnitude of estimated percentage reductions in abundance due to losses of fish eggs and larvae entrained in water project exports is substantial. Such losses have been estimated (Exhibit 25, pages 70-78) to cause from 31%

to 99% reductions in the population before young bass reach the 20 mm stage (Table 9).

5. Irregardless of assumptions about: 1) pre-screening loss rates at the State and Federal water project intakes and 2) netting efficiencies from 25 to 100% when the young striped bass abundance index (38 mm index) is set, estimates of entrainment losses of young striped bass larger than 20 mm (Tables 10 and 11) are large enough relative to estimates of young bass abundance (Table 12) that significant population reductions would be expected. The only uncertainty is the exact extent of those reductions. If the assumed prescreening losses are based on the experimental data (Table 11), the estimated total loss of young striped bass since 1970 is about twice (2.2 X) the corresponding total for the number of bass remaining in the Estuary based on 100% net efficiency, about equal to the number of bass remaining (1.1 X) based on 50% net efficiency, and about one-half of the number remaining (0.56 X) based on 25% net efficiency. Even conservatively assuming only a 15% prescreening loss, estimated total losses since 1970 are 58, 29, and 14% of the total of the estimated abundances of young bass in the Estuary assuming 100%, 50% and 25% net efficiencies, respectively.

6. Our striped bass model (WRINT-DFG-Exhibit 3) indicates that the adult stock and recruitment of new fish to the adult population have declined in response to the decline in young striped bass abundance and subsequent losses of fish entrained in water exports (Figure 18). In combination, the various relationships in the model indicate that entrainment losses erode the population throughout the year, both before and after the annual index of young bass abundance is set. It is the decline in spawners caused by past entrainment losses, their egg production and current entrainment losses that are now inhibiting the production of new fish. A persistent decline in survival of young striped bass relative to flow and water diversion rates did not occur

Table 9. Estimated percent reduction of young striped bass before the 20 mm stage caused by entrainment losses in CVP and SWP diversions.

| Year | Percent Reduction |
|---|---|
| 1985 | 73.5 |
| 1986 | 31.3 |
| 1988 | 84.3 |
| 1989 | 99.6 |

Table 10. Case 1: Striped Bass (21-150 mm) loss estimates for the SWP and CVP * (Table 10 A in Exhibit **WRINT-DFG-1**)

| Year | SWP Loss Estimate | CVP Loss Estimate | Total Estimate |
|---|---:|---:|---:|
| 1957 | 0 | 1,620,478 | 1,620,478 |
| 1958 | 0 | 595,613 | 535,613 |
| 1959 | 0 | 7,588,877 | 7,588,877 |
| 1960 | 0 | 9,544,050 | 9,544,050 |
| 1961 | 0 | 14,914,306 | 14,914,306 |
| 1962 | 0 | 14,557,701 | 14,557,701 |
| 1963 | 0 | 22,821,857 | 22,821,857 |
| 1964 | 0 | 25,964,189 | 25,964,189 |
| 1965 | 0 | 12,595,389 | 12,595,389 |
| 1966 | 0 | 33,905,326 | 33,905,326 |
| 1967 | 0 | 5,001,887 | 5,001,887 |
| 1968 | 1,518,640 | 14,009,334 | 15,527,974 |
| 1969 | 1,509,202 | 8,329,794 | 9,838,996 |
| 1970 | 10,996,834 | 18,717,177 | 29,714,011 |
| 1971 | 7,635,924 | 8,459,477 | 16,095,401 |
| 1972 | 5,721,871 | 9,133,657 | 14,855,528 |
| 1973 | 9,906,979 | 8,547,806 | 18,454,785 |
| 1974 | 16,884,849 | 5,935,344 | 22,820,193 |
| 1975 | 4,405,373 | 6,192,385 | 10,597,758 |
| 1976 | 1,651,017 | 4,403,134 | 6,054,151 |
| 1977 | 516,665 | 613,848 | 1,130,513 |
| 1978 | 3,507,951 | 3,332,958 | 6,840,909 |
| 1979 | 2,845,227 | 2,399,012 | 5,244,239 |
| 1980 | 2,786,574 | 1,278,896 | 4,065,470 |
| 1981 | 857,229 | 5,746,387 | 6,603,616 |
| 1985 | 815,078 | 1,368,322 | 2,183,400 |
| 1983 | 99,554 | 160,702 | 260,256 |
| 1984 | 8,491,434 | 5,640,468 | 14,131,902 |
| 1985 | 4,181,702 | 1,699,641 | 5,881,343 |
| 1986 | 15,061,909 | 4,932,410 | 19,994,319 |
| 1987 | 14,596,798 | 2,674,519 | 17,271,317 |
| 1988 | 12,759,277 | 716,615 | 13,475,892 |
| 1989 | 9,016,015 | 1,435,483 | 10,451,498 |

* SWP losses are based on a 15% pre-screening loss rate.
CVP losses are based on a 15% pre-screening loss rate.

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Table 11 Case 2: Striped Bass (21-150 mm) loss estimates for the SWP and CVP * (Table 12 A in Exhibit **WRINT-DFG-1**).

| Year | SWP Loss Estimate | CVP Loss Estimate | Total Estimate |
|---|---:|---:|---:|
| 1957 | 0 | 1,620,478 | 1,620,478 |
| 1958 | 0 | 595,613 | 535,613 |
| 1959 | 0 | 7,588,877 | 7,588,877 |
| 1960 | 0 | 9,544,050 | 9,544,050 |
| 1961 | 0 | 14,914,306 | 14,914,306 |
| 1962 | 0 | 14,557,701 | 14,557,701 |
| 1963 | 0 | 22,821,857 | 22,821,857 |
| 1964 | 0 | 25,964,189 | 25,964,189 |
| 1965 | 0 | 12,595,389 | 12,595,389 |
| 1966 | 0 | 33,905,326 | 33,905,326 |
| 1967 | 0 | 5,001,887 | 5,001,887 |
| 1968 | 1,518,640 | 14,009,334 | 15,527,974 |
| 1969 | 1,509,202 | 8,329,794 | 9,838,996 |
| 1970 | 10,996,834 | 18,717,177 | 29,684,011 |
| 1971 | 42,184,312 | 8,459,477 | 56,643,789 |
| 1972 | 39,204,045 | 9,133,657 | 48,337,702 |
| 1973 | 64,119,555 | 8,547,806 | 72,667,361 |
| 1974 | 107,357,174 | 5,935,344 | 113,292,518 |
| 1975 | 30,287,231 | 6,192,385 | 36,479,616 |
| 1976 | 11,086,639 | 4,403,134 | 15,489,773 |
| 1977 | 3,701,322 | 613,848 | 4,315,170 |
| 1978 | 24,358,333 | 3,332,958 | 27,691,291 |
| 1979 | 18,640,005 | 2,399,012 | 21,039,017 |
| 1980 | 17,890,370 | 1,278,896 | 19,169,266 |
| 1981 | 6,337,892 | 5,746,387 | 12,084,279 |
| 1985 | 6,001,195 | 1,368,322 | 7,369,517 |
| 1983 | 781,438 | 160,702 | 942,140 |
| 1984 | 51,916,076 | 5,640,468 | 57,556,544 |
| 1985 | 26,371,523 | 1,699,641 | 28,071,164 |
| 1986 | 92,705,392 | 4,932,410 | 97,637,802 |
| 1987 | 88,480,625 | 2,674,519 | 91,155,144 |
| 1988 | 77,770,704 | 716,615 | 78,487,319 |
| 1989 | 56,192,155 | 1,435,483 | 57,627,638 |

* SWP losses are based on an 82% pre-screening loss rate (1968 through 1970 are based on a 15% pre-screening loss rate). CVP losses are based on a 15% pre-screening loss rate.

Table 12. Estimated abundance of striped bass (in millions) when the mean size is 38 mm based on assumptions of 100, 50, and 25 percent net efficiency. Estimated abundance is the product of the catch per acre foot of water strained by the net and the water volume in acre feet sampled in the nursery area.

| **Year** | 100 percent net efficiency | **50 percent net efficiency** | **25 percent net efficiency** |
|---|---|---|---|
| 1959 | 19 | 38 | 75 |
| 1960 | 26 | 51 | 102 |
| 1961 | 18 | 35 | 71 |
| 1962 | 44 | 88 | 177 |
| 1963 | 46 | 91 | 183 |
| 1964 | 42 | 84 | 169 |
| 1965 | 66 | 131 | 262 |
| 1966 | - | - | - |
| 1967 | 61 | 122 | 243 |
| 1968 | 32 | 64 | 128 |
| 1969 | 41 | 83 | 165 |
| 1970 | 44 | 88 | 176 |
| 1971 | 39 | 78 | 156 |
| 1972 | 19 | 39 | 77 |
| 1973 | 35 | 70 | 140 |
| 1974 | 45 | 90 | 181 |
| 1975 | 37 | 73 | 147 |
| 1976 | 20 | 40 | 80 |
| 1977 | 5 | 10 | 20 |
| 1978 | 17 | 33 | 66 |
| 1979 | 9 | 19 | 38 |
| 1980 | 8 | 16 | 31 |
| 1981 | 16 | 33 | 65 |
| 1985 | 27 | 54 | 109 |
| 1983 | - | - | - |
| 1984 | 15 | 29 | 59 |
| 1985 | 4 | 7 | 14 |
| 1986 | 36 | 73 | 145 |
| 1987 | 7 | 14 | 28 |
| 1988 | 3 | 5 | 10 |
| 1989 | 3 | 6 | 11 |
| 1990 | 2 | 5 | 10 |

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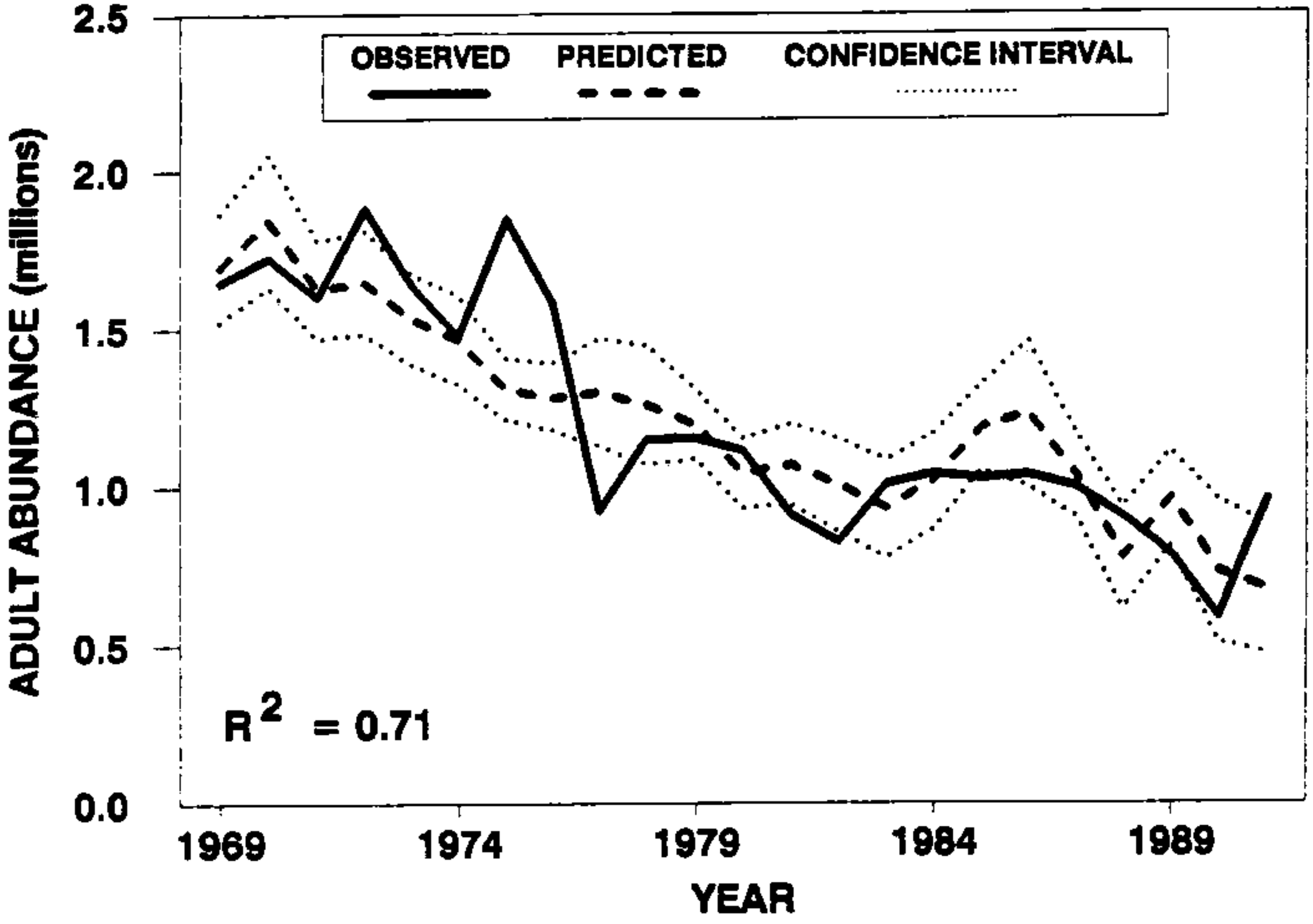

Figure 18. Observed and predicted adult striped bass abundance (exclusive of hatchery raised fish) in the Sacramento-San Joaquin Estuary from 1969-1991. Predicted values are from the relationship between adult abundance and weighted mean young-of-the-year index and export loss rate 3-7 years earlier. The 95% confidence limits for the predicted values are shown.

coincident with the decline in young striped bass abundance (Figure 19) indicating that survival of young bass did not suddenly decline in response to other environmental changes.

## Factors Other than the Process Described by the Striped Bass Model Which Have Been Hypothesized as Potential Causes of the Decline in Striped Bass Abundance.

The possible adverse effects of a decline in food availability and increased toxicity are the primary factors that have been considered as potential causes of the decline in striped bass abundance. These and several other factors: competition and predation by other fishes, predation by sea lions, poaching, and temperature, are discussed in Exhibit 25.

## The Hypothesis that a Decline in Food Availability Has Caused the Decline in Young Striped Bass Abundance.

This hypothesis is that young striped bass mortality has increased because the zooplankton that they have historically eaten have declined in abundance. There have been substantial changes in the species composition of the zooplankton, at least partly due to accidental introductions of exotic species (Exhibit 28). The historically predominant striped bass food species, Eurytemora affinis, has declined in abundance, possibly partly due to predation or competition from the exotic zooplankton species (Exhibit 28), and also since 1988 probably due to consumption by the clam, Potamocorbula amurensis, which also was accidentally introduced through ship ballast discharge.

### *The Test of the Food Limitation Hypothesis.*

There are two important pieces of information for evaluating the food limitation hypothesis:

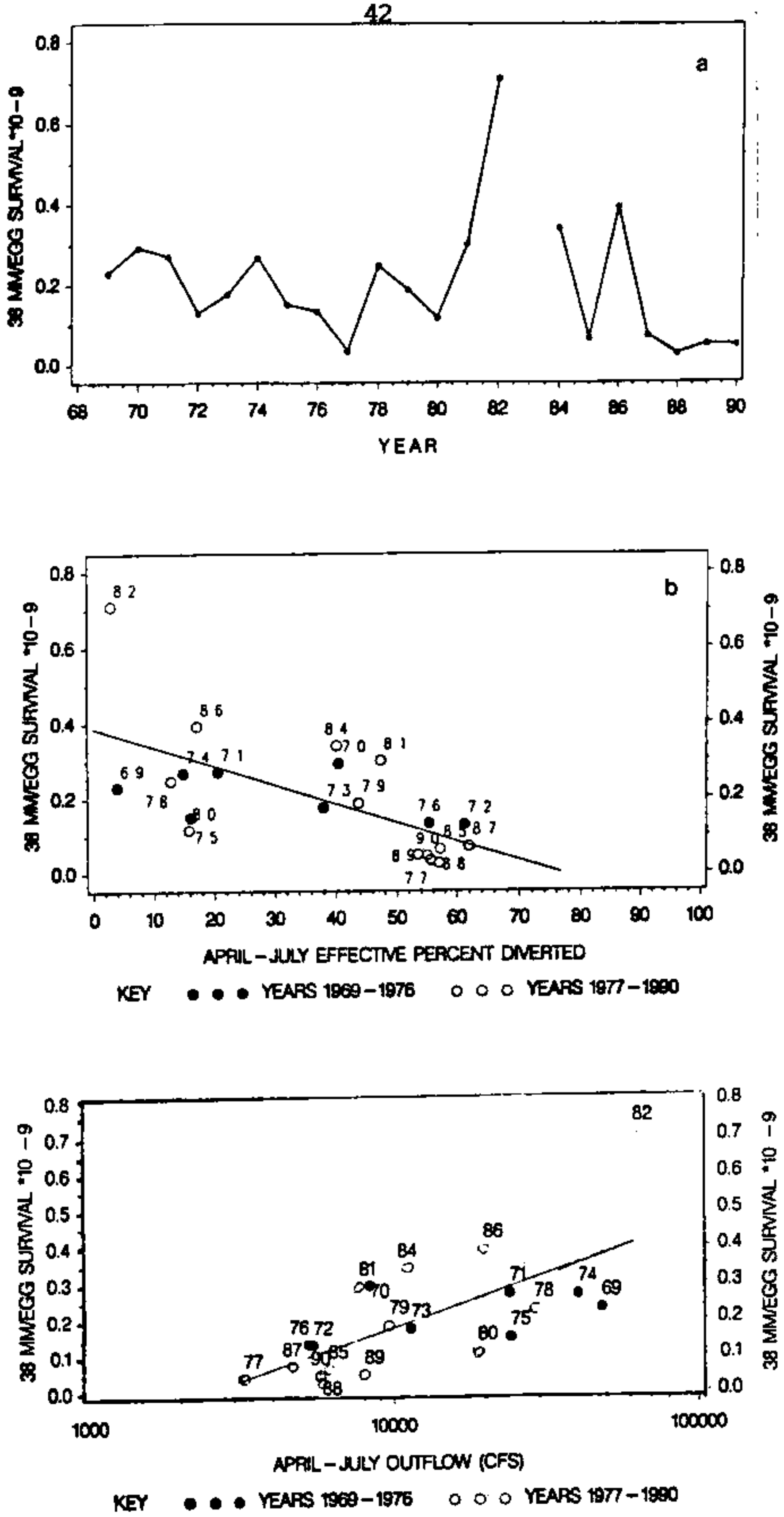

Figure 19. Survival index between striped bass egg production, based on the Petersen population estimates and age-specific fecundity, and the 38-mm abundance index. There is no persistent decline over the years of record (a). There is no trend in recent years of lower survival in relation to either the percent of effective Delta inflow diverted (b) or April-July outflow (c).

1) A study at U.C. Davis recently compared the condition and tissue structure of field caught striped bass larvae with condition and tissues of fed and starved larvae maintained in a laboratory. Despite recent changes in the kinds and abundances of food organisms in the Estuary, over 94 percent of field-caught larvae classified by morphometric analysis (N= 793 for 1988-1990) appeared in as good or better condition than laboratory-fed larvae (Table 13, Figure 20). Furthermore, all 363 field-caught specimens evaluated for tissue structure were scored as fed and had food in their guts (Figure 21). The tissue method is considered to be the most accurate so the U.C. Davis researchers have concluded that none of the field-caught larvae should have been classified as starved. Thus, these results are inconsistent with the hypothesis that reduced food availability has limited striped bass survival.

2) If an environmental factor such as reduced food was the cause of the reduced abundance of young striped bass, recent survival rates would be lower for young bass at any given outflow or diversion rate. In contrast, the process described by our striped bass model is consistent with our observation (described below) that survival is unchanged except for effects of water exports and outflows. The reduced spawning of the depleted adult stock alone accounts for the decline in abundances of young fish.

We have used several approaches to evaluate whether or not the survival rate has declined. All approaches indicate that the survival rate varies among years, but there has not been a persistent unexplained decline in this rate. An example is in Figure 19. The top portion of this figure shows the trend in an annual index of survival between the egg and 38 mm stages. Note that survival is quite variable over the period of record and also that survival has been low during the low flow drought years since 1987. However, also note that there have been several years since 1977 with higher than average survivals, for example 1981, 1982, 1984, and 1986. Yet, these years all

Table 13. Classification results (Percent classified as fed) from discriminate analyses of the condition of striped bass larvae from the Sacramento-San Joaquin Estuary, 1988-1990. Table from William Bennett, U.C. Davis.

| | 1988 | | | 1989 | | | 1990 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Classification Method | | | Classification Method | | | Classification Method | | |
| **Group** | N | Ratio[1] | PCA[2] | N | Ratio | PCA | N | Ratio | PCA |
| With Food | | | | 89 | 74.4 | 83.2 | | | |
| Starved | | | | 79 | 19.0 | 13.9 | | | |
| Sacramento River | 117 | 92.3 | 95.7 | 76 | 68.4 | 88.2 | 75 | 84.0 | 94.7 |
| San Joaquin River | 221 | 93.7 | 95.5 | 63 | 90.5 | 100.0 | 82 | 75.6 | 89.0 |
| Antioch | - | - | - | 59 | 64.4 | 97.0 | 20 | 100.0 | 94.7 |
| Collinsville | - | - | - | 61 | 95.1 | 93.4 | 19 | 89.5 | 95.0 |
| Total Field | 338 | 93.2 | 95.6 | 259 | 79.2 | 94.2 | 196 | 82.6 | 92.4 |

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1/ Classified based on eye diameter: length ratio

2/ Classified by Principle Components Analysis

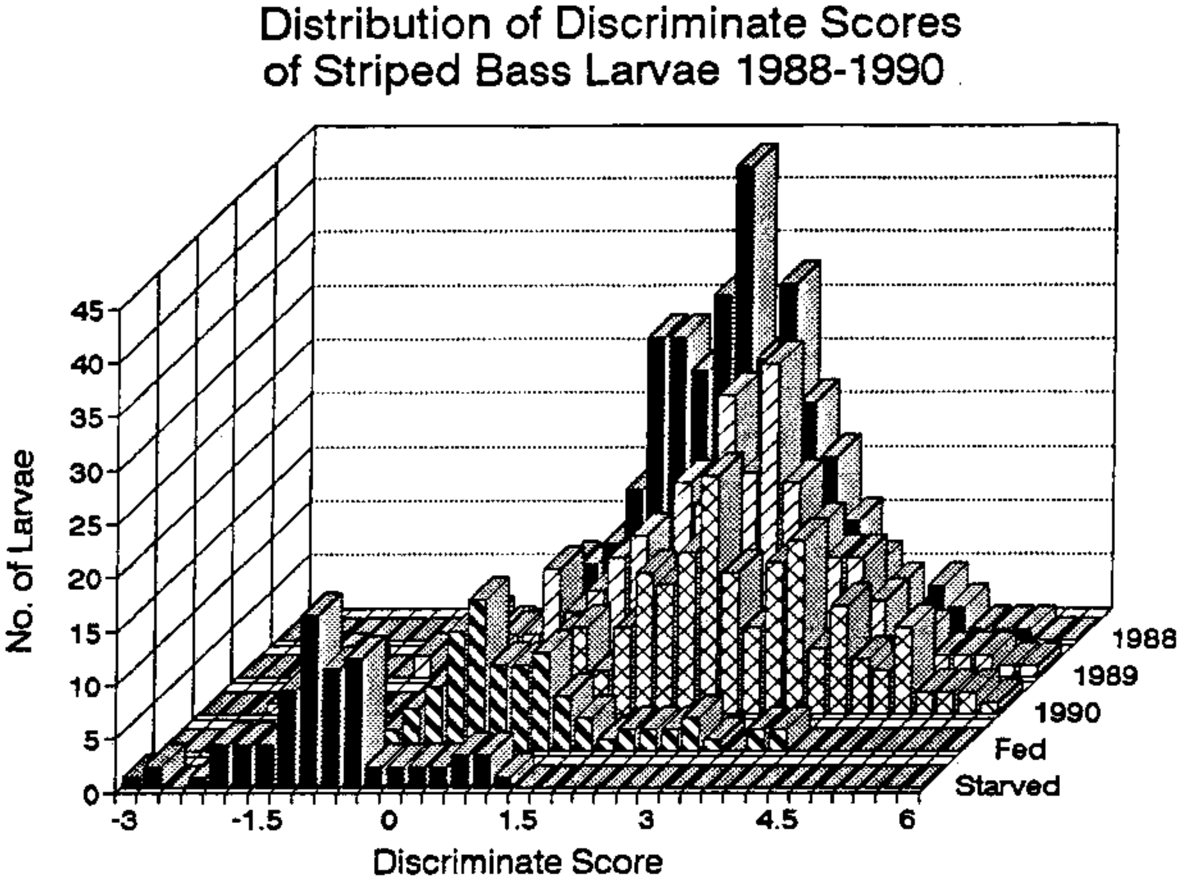

Figure 20. Discriminate scores of striped bass larvae show differences between fish from the Estuary (1988-1990) and fish starved or fed in the laboratory. (Figure from William Bennett, U.C. Davis.)

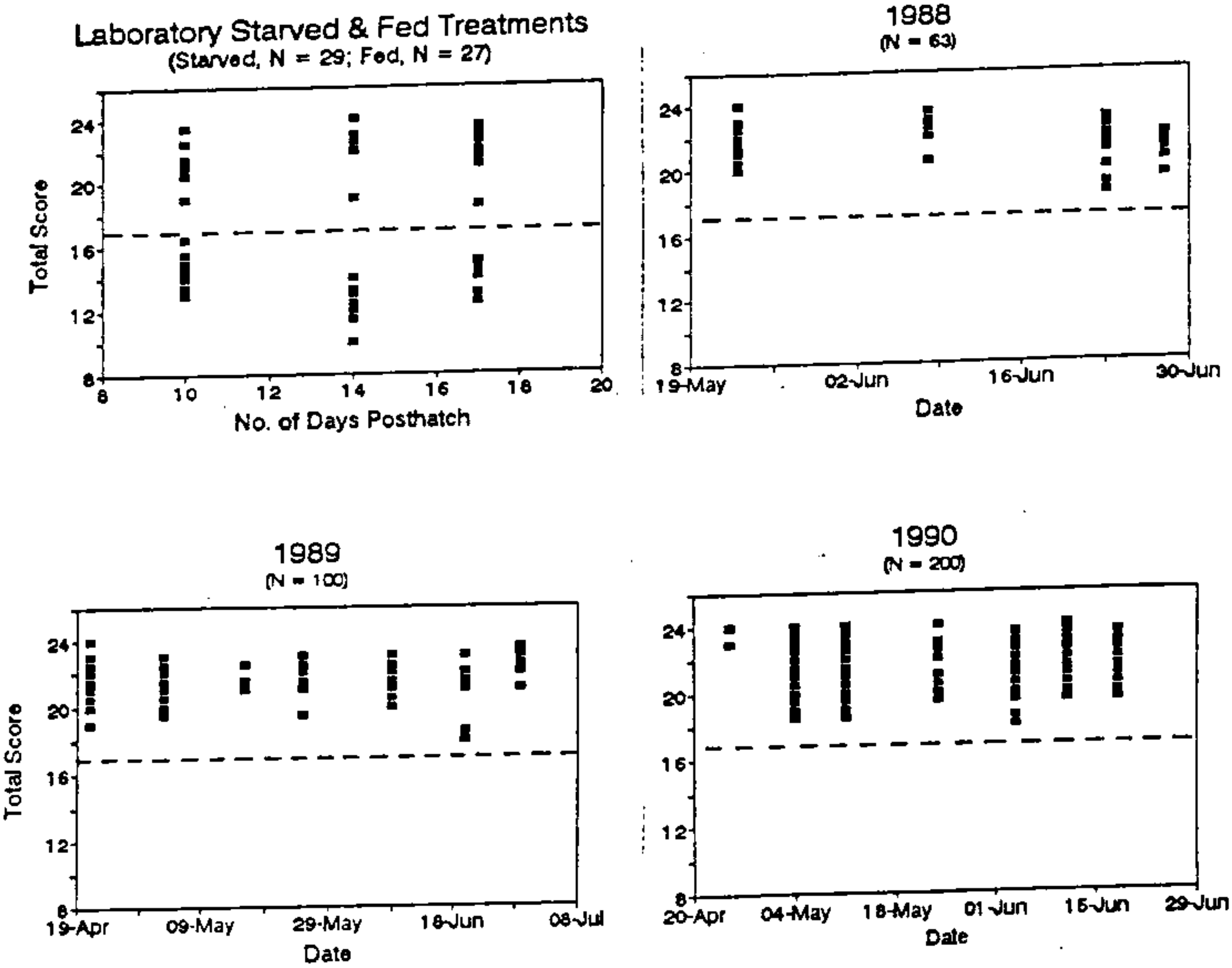

Figure 21. Results from histological analyses of striped bass larvae: Comparison of laboratory "starved and fed" treatments with specimens from the Sacramento-San Joaquin Estuary. (Figure from William Bennett, U.C. Davis).

produced year classes that were less abundant than predicted by the relationship between young bass abundance, outflow, and diversions from 1959-1976. The middle and lower portions of this figure reveal that, since 1977, the survival rate has not been persistently lower than expected from the outflow and diversion conditions that have occurred. The years since 1977, depicted by the open data points, are spread about equally above and below the regression lines representing the best straight line fit to the data over the entire period of record back to 1969.

These results are inconsistent with any explanation for the decline in young striped bass abundance except the one regarding the reduced egg supply associated with the depleted spawning stock which we have shown is strongly associated with past losses of young fish to water exports (WRINT-DFG-Exhibit 3).

## The Hypothesis that Increased Toxicity Has Caused the Decline in Young Striped Bass Abundance.

Much concern has been expressed regarding the possibility that young striped bass survival has been reduced due to toxic effects of insecticides, herbicides, and trace elements in agricultural drains which discharge to the Sacramento and San Joaquin rivers. A particularly appealing hypothesis to some, is that there may have been increased toxicity related mortality starting in the late 1970's associated with the increase in rice cultivation and changes in kinds and amounts of pesticides used on rice. These changes roughly coincided with the major decline in young striped bass abundance and led to analyses (Central Valley Regional Water Quality Control Board Division of Standards and Assessment) which have shown strong statistical associations between the use of some of the pesticides and young striped bass abundance over part of the 1959-1991 striped bass record (pesticide analysis is from 1970-1988 or subset of those years depending on chemical).

In the early 1980's there were highly visible fish kills in the agricultural drains that discharge rice field water to the Sacramento River. These kills consisted largely of carp which are particularly susceptible to the rice herbicide: molinate (Finlayson and Faggella 1986). However, two hazard assessments completed by the Department of Fish and Game have concluded that rice herbicides: molinate and thiobencarb, have had minimal, if any, adverse effects on striped bass inhabiting the Sacramento-San Joaquin Estuary (Faggella and Finlayson, 1987; Harrington 1990).

Additionally, according to a Central Valley Region Water Quality Control Board staff report (Consideration of Approving Department of Pesticide Regulation's 1992 Management Procedures for Rice Pesticides), in addition to the herbicides: molinate and thiobencarb, three insecticides used on rice: carbofuran, malathion, and methyl parathion, were present in drains at concentrations that posed a threat to aquatic resources. Laboratory studies by the U.S. Fish and Wildlife Service (Saiki et al. 1992), and scientists at U.C. Davis (Bailey et al 1991) have shown that drain waters from both the Sacramento and San Joaquin valley's may sometimes be toxic to striped bass larvae, although testing by the Department of Fish and Game's Aquatic Toxicology Laboratory has not shown such evidence of toxicity to striped bass larvae either in the major Sacramento Valley drain (Colusa Basin Drain) or in the Sacramento River (Finlayson et al. 1991; Figures 22, 23, and 24).

### ***Why the Department of Fish and Game Model Provides a Better Explanation for the Decline in Striped Bass Abundance than the Statistical Associations between the Use of Some of the Pesticides and Young Striped Bass Abundance.***

The statistical associations are based on insecticide and herbicide use, not on drain discharge, environmental exposure levels, or measurements of toxicity. Thus, they do not reflect the chemical degradation that occurs before the insecticides and herbicides are discharged to the river and the actual exposure of striped bass. This point is important because major changes in rice field water management have been

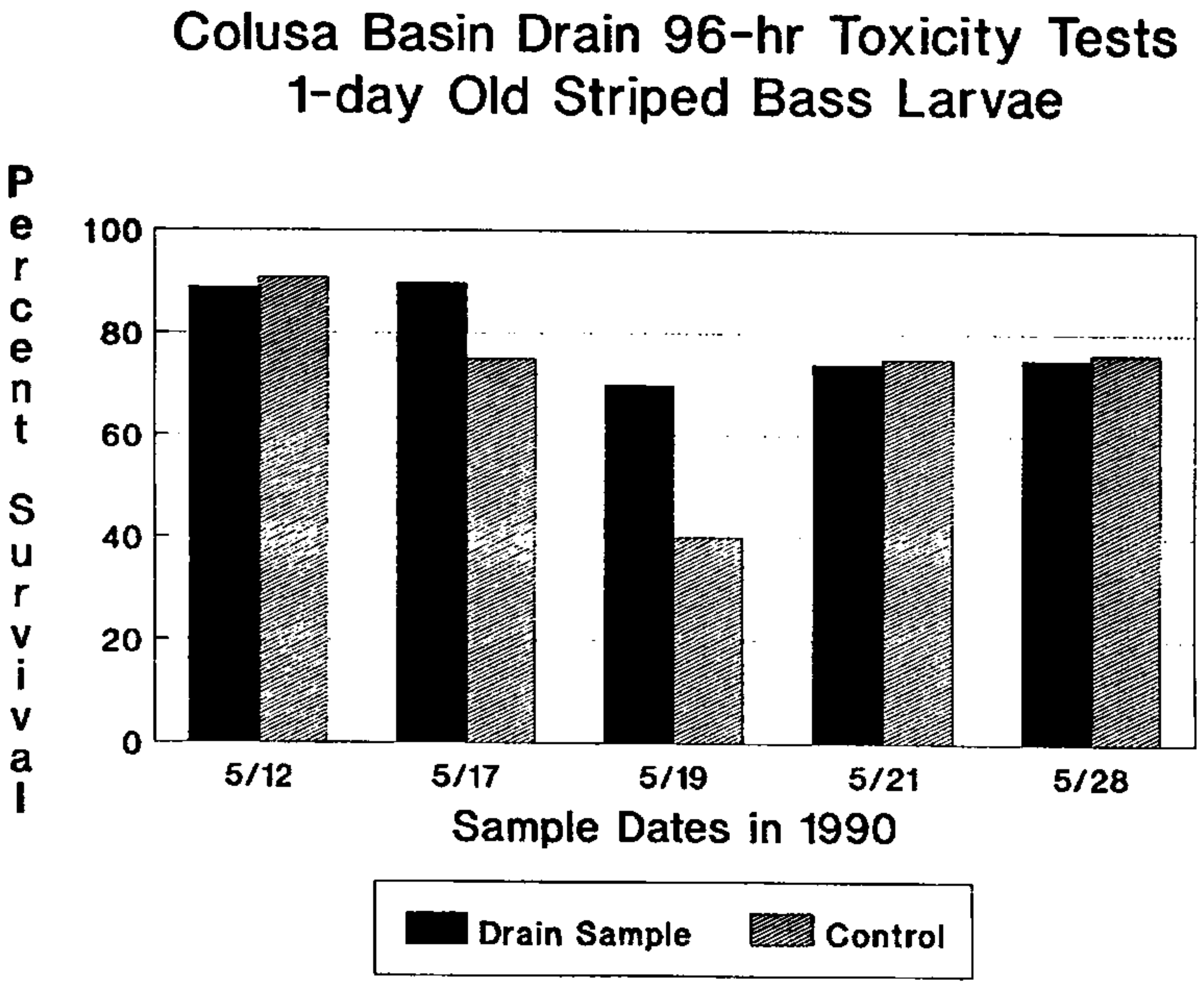

Figure 22. Colusa Basin Drain 96-hour toxicity tests in 1990: 1-day old striped bass larvae.

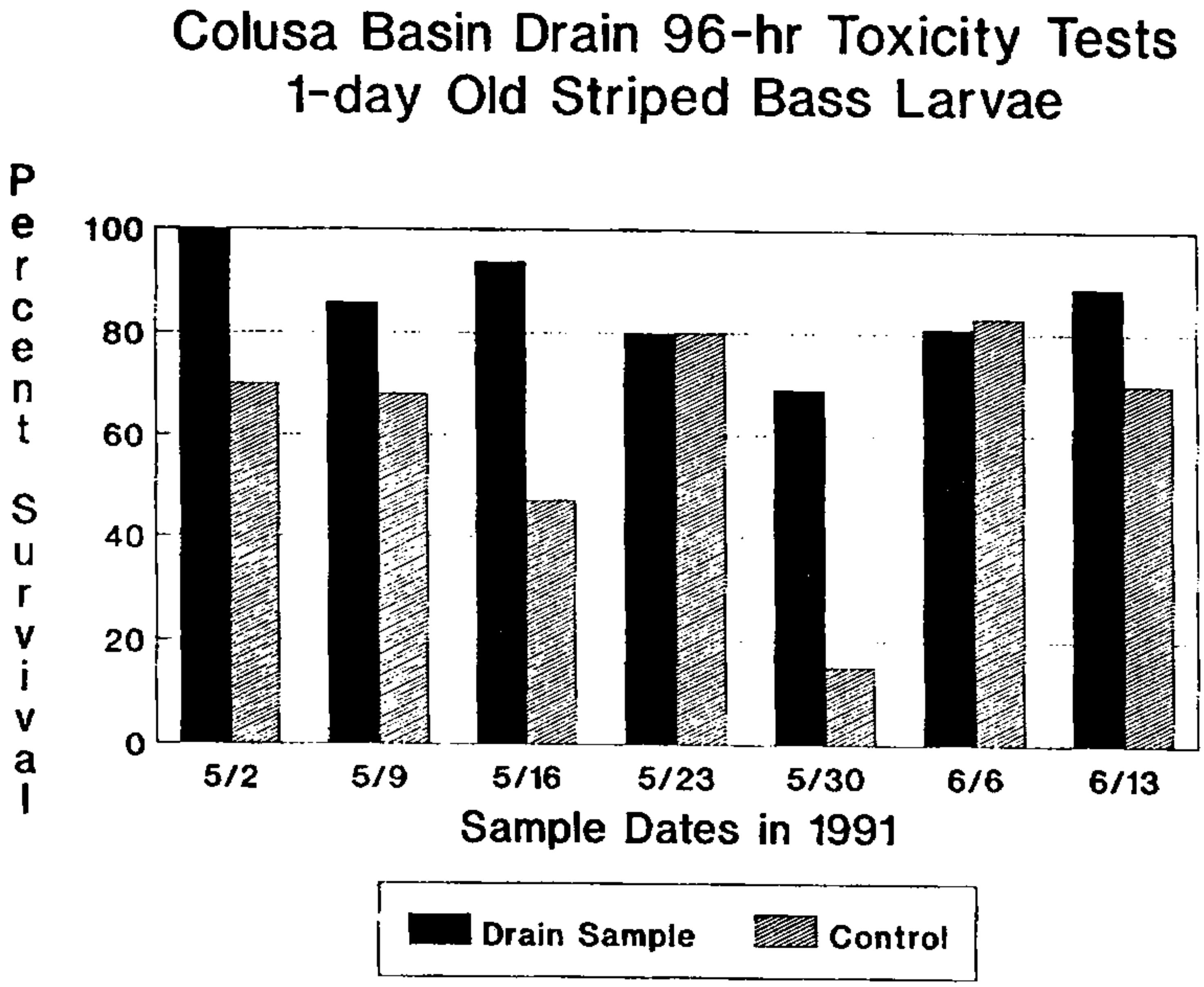

Figure 23. Colusa Basin Drain 96-hour toxicity tests in 1991: 1-day old striped bass larvae.

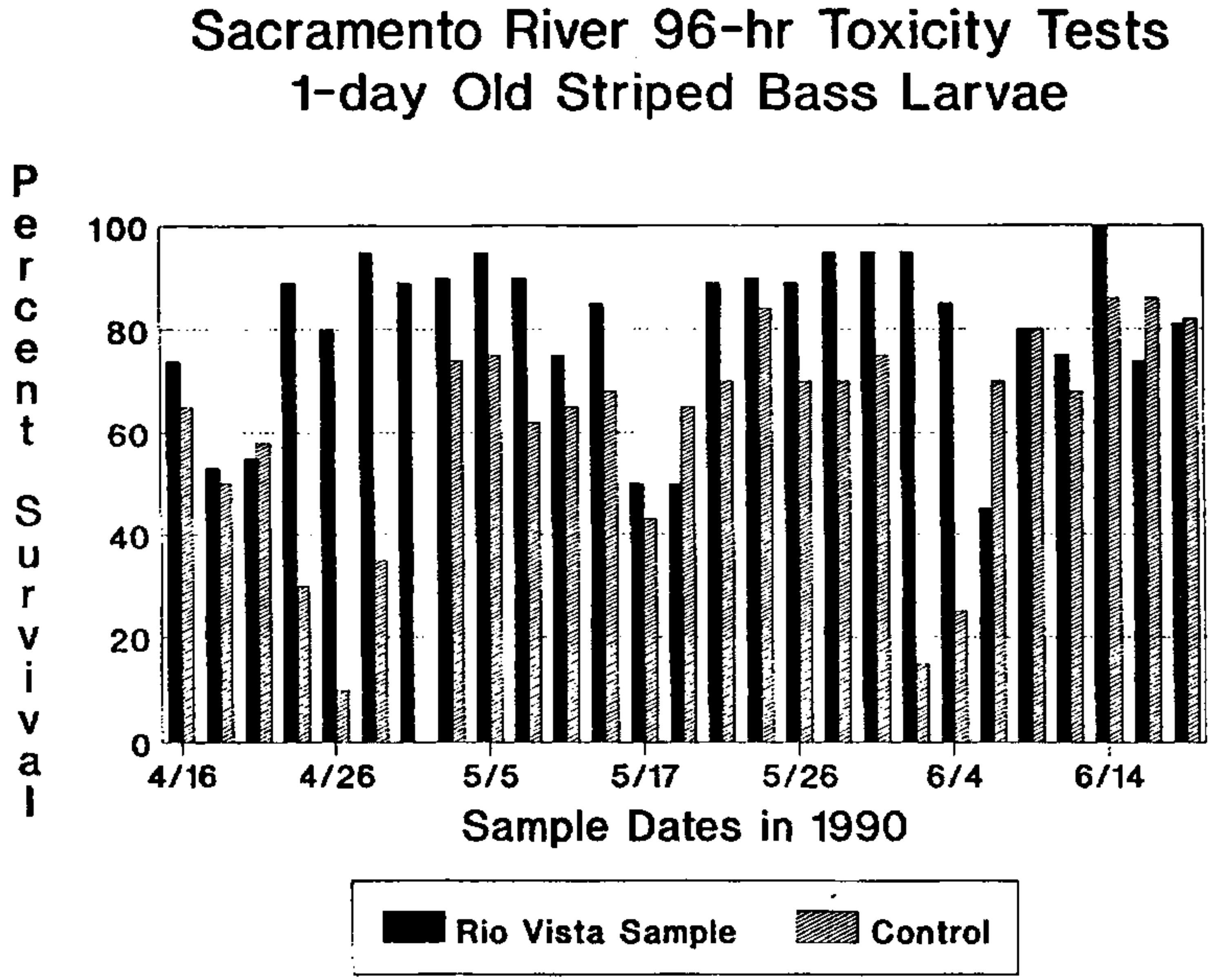

Figure 24. Sacramento River 96-hour toxicity tests in 1990: 1-day old striped bass larvae.

implemented to increase chemical degradation and reduce potential toxic effects of these chemicals. It is the amount discharged, not amounts applied, that potentially affect fish in the Sacramento River. For any given amount applied, the amount discharged is now less than it used to be. This change has come about because the Department of Pesticide Regulation (formerly Department of Food and Agriculture) established a program in 1984 to reduce and control the discharge of pesticides from rice fields. This program has resulted in the prohibition of discharge of carbofuran, malathion, methyl parathion, molinate, and thiobencarb unless the discharger is following a management practice approved by the Regional Water Quality Control Board. The program requires that rice field water be held for varying periods of time, depending on herbicide or insecticide, before it can be discharged.

As indicated by Tables 14 and 15, the quantity of the major insecticides and herbicides transported by the river past Sacramento has been <u>substantially</u> reduced in recent years. In 1991, the total mass transport of the herbicide, molinate was reduced 96.9 percent from 1990 and 99.5 percent since 1982. Concurrently, concentrations of the herbicides in the Colusa Basin Drain have been reduced from 340 to 18 ug/L for molinate and from 57 to less than 1 ug/L for thiobencarb during the last 10 years. Similarly, concentrations of these herbicides in the Sacramento River have been reduced from 16 to 0.6 ug/L for molinate and from 3.7 to $< 0.1$ ug/L for thiobencarb during the same period (Harrington and Lew 1992.)

Data on insecticides also show order of magnitude reductions in the Colusa Basin Drain (R. Schnagel, Central Valley Regional Water Quality Control Board). In 1991, the <u>maximum</u> concentration of malathion was 0.11 ug/L in the Colusa Basin drain at Knights Landing. (CVRWQCB staff report on Consideration of Approving Department of Pesticide Regulation's 1992 Management Practices for Rice Pesticides). For comparison, in 1990 (data from R. Schnagel) the maximum for malathion was 0.59 ug/L, and in 1989 the maximum malathion concentration was 14.0 ug/L in the Colusa Basin Drain. Similarly, the maximum concentration for

**Table 14.** Estimated mass transport of molinate and thiobencarb in the Sacramento River past Sacramento in the years 1982-1991. This table is Table 10 in Central Valley Regional Water Quality Control Board Staff Report: *Consideration of Approving Department of Pesticide Regulation 1992 Management Practices for Rice Pesticides.*

| **Year** | Kg (pounds) Transported<br>molinate | | thiobencarb | |
|---|---|---|---|---|
| 1982 | 18,464.9 | (40,666.9) | [1] | |
| 1983[2] | 2,752.9 | (6,056.5) | 623.7 | (1,372.2) |
| 1984 | 7,352.0 | (16,174.4) | 715.2 | (1,573.5) |
| 1985 | 6,014.8 | (13,232.5) | 2,317.5 | (5,098.6) |
| 1986 | 4,622.1 | (10,168.7) | 845.7 | (1,860.6) |
| 1987 | 2,342.3 | (5,153.2) | 22.8 | (50.2) |
| 1988 | 3,194.2 | (7,027.2) | 68.1 | (149.8) |
| 1989 | 1,984.1 | (4,365.2) | 11.4 | (25.1) |
| 1990 | 3,204.1 | (7,049.1) | 51.4 | (113.1) |
| 1991 | 99.2 | (217.9) | 0 | (0)[3] |

1. Mass transport was not calculated due to incomplete monitoring data.

2. The Colusa Basin Drain, a major agricultural drain, did not contribute to the mass transport at Sacramento because the drain was routed into the Yolo Bypass during unusually high Sacramento River flows.

3. Thiobencarb was not detected in the Sacramento River in 1991 (limit of detection = 0.1 ppb).

Table 15. Maximum concentrations (MC) and frequency of detection (FD) of major rice pesticides in the Coulsa Basin Drain near Knights Landing during April, May and June. Data from Central Valley Regional Water Quality Control Board and Harrington and Lew (1989). N.D. means not detected.

| | Year | | | | |
|---|---|---|---|---|---|
| Pesticide | 1987 | 1988 | 1989 | 1990 | 1991 |
| Malathion | | | | | |
| MC(ug/L.) | | | 14.0 | 0.59 | 0.11 |
| FD | | | 7 of 10 days | 3 of 31 days | 1 of 13 days |
| Methyl Parathion | | | | | |
| MC | | | 6.04 | 0.66 | 0.20 |
| FD | | | 9 of 10 days | 13 of 31 days | 4 of 13 days |
| Carbofuran | | | | | |
| MC | 13.0 | 4.4 | 1.5 | 0.8 | N.D. |
| FD | 9 of 12 days | 8 of 13 days | 16 of 16 days | 8 of 23 days | 0 of 9 days |

methyl parathion in the Colusa Basin Drain in 1991 was 0.2 ug/L, in 1990 the maximum concentration detected was 0.66 ug/L, and in 1989 the maximum detected concentration was 6.04 ug/L. Concentrations of carbofuran have also declined dramatically in the Colusa Basin Drain. Maximum concentrations of carbofuran in the Colusa Basin Drain at Knights Landing have declined from 13 to < 0.1 ug/L between 1987 and 1991. Thus, due to restrictions on rice field water management, the amounts of herbicides and insecticides discharged to the Sacramento River have decreased substantially as a result of the Department of Pesticide Regulation Program.

Based on this information, if discharges of herbicides or insecticides had been responsible for the decline in young striped bass abundance, one would expect to see a substantial recent rebound in the young striped bass abundance index, particularly in 1991. Yet, the 1991 index of 5.5 was the fourth lowest of record and consistent with expectations based on the Department of Fish and Game's model. Furthermore, if rice field drain toxicity accounted for the post-1976 decline in young striped bass abundance to about 30% of its previous average level, toxic exposure would have to be sufficient to kill more than the entire production of the roughly 55% of the population that spawns in the Sacramento River. This is inconsistent with sampling by ourselves, the U.S. Bureau of Reclamation and State Water Contractors which shows that numerous live striped bass eggs and larvae still occur in the Sacramento River.

### *Toxicity as a Potential Source of "Background Mortality".*

The conclusion that toxicity is not responsible for the striped bass decline does not mean that toxicity does not affect striped bass. Our findings do not discount toxicity as a potential source of "background" striped bass mortality.

The studies of larval bass tissue structure from 1988-1990 at U.C. Davis, while showing no evidence of starvation in field-caught fish, do show evidence of toxicity in 26-30 percent of the larvae (Table 16). We do not dispute the results of these U.C. Davis studies which suggest that toxicity is adversely affecting some bass larvae. A reasonable conclusion that is consistent with all of the available information is that toxicity is the source of an unknown level of "background mortality" which has not changed appreciably over the past 30 years. As discussed previously, toxicity dilution may be included in the correlations which show that young striped bass survival improves with increasing outflow.

**Table 16.** Number and percent of striped bass larvae with "poor" liver scores (1 or 1.5) from histological analyses of specimens from the Sacramento-San Joaquin Estuary. Table from William Bennett U.C. Davis.

| | 1988 | | | 1989 | | | 1990 | | |
|---|---|---|---|---|---|---|---|---|---|
| **Group** | **N** | **No** | **Percent** | **N** | **No.** | **Percent** | **N** | **No.** | **Percent** |
| Sacramento River | 32 | 15 | 46.8 | 46 | 13 | 28.2 | 78 | 28 | 35.9 |
| San Joaquin River | 31 | 2 | 6.5 | 19 | 4 | 21.0 | 87 | 21 | 24.1 |
| Antioch | - | - | - | 7 | 3 | 42.8 | 21 | 5 | 23.8 |
| Collinsville | - | - | - | 28 | 6 | 21.4 | 14 | 6 | 42.8 |
| **Total** | 63 | 17 | 27.0 | 100 | 26 | 26.0 | 200 | 60 | 30.0 |

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