The STRIPED BASS DECLINE

in the San Francisco Bay- Delta Estuary

An Analysis by the Striped Bass Working Group for the

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

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CHAPTER I. INTRODUCTION AND SUMMARY

The striped bass population and the fishery that it supports are in very serious trouble. The adult population is presently one-quarter of what it was twenty years ago, and the production of young over the past five years has been one-third to one-half of the expected values. These poor year classes of young will further depress the adult stock as they grow old enough to enter the fishery.

In January of 1982, the State Water Resources Control Board asked a group of scientists, who had been concerned with the striped bass decline, to attempt a better definition of its causes and to identify corrective action that could be initiated. The initial Striped Bass Working Group consisted of: James F. Arthur, of the US Bureau of Reclamation; Louis W. Botsford, UC, Davis; Thomas Cannon, Envirosphere; Charles Hanson, Ecological Analysts; Martin A. Kjelson of the US Fish & Wildlife Service; Donald Stevens of the California Department of Fish and Game; Jerry L. Turner and Don W. Kelley of D. W. Kelley & Associates; and, Roger Wolcott and Thomas Yocom of the National Marine Fisheries Service.

Stephen Hansen of Ecological Analysts, David Kohlhorst and Lee Miller of the California Department of Fish and Game, and Richard Sitts and Gerald C. Cox of the Department of Water Resources, joined us by later invitation.

Our group met almost weekly from late January through March. We were then interrupted for three months by the Governor's freeze on State contracts, but began again in mid-July, and have met regularly ever since. The meetings were usually full-day working sessions at which the whole group or subgroups developed and criticized ideas and hypotheses using available data.

We began with a generalized conceptual model of factors that may influence striped bass stocks (Figure 1). Individual group members reviewed all of the information they could find on the various possible causes of the decline and submitted working papers to the group. We examined old hypotheses and developed new ones. Frustrations were evident over our inability to do the kind of analysis we wanted to do for lack of both data and time. We constantly reminded ourselves that this was not a research project, but an analysis of existing information and ideas. Some new ideas have arisen about the cause of the striped bass decline, but we have found no real surprises. Out of a large number of possibilities, we believe that one or more of the following caused the recent decline.

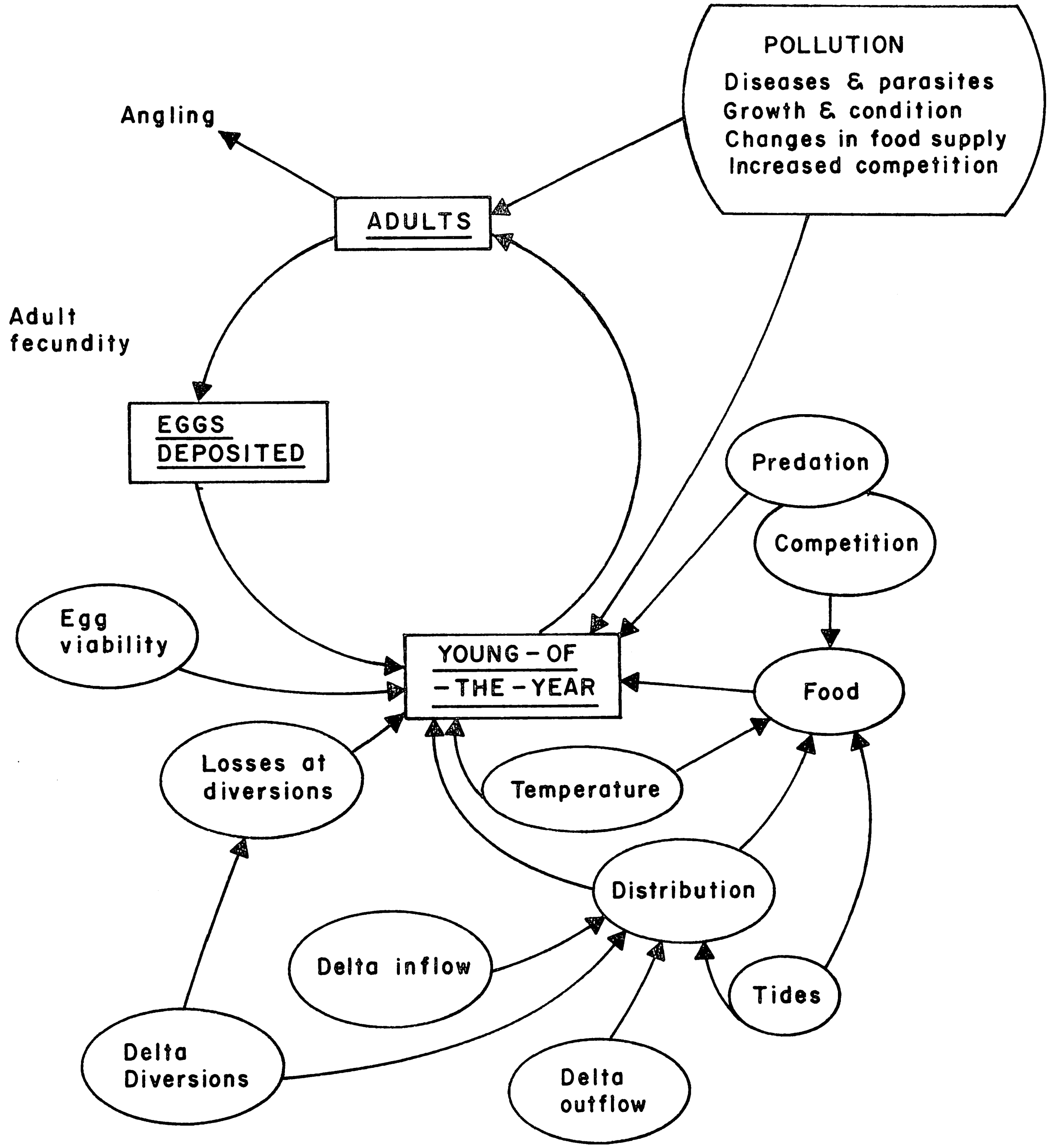

FIGURE 1. One of several conceptual models used to help assess what happened to the bass. The model illustrates the facts that adult bass lay eggs that become young-of-the-year that grow, in three or four years, into adults. The size of the adult population depends on the numbers of young-of-the year previously produced and, before that, on the number of eggs deposited. Many factors influence these relationships.

INADEQUATE FOOD SUPPLY FOR THE YOUNG BASS

Phytoplankton necessary for the development of the zooplankton, which is the food for young bass, fell to extremely low levels in both the western Delta and Suisun Bay in 1977. Since then, there has been a partial recovery only in Suisun Bay, but, even there, the spring blooms necessary to produce high zooplankton densities at the time when the young bass begin to feed, have been delayed until after the bass need them.

There is evidence implicating the CVP/SWP use of the Delta channels to convey water to the export pumps. Only two spring blooms have occurred in the western Delta since 1976. Both occurred shortly after the State Water Project pumps were shut down for repairs to the system and the CVP pumping was reduced. More detailed assessment of existing data followed by field experiments involving CVP/SWP operations are needed. We recommend experimental reductions of total CVP/SWP Delta water exports to 2500 cfs during late April and early May.

Some of our group have suggested that the conversion of many waste treatment plants from primary to secondary levels of treatment may have affected productivity and the bass. They have developed some preliminary information that suggests the matter is worthy of further analysis.

Many of our group favor this hypothesis that inadequate food is the most probable cause for the decline. We have different opinions on the root cause of lower production and all agree that an accelerated search for that cause is urgently needed.

ENTRAINMENT LOSSES IN DIVERSIONS

Current estimates of losses of young fish in the diversions of the CVP/SWP, the agricultural diversions within the Delta, and the PG&E power plants at Pittsburg and Antioch are high. Our group agrees that these diversions themselves are unlikely to be the direct cause of the recent decline, but over the years they could well have contributed to the reduced populations. Available funds should be spent on developing and implementing ways to reduce losses, not in refining estimates of them.

TOXIC SUBSTANCES

There is evidence that adult bass have accumulated some toxins in their flesh at levels exceeding those recommended for the protection of aquatic life, and that pesticides drained from rice fields in the spring, could sometimes affect eggs, larvae, or adults when they are in the Sacramento River. Due to insufficient data prior to 1978, it is currently impossible to rigorously test whether toxic substances were a major cause of the striped bass decline, but many of us believe that these toxicants may be contributing to the striped bass problem. We offer some specific suggestions for continued investigation. Special attention should be paid to gathering data that can be used to test specific hypotheses about the cause and effect associated with these toxic substances.

LACK OF STRIPED BASS EGGS

The adult populations of striped bass have been reduced to the point where their total egg production is only about 10% of what it was two decades ago. Even though billions of eggs are still produced each year, most of us agree that reduced egg production may be reducing the population of young bass. We present some evidence to support the hypothesis, and encourage angling regulations and experimental stocking that will increase adult stocks and their egg production.

*　　　　　*　　　　　*

This report describes those four possible causes of the bass decline as hypotheses. In reality, the decline may be the combined effect of several problems. It may never be possible to find a single cause for either the long-term striped bass decline since the middle 1960s, the accelerated decline that occurred in 1977, or the population's failure to recover. We believe it is essential to pursue all four hypotheses with vigor and we have recommended how that can be done.

The decline and loss of fisheries resources is usually accompanied by much argument over what is the real cause or who is the real culprit. Rarely is a single cause proven and, while the argument rages, the resource disappears--usually forever. We urge the State Water Resources Control Board and other agencies, to take prudent action to restore the Delta as productive striped bass nursery habitat, to reduce losses by entrainment, to reduce the deposition of toxic substances, and to help maintain adult populations and the needed egg production by temporarily reducing angler take and by experimental stocking.

The maintenance of adequate Delta outflow is, of course, essential. The events of recent years and our assessment, leads to the conclusion that outflow alone is not enough.

CHAPTER II. DECLINE IN THE ABUNDANCE OF YOUNG STRIPED BASS

Since 1959, the California Department of Fish and Game has measured the abundance of juvenile striped bass throughout their nursery habitat in the Sacramento/San Joaquin Estuary (Figure 2). Field crews sample these small fish every other week from spring to mid- or late summer. The fish are measured and a young-of-the-year index for striped bass of that current year class is calculated on the basis of catch per net tow and the volume of water in the areas where the fish are caught, when the average length is 1.5 inches or 38 mm. Our group believes that the method is sound and that it has produced one of the best measures of long-term population trends of juvenile fish populations anywhere in the world.

The young-of-the-year index has a well recognized bias that in high flow years a larger proportion of the young are washed downstream into San Pablo Bay, or even further, where the very large volume of water is difficult to sample effectively. Thus, in very wet years, the index is an underestimate of the actual population. Corrections for that underestimate can be made, but the matter does not affect our conclusions.

The young-of-the-year striped bass index has been unsteadily, but persistently, declining since high levels of the mid-1960s (Figure 3). The decline has been steadier in the Delta, but is clearly visible in Suisun Bay even though the year to year fluctuations there have historically been much greater.

The distribution of young bass within the Delta or in Suisun Bay is only remotely related to where the adults spawn. The two major spawning areas are in the Sacramento River from the city of Sacramento to Colusa; and in the San Joaquin River, from the vicinity of Antioch to the mouth of the Mokelumne River. The eggs are almost the same density as water, and they drift freely for two to three days, hatch into small larvae and, in about five days become small feeding striped bass 4-7 mm long. When they have reached 38 mm in length about nine weeks later, these bass are much better swimmers but their distribution to that time, and perhaps for months later, is primarily the result of their movement with the water currents.

This knowledge has led biologists for many years to worry about construction and operation of the Central Valley Project and the State Water Project. In the early 1950s, before construction of the Central Valley Project, they warned of the dangers of diverting large numbers of young fish along

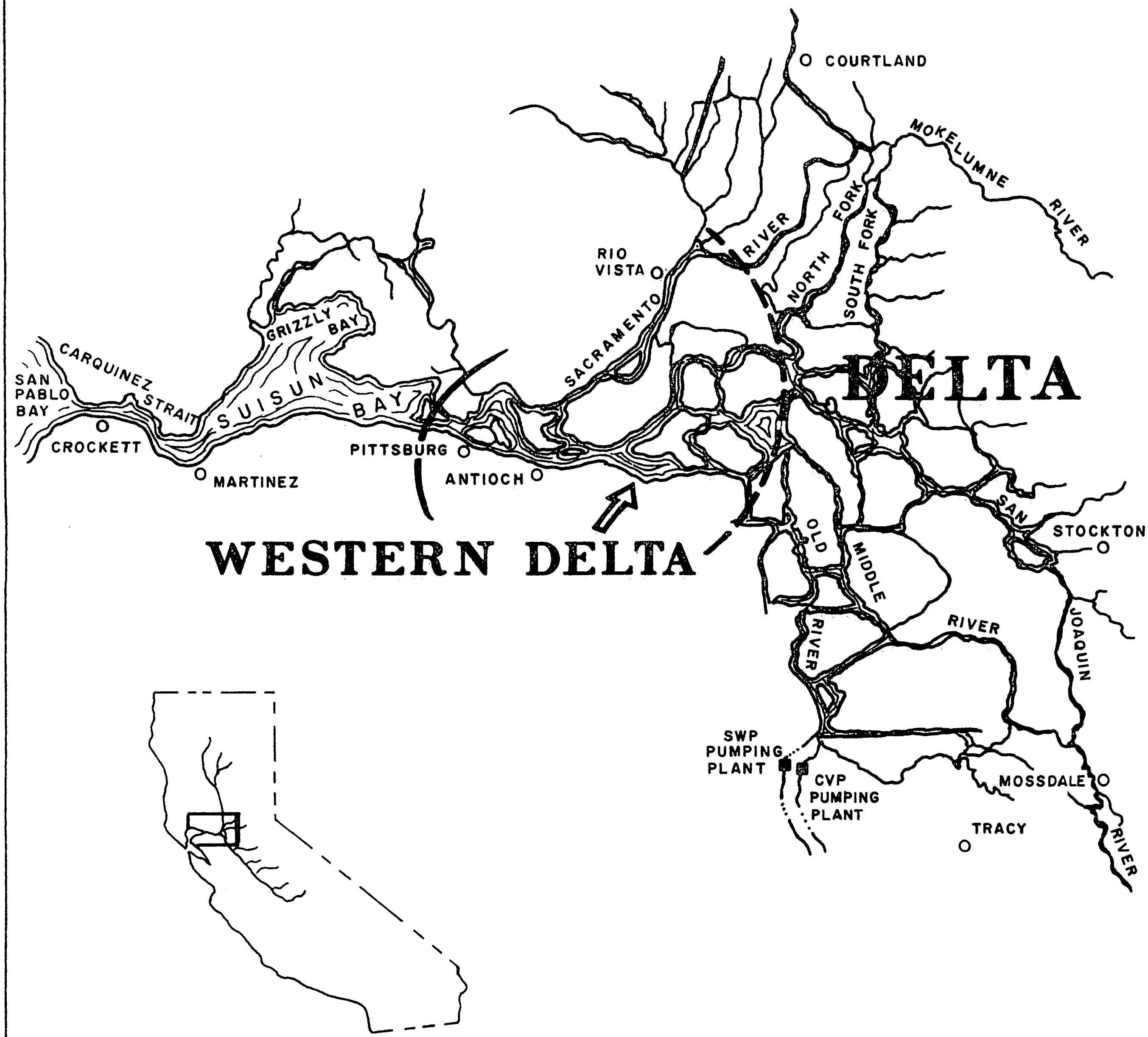

FIGURE 2 . The upper end of the Sacramento–San Joaquin Estuary. The principal striped bass nursery areas are the broad channels of the western Delta and in Suisun Bay.

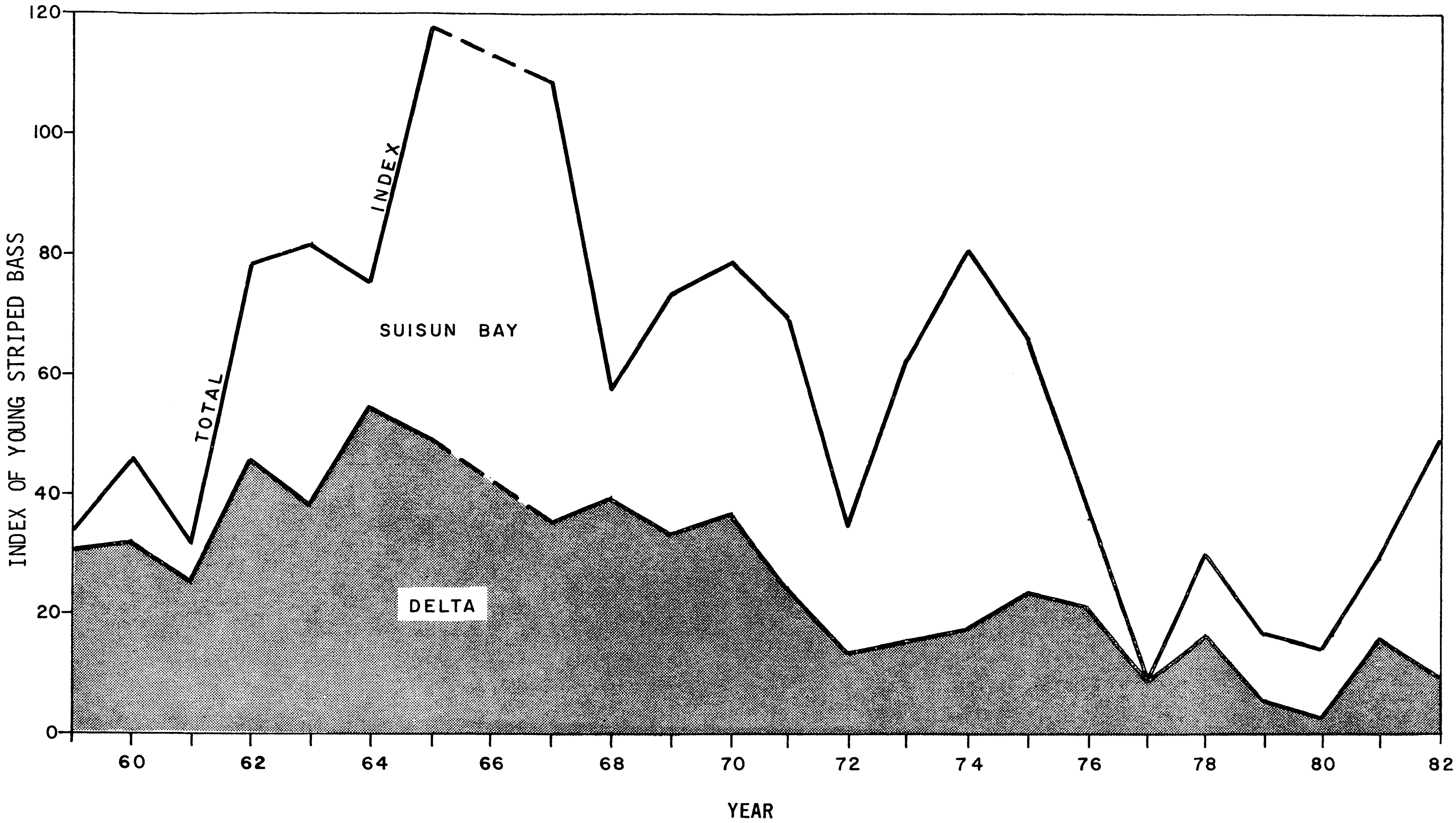

FIGURE 3 . Annual index of young striped bass by area in Sacramento-San Joaquin Estuary. No sampling was conducted in 1966. There has been a major decline in the annual population of young striped bass. The population in the Delta has declined at a steadier rate than the population in Suisun Bay (CF&G, 1981).

with the agricultural water. In the 1960s, investigations added warnings and provided evidence of reduced food production in the interior Delta channels. In the 1970s, more concern was expressed about the reductions of freshwater outflow to the Bay. These and other matters have been investigated by several agencies.

During the years 1959-70, the abundance of young bass was correlated with both June-July outflow and the percent of June-July Delta inflow diverted by the CVP, SWP, and Delta agriculture. In years when spring outflow was higher and the percent of inflow diverted was low, the bass index was high, whereas when outflows were low and the percent diverted was high, the young bass index was low.

In the early 1970s, bass abundance was lower than expected based on the 1959-70 relationships of abundance-outflow and abundance-percent diverted (Figure 4). In particular there was a decline in young bass abundance in the Delta portion of the estuary. This decline was explained by the higher diversion rates in May and June of those years. Hence, for years 1959-76, May and June outflows and the amount of water diverted in those months explained bass abundance in the Delta (Figure 5). Bass abundance in Suisun Bay for those years was best explained by June-July outflow (Figure 6).

This analysis was the basis for the State Water Resources Control Board's Decision 1485 which placed constraints on the amount of water exported by the CVP and SWP during the spawning and early postspawning period. Outflow and export criterion established in D-1485 were designed to maintain the young-of-the-year index at levels which the State Board staff estimated would have existed without the project.

In 1977, the second year of a severe drought, the relationships between bass abundance and outflow and diversions fell apart. The expected index based on the flows and diversions was 47 but the observed index was 9. However, the real cause for alarm has been the fact that the index has remained much lower than expected for every year since 1977. In 1982 the index was the highest (48.7) since 1975 but was much lower than predicted (79). Obviously something has been different since 1976.

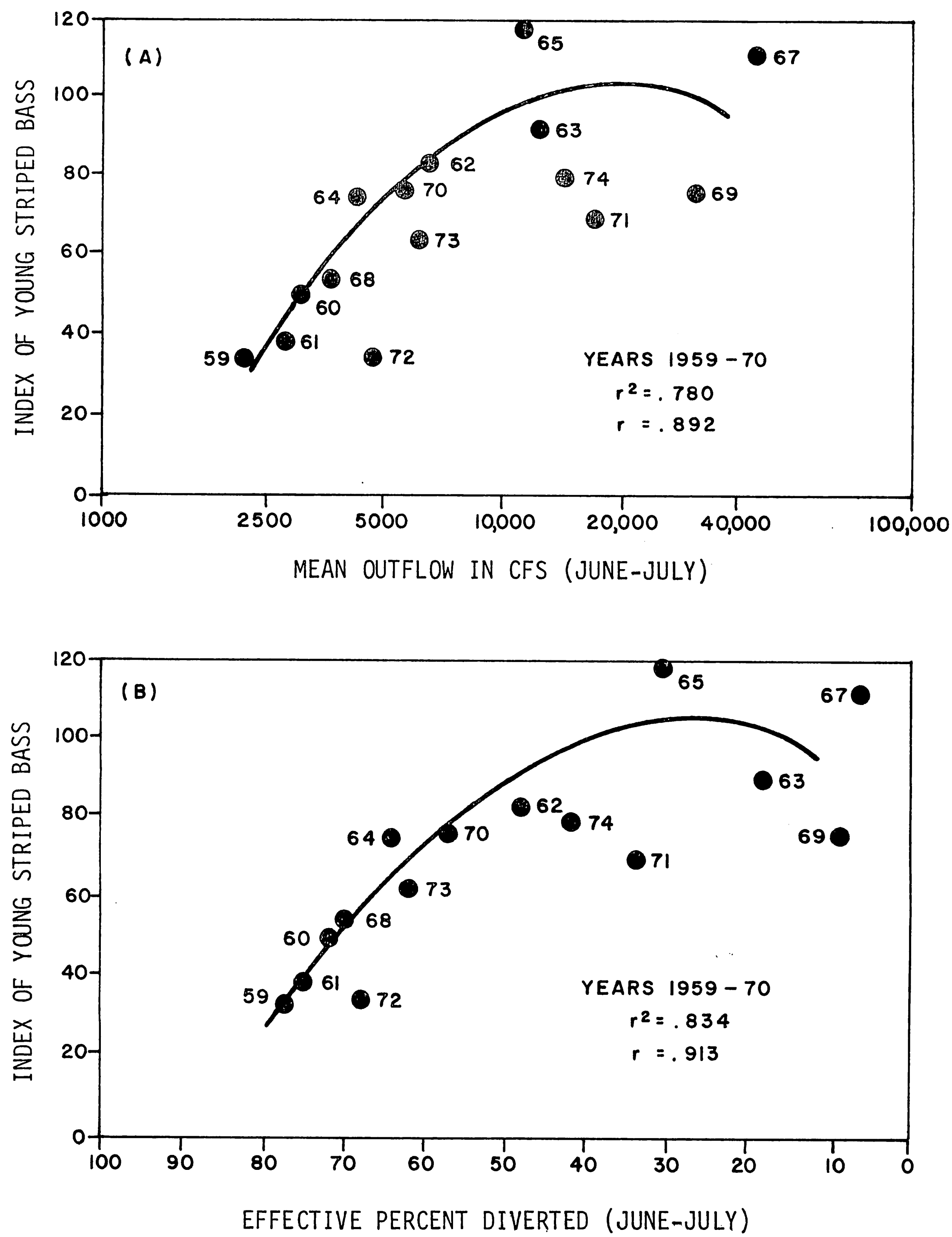

FIGURE 4. Relationships between (A) young striped bass abundance and Delta outflow past Chipps Island and (B) young bass abundance and effective percent of Delta inflow diverted to CVP/SWP pumping plants. Lines fitted for 1959-1970. Numbers adjacent to points indicate years. No samples collected in 1966. Note values in early 1970's falling below line. (CF&G, 1975).

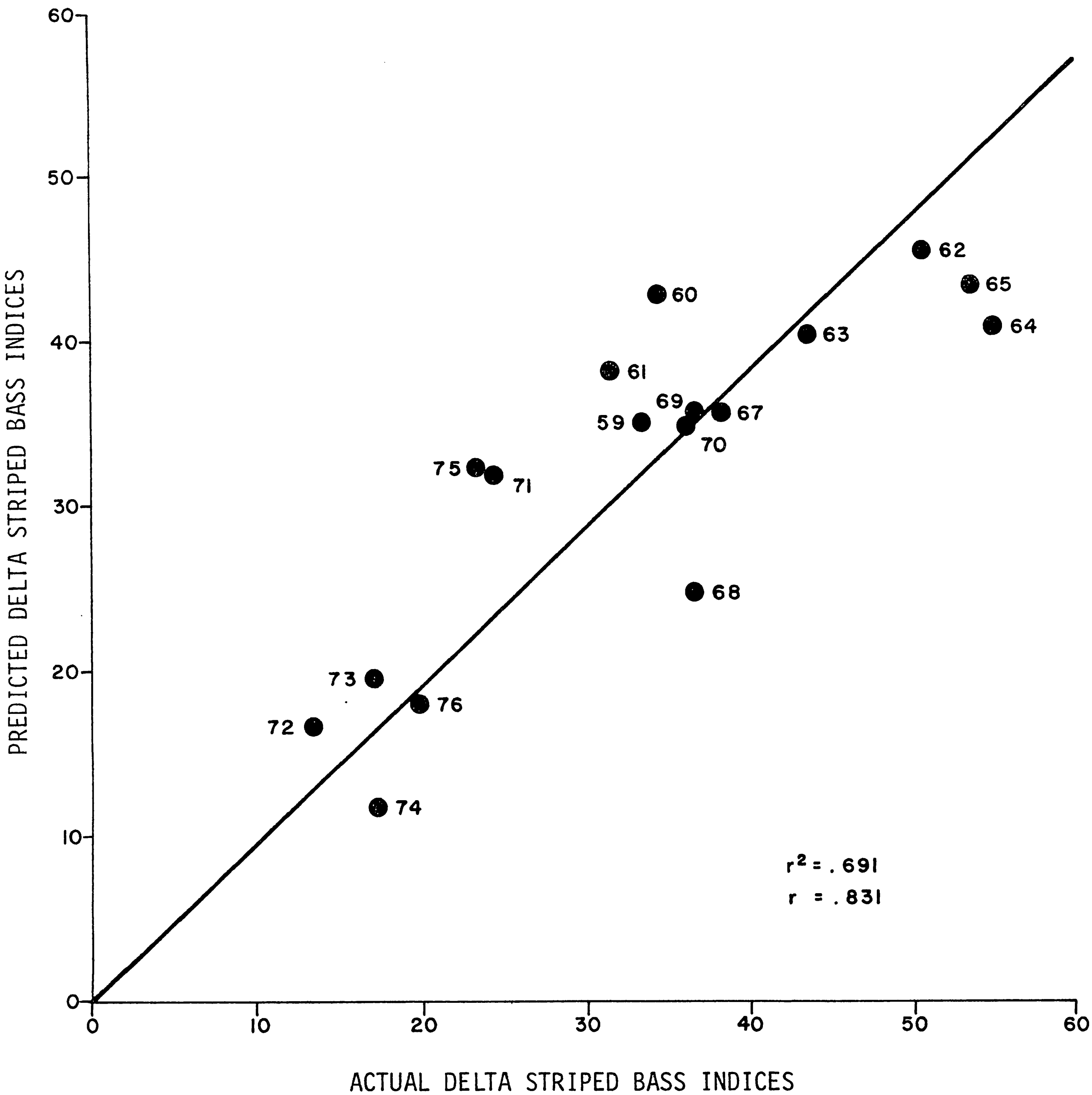

FIGURE 5. Relationship between actual striped bass abundance in the Delta and predicted striped bass abundance in the Delta based on May-June diversions and May-June Delta outflows.

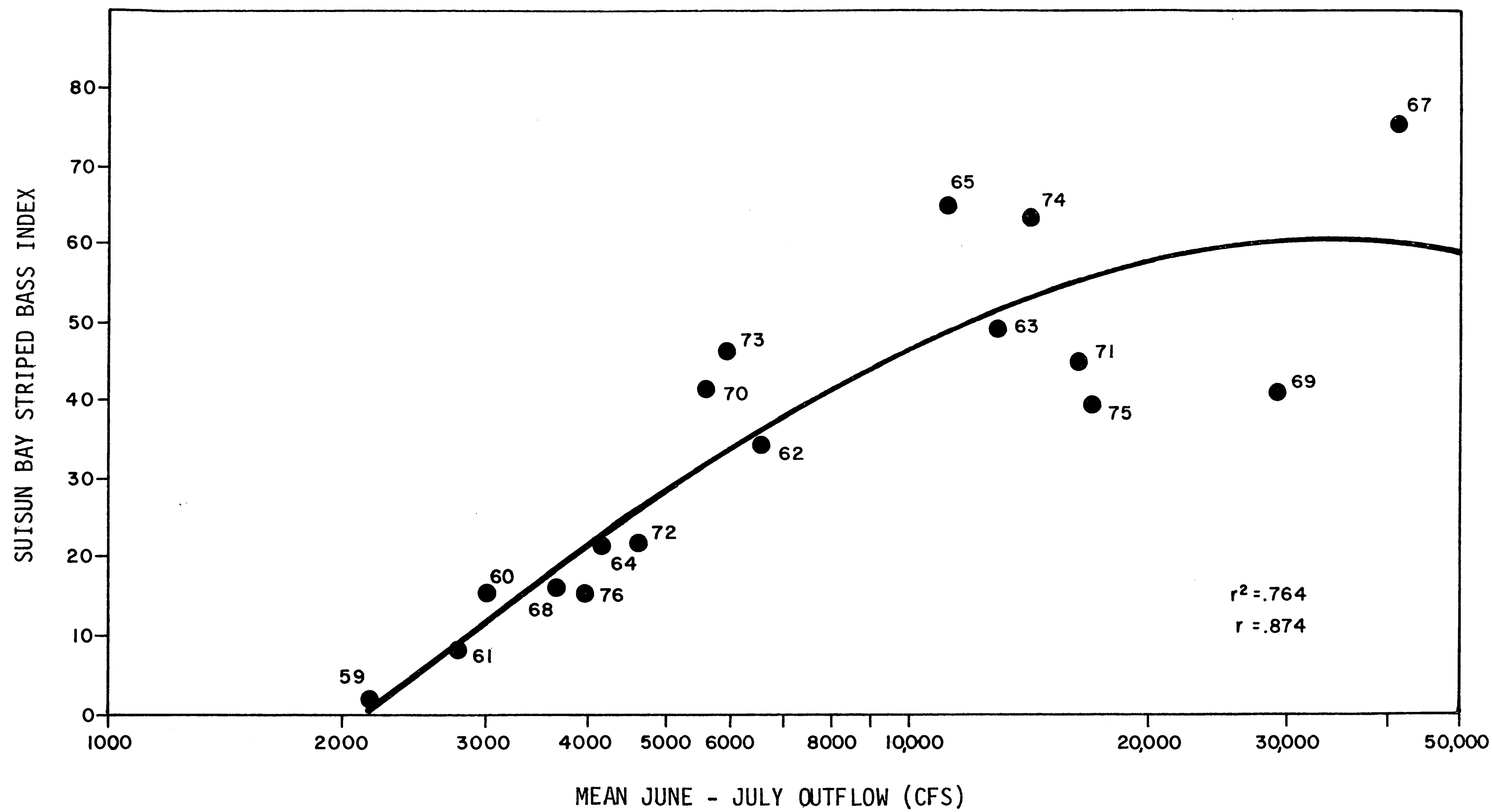

FIGURE 6. Relationship between young striped bass abundance in Suisun Bay and mean June-July outflow.

CHAPTER III. THE ADULT STRIPED BASS POPULATION AND THE FISHERY

Most adult striped bass spend much of their time in central San Francisco Bay. In the spring, sexually mature fish migrate upstream to broadcast and fertilize their eggs in the San Joaquin River near Antioch and in the Sacramento River as far as 140 miles above the Delta. After spawning, the adults return quickly to central San Francisco Bay and the Pacific Ocean near San Francisco where they spend the summer feeding actively on the numerous small fishes that live there. About half of the striped bass caught by the anglers in the Sacramento-San Joaquin system are caught in the Bay area.

ESTIMATES OF ADULT POPULATION SIZE

The Department of Fish and Game has estimated abundance or changes in abundance of adult bass by several methods during the past 20 years. Each series of estimates is available for different but overlapping periods within the 20-year interval. CF&G uses different methods because estimating the adult bass population is very difficult and imprecise. Each method is subject to different types of errors that can greatly influence the estimate, and all but long-term trends demonstrated by several methods must be viewed with caution.

(1) "Petersen population estimates" of the adult striped bass population are made by tagging large numbers of the adults during their upstream migration in the spring and subsequently comparing the proportion of tagged to untagged fish that are caught by anglers and by CF&G in subsequent tagging operations. According to Petersen estimates, the adult striped bass population was remarkably stable between 1969 (when the estimates began) and the spring of 1976 (Figure 7a). It was then reduced to half by the spring of 1977 and had recovered only slightly by 1979, the last year that Petersen estimates are available.

(2) An index of adult abundance is based on catches of bass in nets and traps that are set in the spring by CF&G to catch fish for tagging. The index represents a large amount of netting by skillful fishermen. Variations in effort from one year to the next are standardized so that the index represents the numbers of fish caught in 80 netting boat days and 36 fyke trap months each year.

This index indicates that the adult bass population declined steadily from the late 1960s to a low level in 1975, rose briefly but declined to even lower levels in 1980 (Figure 7b). Subsequent indices have not yet been calculated by CF&G, but the recent year catches in gill and trap nets have been extremely poor and the 1981 and

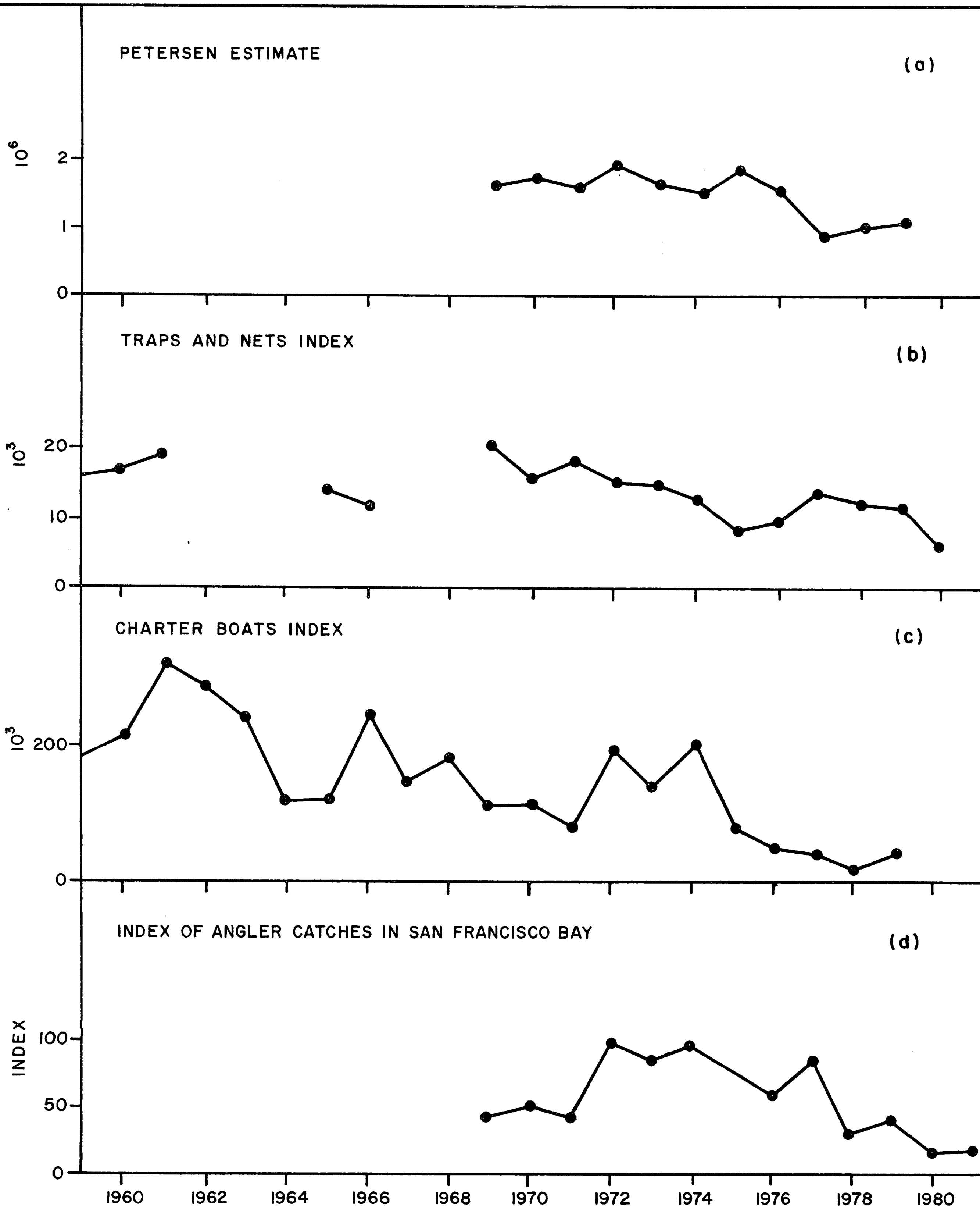

FIGURE 7. Comparison of population estimates of adult striped bass.

1982 indexes will be lower than all previous ones.

(3) Another index is based on a procedure that involves the catch of bass reported by charter boat operators in the Bay area and the return of tags placed on the bass by the Department of Fish and Game in the spring. This estimate shows a long-term but very uneven decline in the adult population since the early 1960s when bass fishing was very good to the late 1970s when it was extremely poor (Figure 7c). It indicates cycles of good and poor catches with the low points becoming lower over the 20-year period. According to this estimate, the last such decline started in 1974 and the index dropped to about 10% of what it was 20 years ago.

(4) Another index is based on Department of Fish and Game inspection of catches by anglers in the San Francisco Bay area. This estimate indicates an adult population drop similar to the one based on charter boat catches, except that information is available only since 1969, and is evidence of a decline since 1974 (Figure 7d).

There is no question that adult striped bass populations have fallen to very low levels - much lower than they have been since estimates were first available, 20 years ago. Our group is divided over whether the precipitous decline in the early and mid-70s suggested by the Petersen and perhaps the charter boat estimates, but not by the others, are real or simply the result of errors that are inherent in the methods. Statistically, the sudden decline estimated by the Petersen method is not proven.

Confidence in "Petersen" estimates which indicate a sudden 1977 decline depends upon tagging very large numbers of fish and, subsequently, observing at least fair numbers of tagged fish caught by anglers or from netting. In recent years, the numbers of tagged fish observed by CF&G creel census personnel have been so small that statistical confidence limits of the 1977, 1978, and 1979 estimates are very broad.

It also seems probable that if there was an abnormally high die-off in 1976 or early 1977, there would have been numerous reports of dead fish. Our group has not found such reports. An annual die-off of striped bass and other fishes has occurred each summer for the past forty years in the Carquinez Strait-Suisun Bay area. The reason for this mortality has never been determined, but field observations suggest its magnitude was not abnormally high in 1976. This die-off reportedly was greater than normal in 1977, but occurred after the Petersen population estimate was made.

Finally, the estimates of annual mortality (Figure 8) indicate that while mortality in 1976 was higher than average, it was not high enough to account for the precipitous decline exhibited by the "Petersen estimates". These mortality estimates are based on much larger numbers of tag returns than are available for estimating abundance by the "Petersen method"; thus, theoretically, the mortality estimates should be much more reliable.

But whether the decline of adult bass stocks was accelerated in 1976 or not, all measures of abundance indicate that in the latter part of the 1970s, adult bass abundance was only about half of what it was in the early 1970s. Department of Fish and Game personnel, checking angler catches five days per week in the last three years, at five major San Francisco Bay ports, have seen fewer striped bass than ever before. And this last spring, Department of Fish and Game tagging crews were able to capture only about 4000 fish with drifting gill nets as compared to between 14,000 and 18,000 fish with similar effort in the mid-1970s. There seems no question that the adult stocks have continued to decline!

ESTIMATE OF ADULT MORTALITY RATE

As with all animal populations, some bass die for various reasons each year. Figure 8 illustrates estimates of the percent of the adult population that died from one spring to the next in each year between 1969 and 1978. These annual mortality rates increased from about 40% to above 50% by 1975 but appear to have begun declining either during or after the drought. More recent estimates have not yet been made.

The most obvious source of adult mortality is, of course, angling. The CF&G tagging studies provide good data on harvest rates. From 1970 to 1974, the percentage of the total adult population taken by anglers per year increased from about 12% to 22% (Figure 8). These angling harvest rates remained at similar levels until 1976, after which they fell rapidly. The increased take of anglers during and through the mid-1970s can explain part, but not all, of the increasing mortality rates. The total mortality rates started to decline as catch declined in the late 1970s.

EFFECTS OF TOXIC SUBSTANCES ON ADULTS

In August 1982, the Cooperative Striped Bass Study (COSBS) of the State Water Resources Control Board, the National Marine Fisheries Service Tiburon Laboratory, and the Department of Fish and Game, released some of their findings about the health of the striped bass in the Sacramento-San Joaquin Estuary and in the rivers above. We have reviewed the data available at this time. The COSBS studies are continuing, and additional information will be forthcoming from that group.

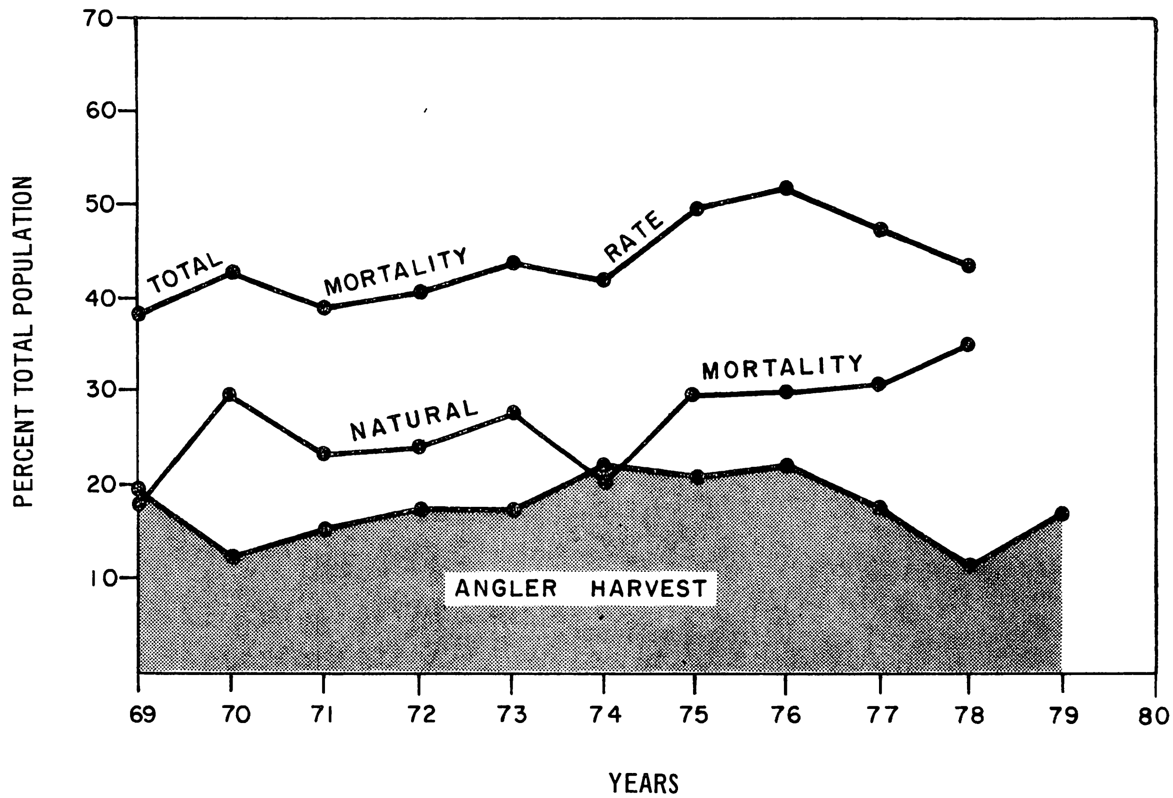

FIGURE 8. Fluctuations in annual mortality of adult striped bass, Sacramento-San Joaquin Estuary. Estimates show an increase in angler harvest rates during the early 1970s, but a much greater increase in total mortality rates in the middle to late 1970s.

In general, the COSBS has found that the gonads, liver, and muscles of striped bass, collected from the Sacramento-San Joaquin system since 1978, had accumulated some toxic substances--primarily, monocyclic aromatic hydrocarbons, chlorinated hydrocarbons, and heavy metals. The tissue levels are evidence that the adult bass had experienced considerable exposure to these compounds. PCB levels in striped bass tissue exceeded values established to protect aquatic life but were still below levels established as safe for human consumption.

They found some correlations between elevated levels of monocyclic aromatic hydrocarbons and zinc in the flesh and organs of the striped bass with a general decline in fish health, as assessed by a reduction in liver condition, gonad condition, and the condition of eggs. They also found that high tissue levels of these compounds sometimes resulted in heavier parasite infestation which altered the uptake and depuration kinetics of benzine and zinc.

Their preliminary findings also suggested that striped bass captured in the San Joaquin Delta near Antioch may be in poorer health than those taken from the Sacramento River near Clarksburg. That is, they tended to have higher concentrations of hydrocarbons, heavy metals, and internal parasites but these differences were not statistically significant.

To explore the possible effect of this on the bass populations, some members of our group calculated natural mortality rates for fish tagged in the San Joaquin Delta and for those in the Sacramento River. The results suggested that mortality rates were not higher for the Delta fish.

Some laboratory studies were subsequently performed, and others are in the process of being performed, in order to determine if there is a cause and effect relationship between the exposure to toxins of this nature and what those working on this problem believe to be poor health of the population.

Another approach to analysis of fish health is to examine the relationship between length and weight, or relative plumpness of fish (K factor). Data gathered by Dr. Jeanette Whipple and staff of the National Marine Fisheries Service Tiburon Laboratory, suggests that while there is no apparent difference in the K factor between Sacramento and San Joaquin fish, the striped bass collected in 1980 appeared somewhat thinner than they were in 1978 and 1979 (Figure 9). Some of our group have obtained historical data on lengths and weights of striped bass from this Estuary, and from the Atlantic Coast and Chesapeake Bay. While those fish measured and weighed from the Sacramento and San Joaquin Estuary in 1980

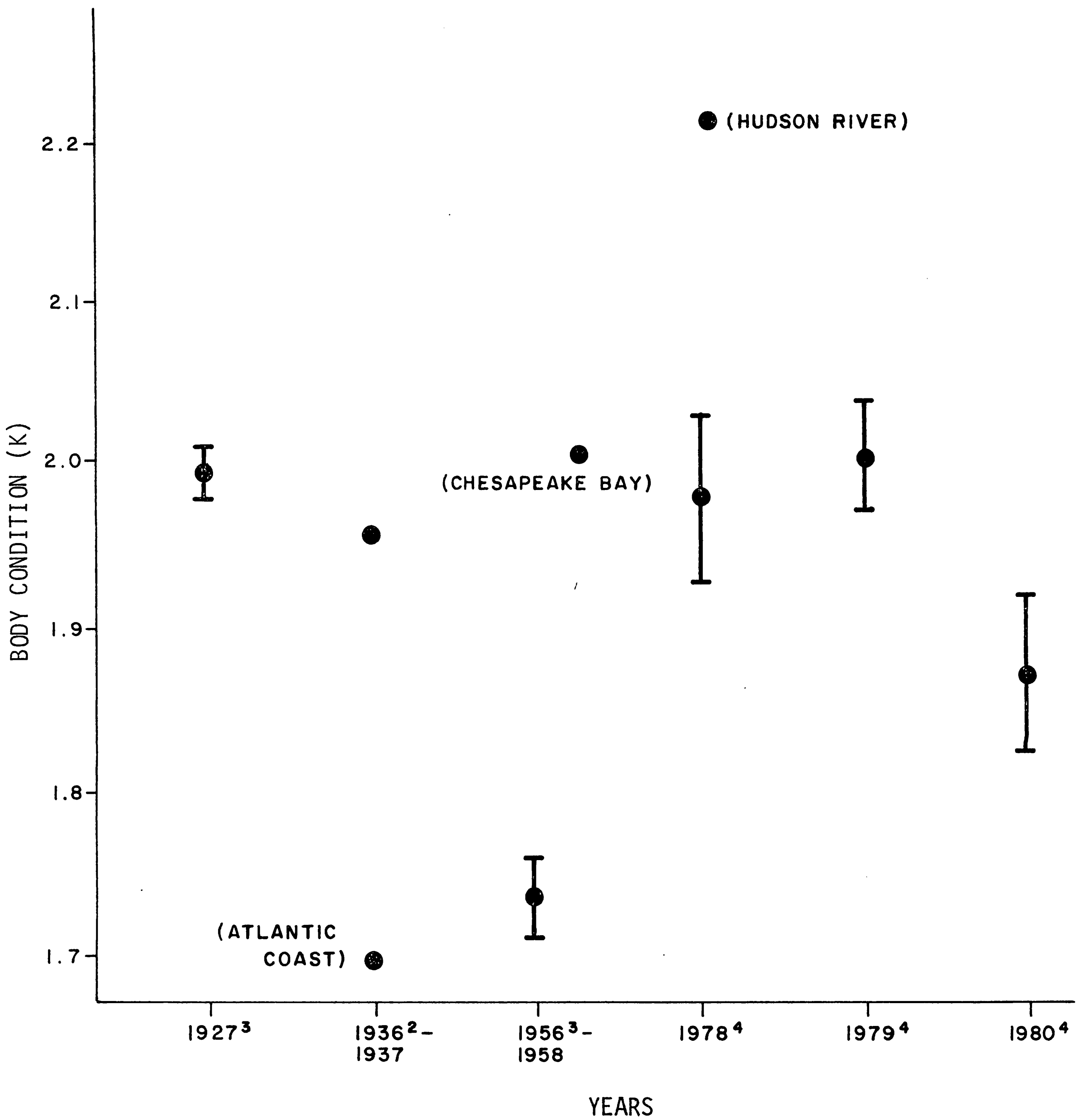

FIGURE 9. Trends in the body condition of adult striped bass in the Sacramento-San Joaquin Estuary and in other systems which are designated as such. Small numbers next to years note references; 1 Scofield (1931), 2 Clark (1938), 3 unpublished CF&G, 4 Whipple, et al. (1982). Data expressed as mean with 95% confidence limits. (Yocom and Wolcott, 1982).

were somewhat thinner than some groups collected at previous times in this and other estuaries, they were not as thin as those collected in the Hudson River, or in this Estuary at other times.

Evidence that toxic substances are damaging bass populations is difficult to obtain. However, documentation of sublethal concentrations of toxic substances known to be damaging in the flesh and vital organs, including the reproductive organs, of striped bass, are unquestionably a matter of concern that needs vigorous and persistent investigation.

DO THE ADULT BASS LACK FOOD?

During the early deliberations of our group we raised the question of whether there might have been a decrease in the abundance of food for adult striped bass and whether such a decrease could have caused increased mortality and ultimately the population decline. We have found no reason to believe this is the case. The adult striped bass do not feed much while on their spawning migrations in the Delta or up the Sacramento River, but feed voraciously in San Francisco Bay, primarily on northern anchovies, herring, and many other kinds of small fishes.

The food supply is not well measured, but our group could find no reason to believe that it had significantly diminished. We concluded that the best approach to determining whether there was a shortage of food would be to examine the growth rates of adult striped bass over the years. That information has been analyzed and published by Barry Collins of the Department of Fish and Game in Stockton. He found that although 1970 and later year classes averaged 2 cm smaller than the 1965 to 1969 year classes, the actual growth rates of adult fish had not changed. The size reduction was due to the recent slower growth during the striped bass' first year of life (Table 1).

INFLUENCE OF THE DECLINING NUMBERS OF YOUNG-OF-THE-YEAR ON THE ADULT POPULATION

Obviously, one of the factors we would expect to influence the size of the adult striped bass population is the number of young-of-the-year produced three or more years earlier. Unless some factor or factors cause the lower numbers of young produced in recent years to survive better, the decline in the young-of-the-year index from the mid-sixties to the late seventies, should produce a much lower adult population.

The question of whether young-of-the-year actually do survive better in years when fewer of them are produced has not

Table 1. Annual growth increments (cm) of striped bass in the Sacramento-San Joaquin Estuary. (Collins, B. W. Growth of adult striped bass in the Sacramento-San Joaquin Estuary. Calif. Fish & Game 68(3):146-159)

	MALES									
	YEAR									
AGE	1969	1970	1971	1972	1973	1974	1975	1976	1977	MEAN
3* . . .	7.2	6.0	8.6	8.2	7.0	7.3	7.4	7.3	7.0	7.3
4 . . .	8.2	7.5	9.4	7.3	7.2	6.6	7.0	6.6	6.3	7.3
5 . . .	6.4	6.5	8.5	6.3	6.5	6.5	6.9	7.2	7.0	6.9
6 . . .	5.3	5.8	6.6	4.7	5.2	5.1	4.9	5.8	6.3	5.5
7 . . .	4.4	4.1	5.0	3.8	4.8	3.8	3.8	3.5	(4.2)+	4.2
8 . . .	2.7	2.6	4.8	2.6	3.6	1.7	3.2	(3.0)+	(3.0)+	3.0
Annual Mean	5.7	5.4	7.2	5.5	5.7	5.2	5.5	5.6	5.6	5.7
AGE	FEMALES									MEAN
3* . . .	11.7	11.4	12.9	11.7	9.9	9.4	8.9	10.1	11.5	10.8
4 . . .	10.0	8.6	9.6	9.2	9.3	10.3	11.2	11.0	9.6	9.9
5 . . .	5.7	6.6	8.7	6.7	6.5	7.5	7.3	7.6	7.5	7.1
6 . . .	5.0	7.3	7.5	5.4	5.8	5.3	5.3	6.2	5.2	5.9
7 . . .	4.4	4.6	5.6	4.2	5.0	3.7	5.2	4.8	(4.7)+	4.7
8 . . .	3.2	3.0	5.2	3.6	4.2	2.2	5.1	(3.8)+	(3.8)+	3.8
Annual Mean	6.7	6.9	8.2	6.8	6.8	6.4	7.2	7.2	7.0	7.0

* Biased low

\+ Growth increment not available for this year; therefore, the mean increment for the age group was used in calculating the annual mean increment for this year.

been definitively answered in this estuary, but our group has found some evidence that they do not. Among the best evidence, is a comparison of the index of the young-of-the-year with an index of the number of four-year-old striped bass caught during the tagging operation (Figure 10). As one would expect, there is a considerable spread in the data. Nevertheless, it does appear that better production of young-of-the-year will produce larger numbers of adults and that a greatly diminished production of young-of-the-year will cause the adult population to decline.

A mathematical model of the striped bass population was constructed to evaluate various hypotheses regarding the influence of adults and environment on young-of-the-year. We can also use the model to see whether a population with an assumed direct relationship between young-of-the-year and year class size is consistent with the observed data and to project the effect of current low levels of young-of-the-year on future adult levels.

The model is an age-structured model that keeps track of the number of bass at each age by removing angler catch and natural mortality from each age class each year. The youngest age class is filled each year by an estimate of recruitment based on the young-of-the-year index multiplied by a constant, chosen to give the actual estimated adult population level in 1970. The model starts with the age structure measured in 1959. It uses estimated harvest rates and a natural mortality rate that begins to increase slightly in 1971. This mimics the increase in natural mortality implied by the estimate in Figure 8 and assumes that it will continue.

If we assume a direct relationship between young-of-the-year bass and subsequent adult populations, the baseline model produces a reasonable picture of the real striped bass population over the last 23 years (Figure 11). In addition to the long-term decline in adults that has already occurred, recent low young indices predict even lower adult abundance in the future. Young-of-the-year indices through 1982 can be used to project adult abundance through 1985, the year in which that age class would enter the population. As seen in Figure 11, adult abundance continues to decline to less than 300,000 in 1984 after which it increases slightly to 400,000 in 1985.

While the model is a useful tool, results must be interpreted with caution. Nevertheless, most members of our group believe that the decline in the abundance of adult striped bass is almost certainly due to the long-term reduction in the abundance of young-of-the-year combined with the increase in adult mortality rates.

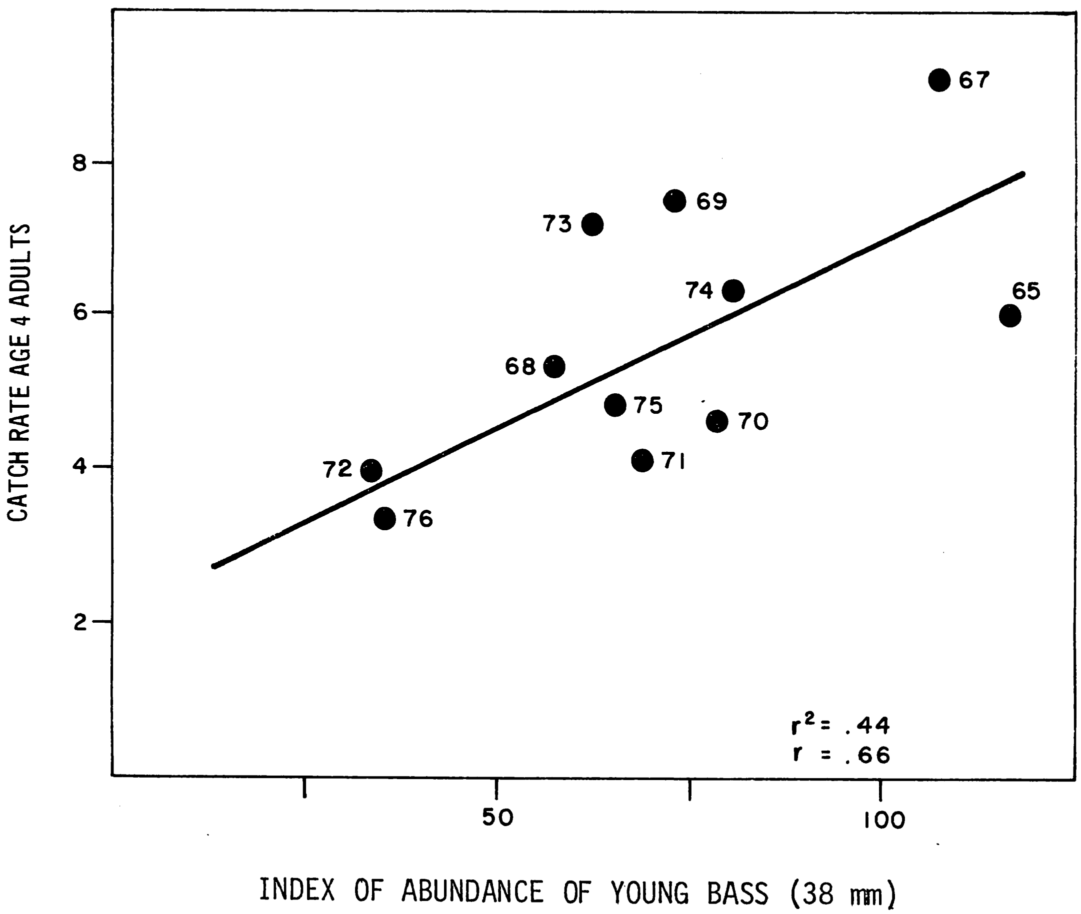

FIGURE 10. Relationship between index of abundance of young striped bass and index of catch per effort of age 4 adults caught four years later in gill nets and fish traps. Unpublished data CF&G.

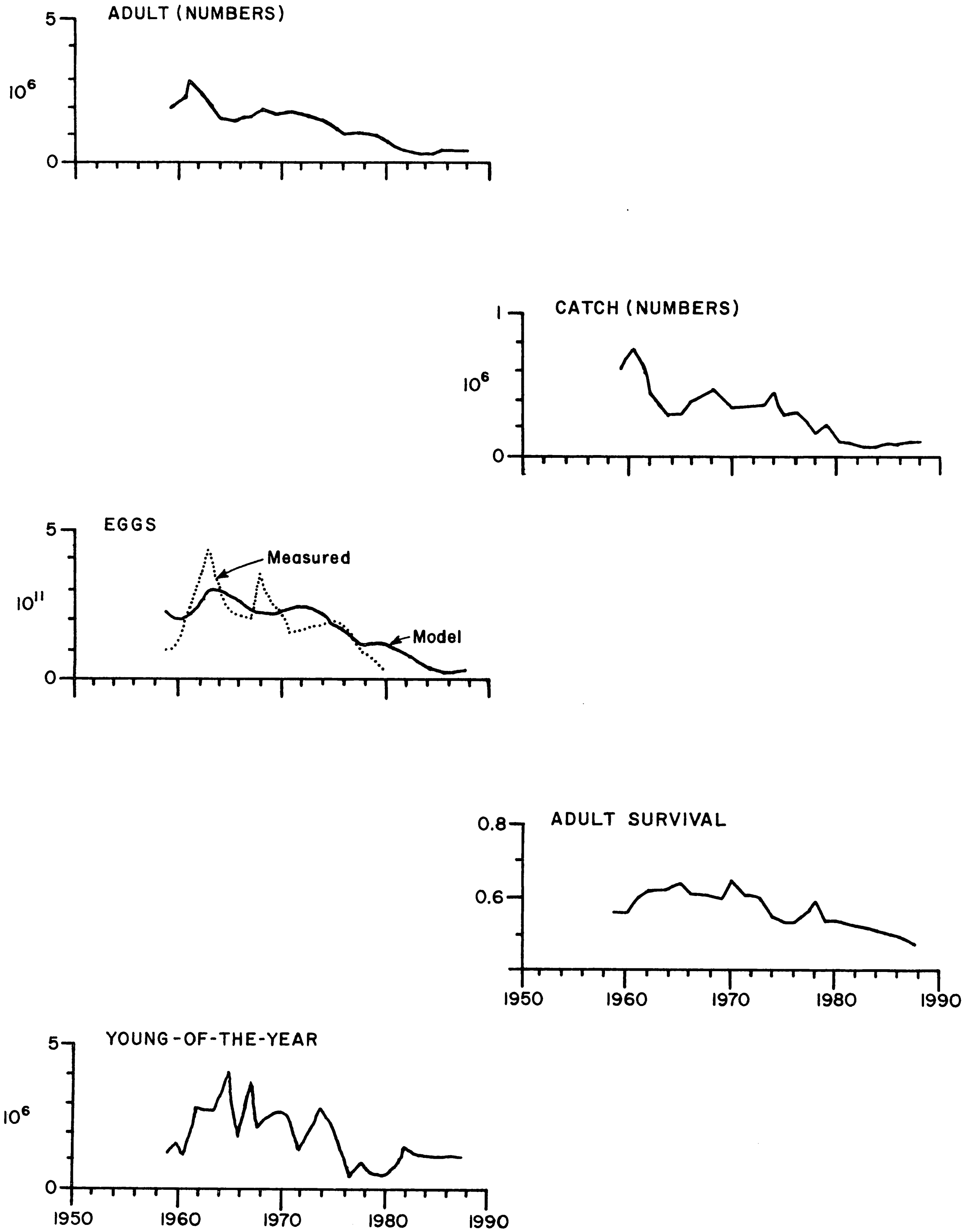

FIGURE 11. Model simulation of the effects of the measured reduction in young-of-the-year loss on adult populations from 1959 to the present with projected future adult levels based on young index through 1982.

CHAPTER IV. PROBABLE CAUSES OF THE DECLINE IN YOUNG STRIPED BASS

We have so far described how both young-of-the-year and the adult population of striped bass have declined and how, at least, the young-of-the-year have done so at an accelerated rate in recent years. We believe that the adult bass population has fallen as a combined result of there being fewer young-of-the-year and because of a recent increase in adult mortality from 1969 to 1976. The combination of these two factors brought the adult population down to one-quarter or less of what it was two decades ago.

Our group has examined many possible causes for the young-of-the-year decline and, of those, we agree that four remain as probable major contributors to the problem. They are:

(A) Production of food for young striped bass has been reduced.

(B) Large numbers of eggs and young bass are removed from the Estuary by diversion with water needed for agriculture, power plant cooling, and other uses.

(C) Point and nonpoint discharges of pesticides and other petroleum products may increase mortality of adults, reduce their ability to reproduce, and/or reduce the survival of eggs and young.

(D) The adult population, reduced by a combination of declining numbers of juveniles and higher mortality rates, produces fewer eggs.

Our purpose in the remainder of this section is to describe what is known about these influences.

REDUCED FOOD PRODUCTION IN THE BASS NURSERY AREA

The upper part of this Estuary, i.e., the tidal channels of the interior Delta, the lower Sacramento and the San Joaquin Rivers themselves, and Suisun Bay - particularly the upstream half, has been the principal nursery habitat for the young striped bass since investigations began in the 1940s. The young bass spend their entire first summer of life there and the numbers that survive during this period probably determine the size of future adult populations.

The young bass begin feeding on small crustacean zooplankton a few days after they hatch and as they grow, feed on larger zooplankters such as the opossum shrimp, Neomysis mercedis. They begin feeding heavily on the small fishes only after their second summer of life.

The large amount of data collected as a result of Fish and Game studies and the monitoring program required by the State Board, provides evidence that there has been a general overall decline in the productivity of this nursery area during the past several years. The decline has been great enough to cause a major reduction in the amount of food available for young bass.

Sampling of phytoplankton and Neomysis has been done for many years--the following assessment makes use of that information. The phytoplankton information is particularly useful as it is a principal food of zooplankton in the system, it is at the base level on the food chain, and it responds rapidly to major environmental changes.

Figure 12 illustrates the mean concentrations of phytoplankton found in the western Delta (upstream from the junction of the two rivers) throughout each year from 1969 through 1982. Until 1977, except for 1969, there was a spring increase (called a bloom) of phytoplankton in the western Delta. No spring bloom occurred in 1977, 1978, 1979, or 1980. Blooms did occur in mid-May 1981 and in late June 1982, soon after the CVP/SWP export pumping was reduced during repairs.

Figures 13 and 14, describe the relative densities of the Neomysis population in two parts of the western Delta. In these important areas of the nursery habitat, Neomysis production was very poor in 1977, 1978, and 1979. In the lower Sacramento River the decline appears to have started several years before 1976.

Figure 15 illustrates the phytoplankton concentrations in Suisun Bay. Seasonal changes there are harder to predict, but we have learned to expect a small bloom in spring followed by a larger bloom in late summer. Suisun Bay has been an area of great biological productivity and importance to the young bass.

In 1977, there was no bloom of phytoplankton in Suisun Bay. This came as a great surprise to many who had predicted that reductions in outflow with accompanying increases in water transparency such as occurred in 1977, would cause very high levels of algal growth in Suisun Bay. Since 1977, phytoplankton populations in Suisun Bay appear to have recovered substantially.

Figure 16 illustrates the concentration of the Neomysis population in the main channel of Suisun Bay. The Neomysis

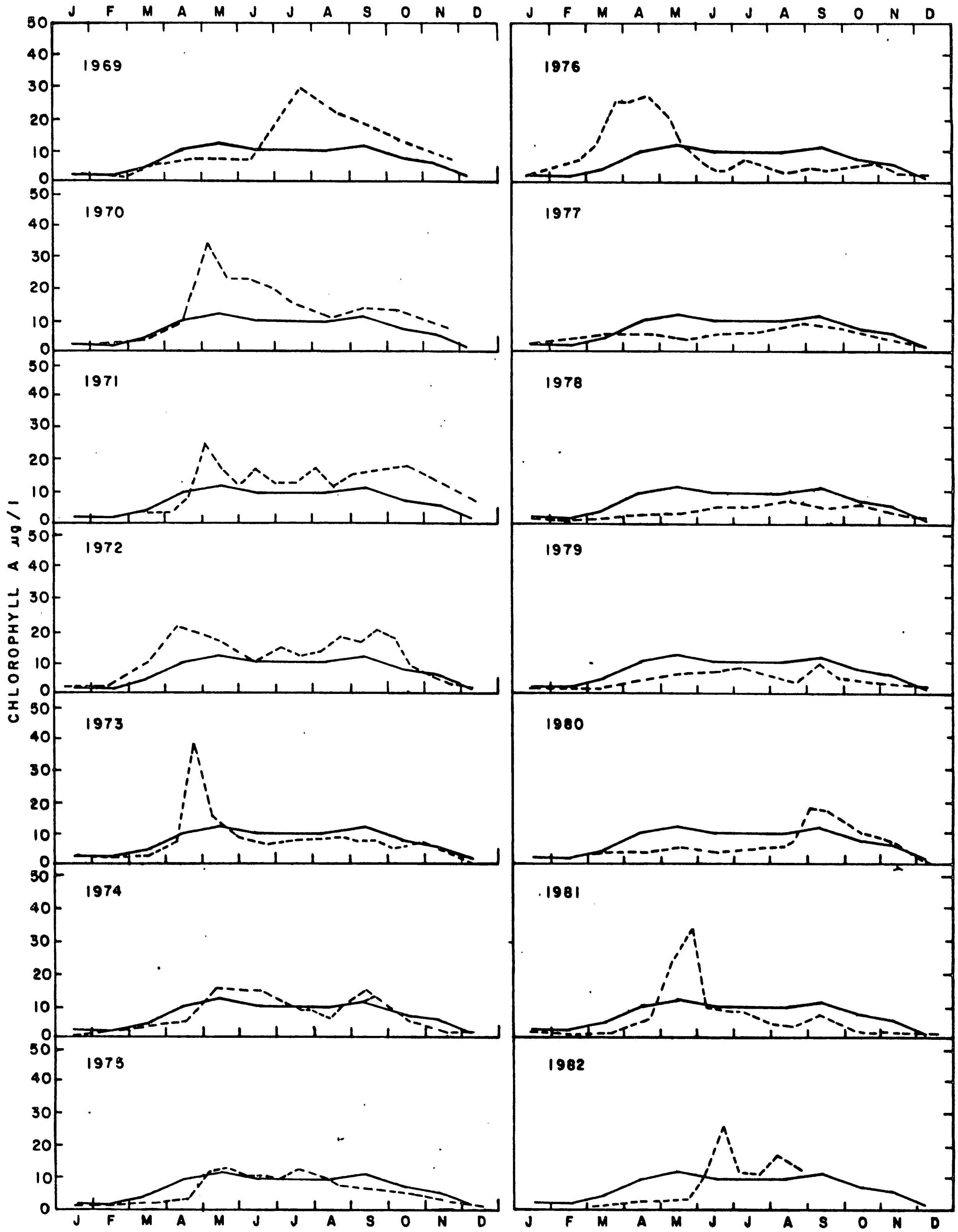

FIGURE 12. Chlorophyll a concentration in western Delta from 1969-1982. Solid line represents monthly mean for all years; dashed line is mean for that year.

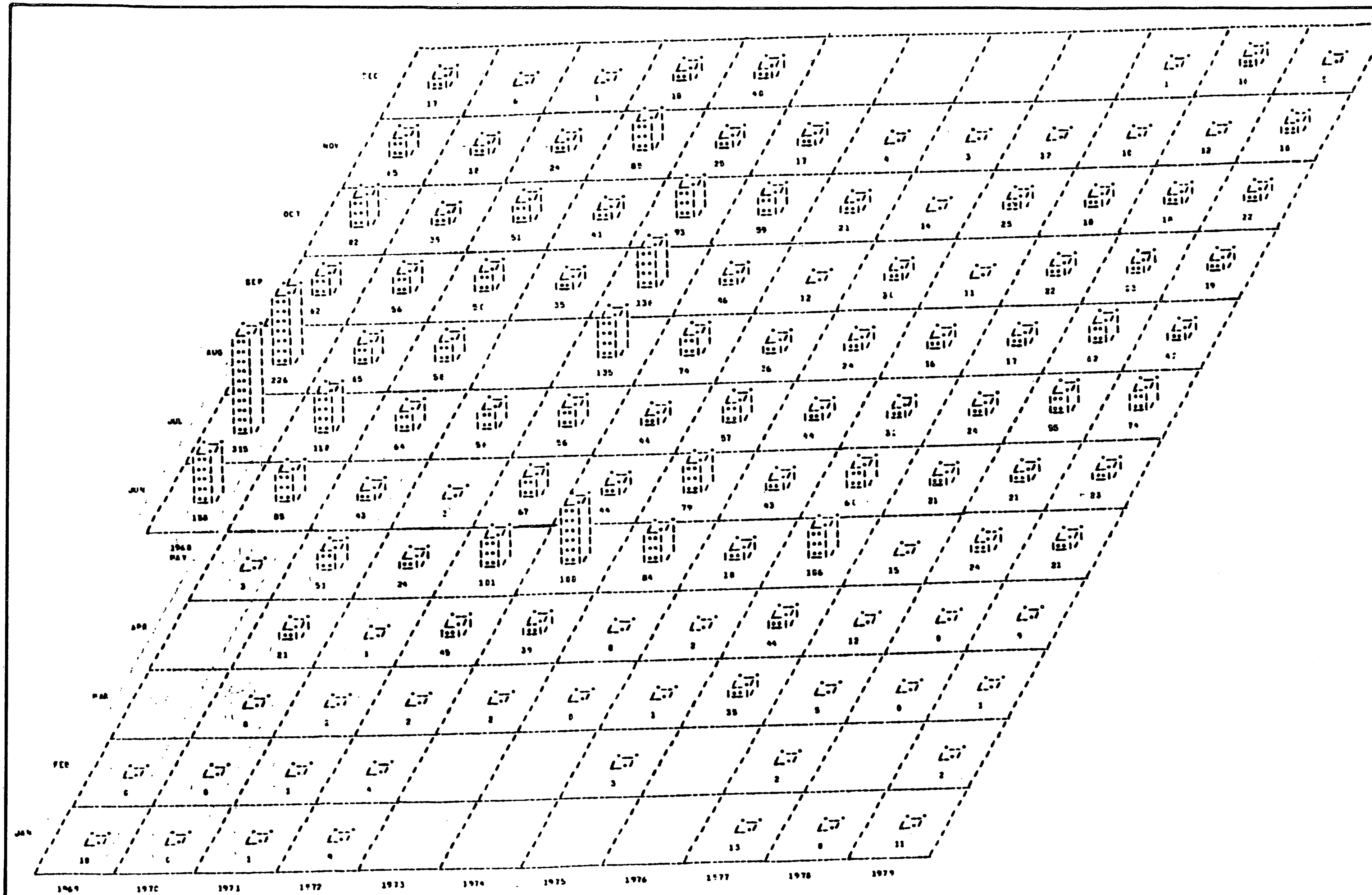

FIGURE 13. Concentrations of <u>Neomysis</u> over time in lower Sacramento River. Populations have been much lower in recent years. Numbers under each block represent numbers per cubic meter.

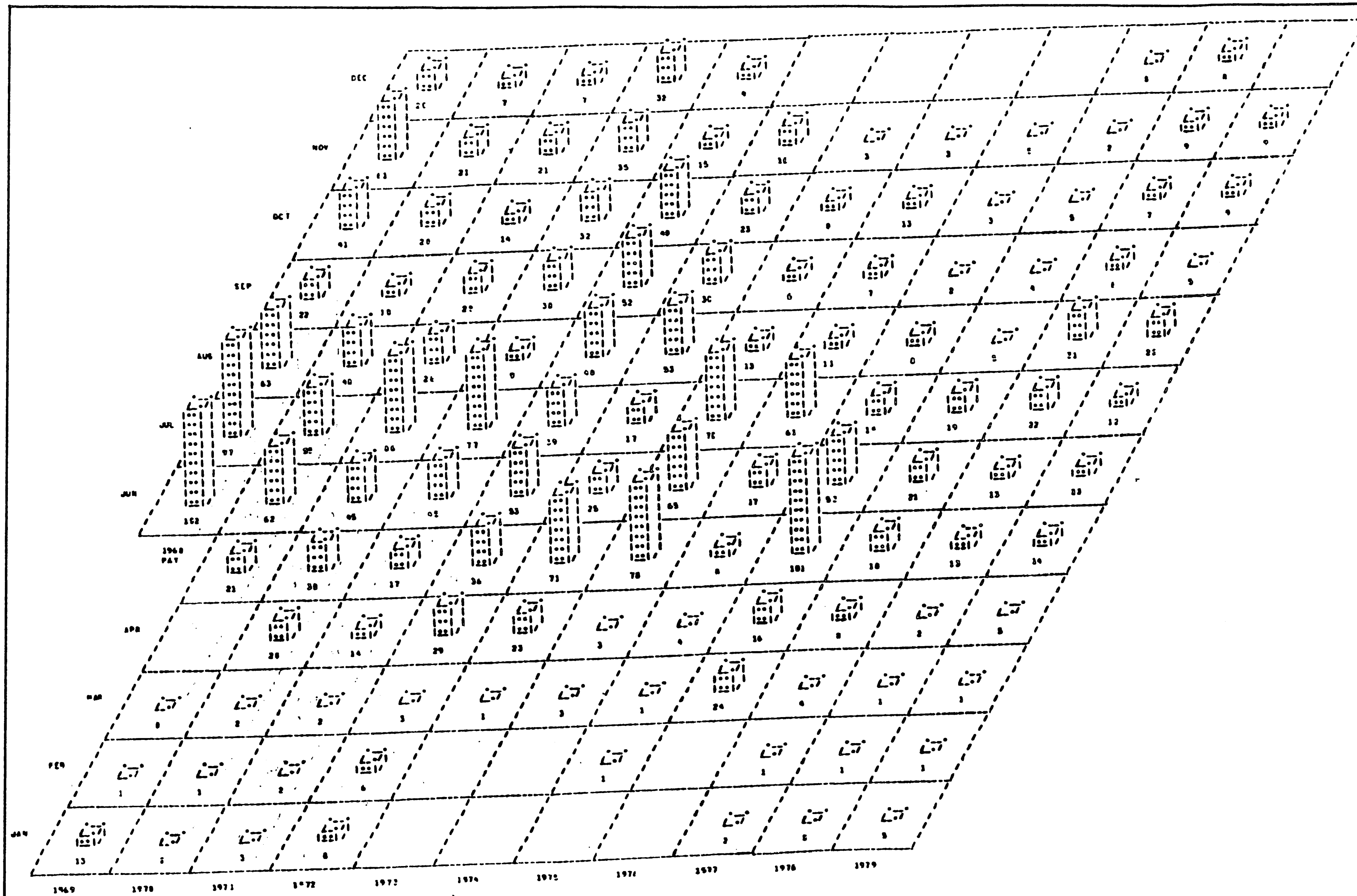

FIGURE 14. Concentrations of Neomysis over time in the lower San Joaquin River. Populations have been much lower in recent years. Numbers under each block represent numbers per cubic meter.

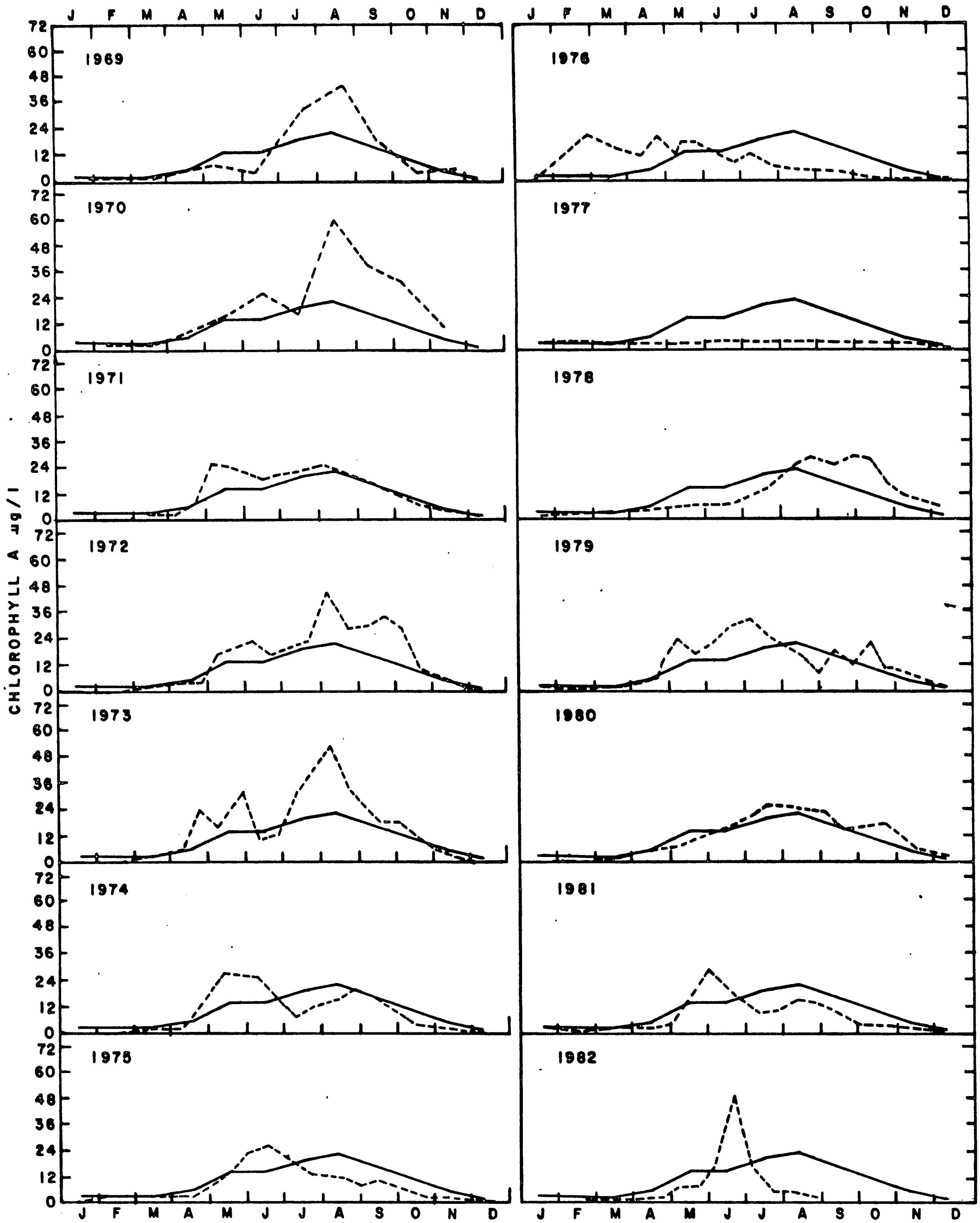

FIGURE 15. Chlorophyll a concentration in Suisun Bay from 1969-1982. Solid line represents monthly mean for all years; dashed line is mean for that year.

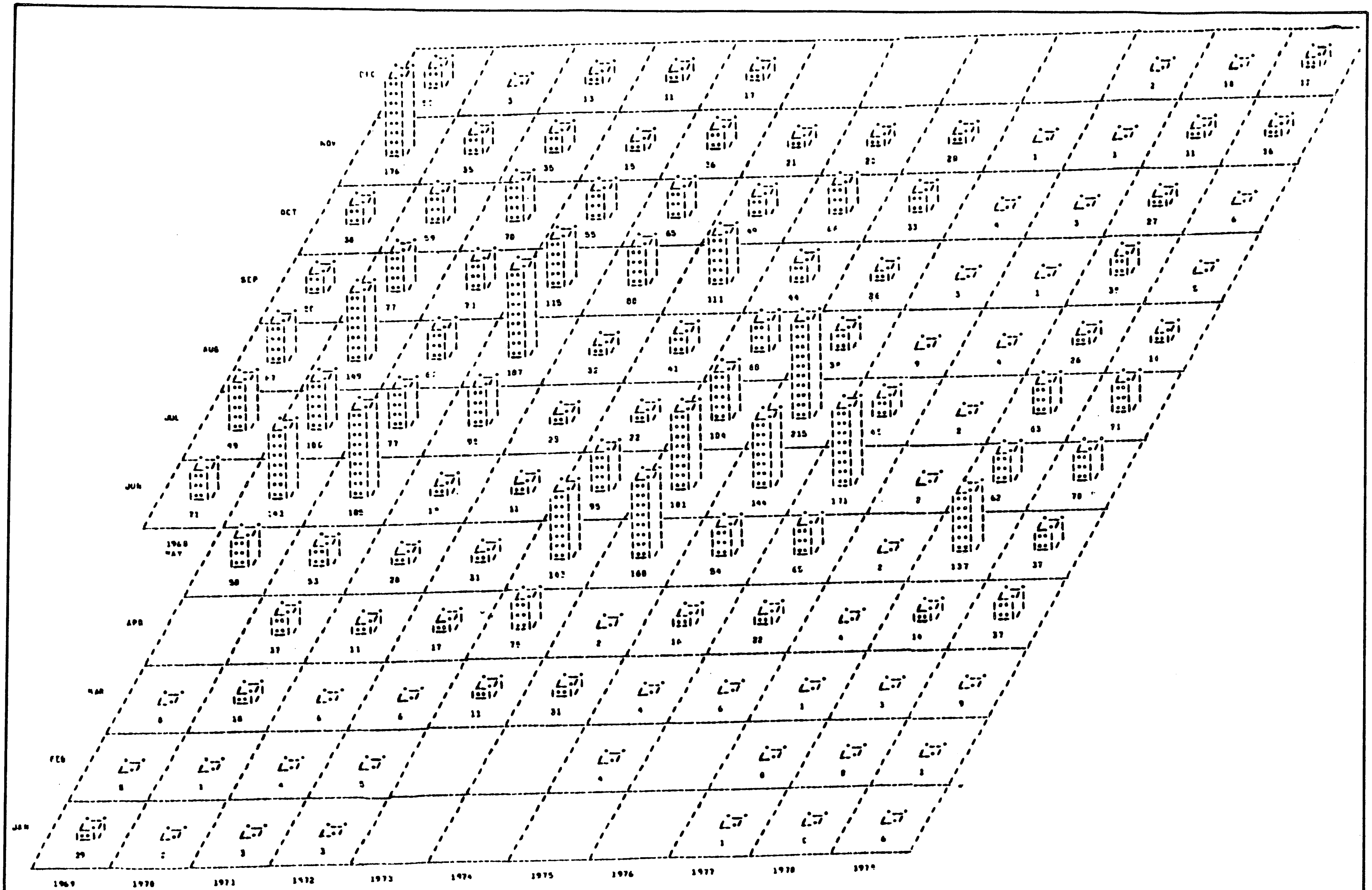

FIGURE 16. Concentrations of <u>Neomysis</u> over time in the main channel of Suisun Bay. Populations were very low in 1977 but have partially recovered. Numbers under each block represent numbers per cubic meter.

population was low in most months of 1976 and near zero in 1977. Although not all postdrought years are on Figure 16, there were moderate populations of *Neomysis* in the normal flow years 1978 and 1980 and abundance was low in the low flow years 1979 and 1981. Preliminary results for 1982 indicate *Neomysis* increased to the point where they may be more abundant than in any previous year.

Our examination of the phytoplankton and *Neomysis* data has led us to conclude there was a widespread and major reduction in biological productivity of the western Delta and Suisun Bay during the recent drought. There is evidence of a partial recovery in Suisun Bay, but not in the western Delta. What has caused this change?

The Influence of Freshwater Outflow

The total amount of freshwater that flows from the Central Valley of California into Suisun, San Pablo, and San Francisco Bays each year has been reduced to about half of what it was years ago under natural conditions. Investigations by some of our working group members, and others, over the years, have defined some important effects of outflow.

There is a zone at the upper end of the salinity gradient called the "nutrient trap", or the "entrapment zone". Phytoplankton populations are often highest in the entrapment zone and its location is thought to be important to the young of many fishes including the young striped bass. The location of the zone depends upon outflow. It is farther downstream, usually in Suisun Bay when freshwater outflows are high, and upstream in the western Delta when the outflows are low. The production of phytoplankton is much greater when the zone is located downstream in Suisun Bay, perhaps because of the shallow tidal flats where the photic zone constitutes a greater percentage of the total depth than in the deep channels of the Delta.

Neomysis also reach their peak concentration in and just upstream of the entrapment zone, and they too tend to be more abundant in years when outflows are high. The sudden decline in the *Neomysis* population when outflows were very low during the drought was expected by biologists familiar with the system.

Since the drought, Delta outflows have increased to predrought levels. Phytoplankton and *Neomysis* populations have partially responded in Suisun Bay. The great mystery, however, is that Delta outflows from 1978 to 1981 have had little effect on either phytoplankton or *Neomysis* in the western Delta.

The Influence of Central Valley Project and State Water Project Pumping

Biologists have long been aware that phytoplankton, zooplankton, *Neomysis*, and other food organisms of the striped bass in the Delta, are not only influenced by the quantity of flows of the Sacramento and San Joaquin Rivers, and the location of the entrapment zone, but also by use of the Delta channels as conduits to carry water south to the export pumps of the Central Valley Project and the State Water Project. More than a decade ago, investigations in the Delta provided good evidence that increasing net velocities through the channels of the interior Delta would lower zooplankton and *Neomysis* populations. The broad, and often deep, channels of the western Delta seemed not as vulnerable.

To assess the effect of export pumping on phytoplankton, we compared monthly chlorphyll *a* levels from April to June with the monthly: (1) total water exports at CVP/SWP pumps, (2) percent of Delta inflow diverted to the CVP/SWP pumps, and (3) magnitude and direction of the net flow in the lower San Joaquin River at Antioch. None were significantly related.

We then compared the mean concentration of chlorophyll *a* in the western Delta (Figure 12) during the peak of the spring phytoplankton bloom, with the total water exports at the CVP/SWP pumps for a period of 7, 14, and 21 days *prior to the start of a bloom*. The most significant time period was seven days prior to the bloom (Figure 17). The magnitude of the bloom in the western Delta was greatly influenced by the amount of water pumped just prior to the bloom.

The only major spring blooms that have occurred in the western Delta since 1976, occurred in May 1981 and June 1982; both immediately following the shutdown of the State Water Project pumps for repairs. Figure 18 illustrates the changes in chlorophyll *a* in the lower San Joaquin River portion of the western Delta in 1981 compared with levels of nitrogen and the volume of water being exported at the State and Federal pumping facilities. The first water sampled following the pump shutdown indicated that a significant phytoplankton bloom had developed. The decline in phytoplankton populations in early June was probably due to the exhaustion of the available nitrogen.

Figure 18 also illustrates the second incidence of this kind in early June 1982 when the SWP pumps were shut down for repair work and a major phytoplankton bloom followed.

These results support the hypothesis that the CVP/SWP water diversions are, in some as yet unexplained way, having a major effect of the phytoplankton population and basic productivity of the western Delta.

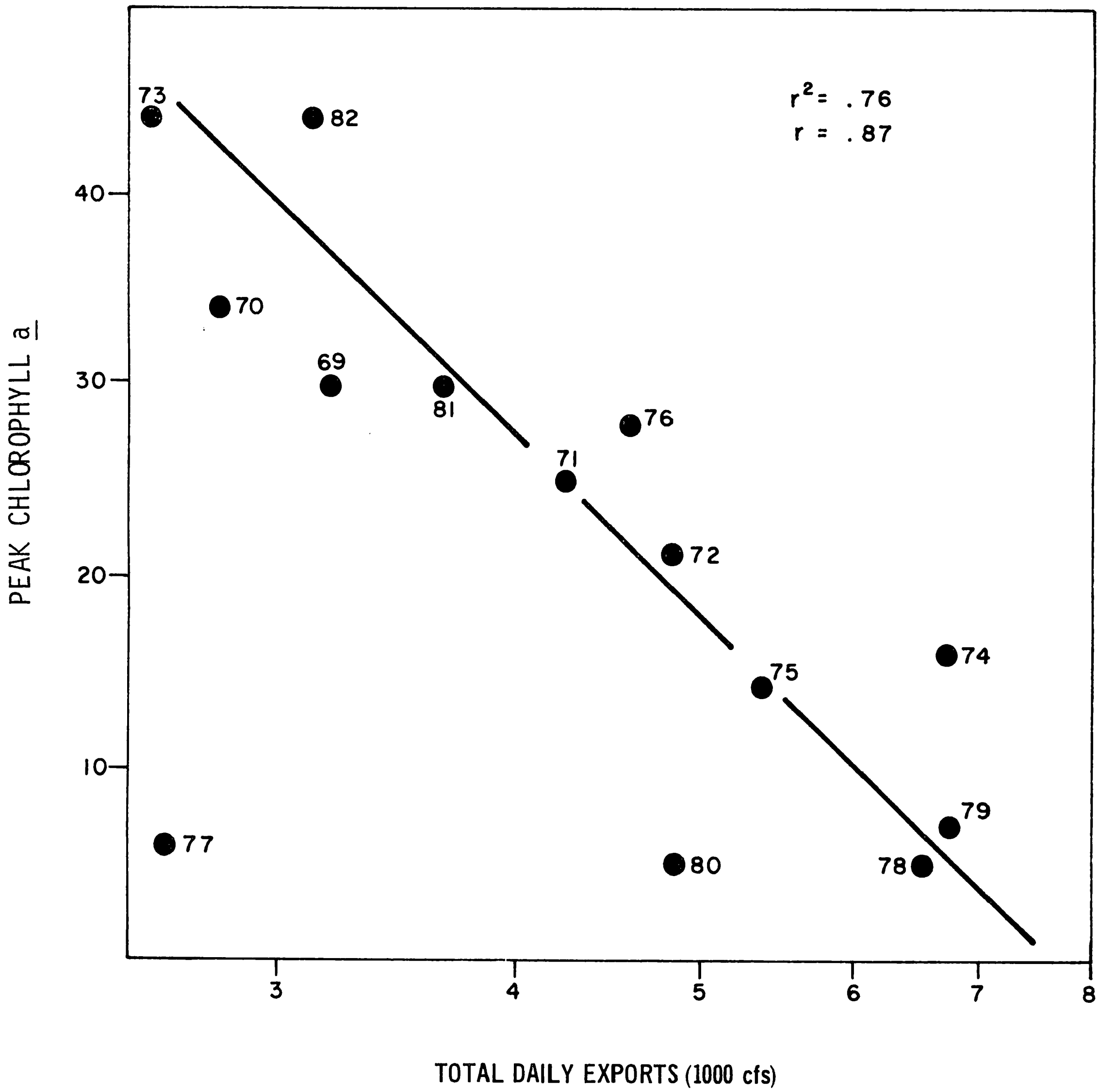

FIGURE 17. Relationship between average peak chlorophyll a levels in the western Delta from April to July and the average daily Delta water exports seven days prior to the start of a phytoplankton bloom (Arthur, 1982). Higher exports appear to limit the level of phytoplankton blooms that develop. Data point for 1977 not included in correlation coefficient.

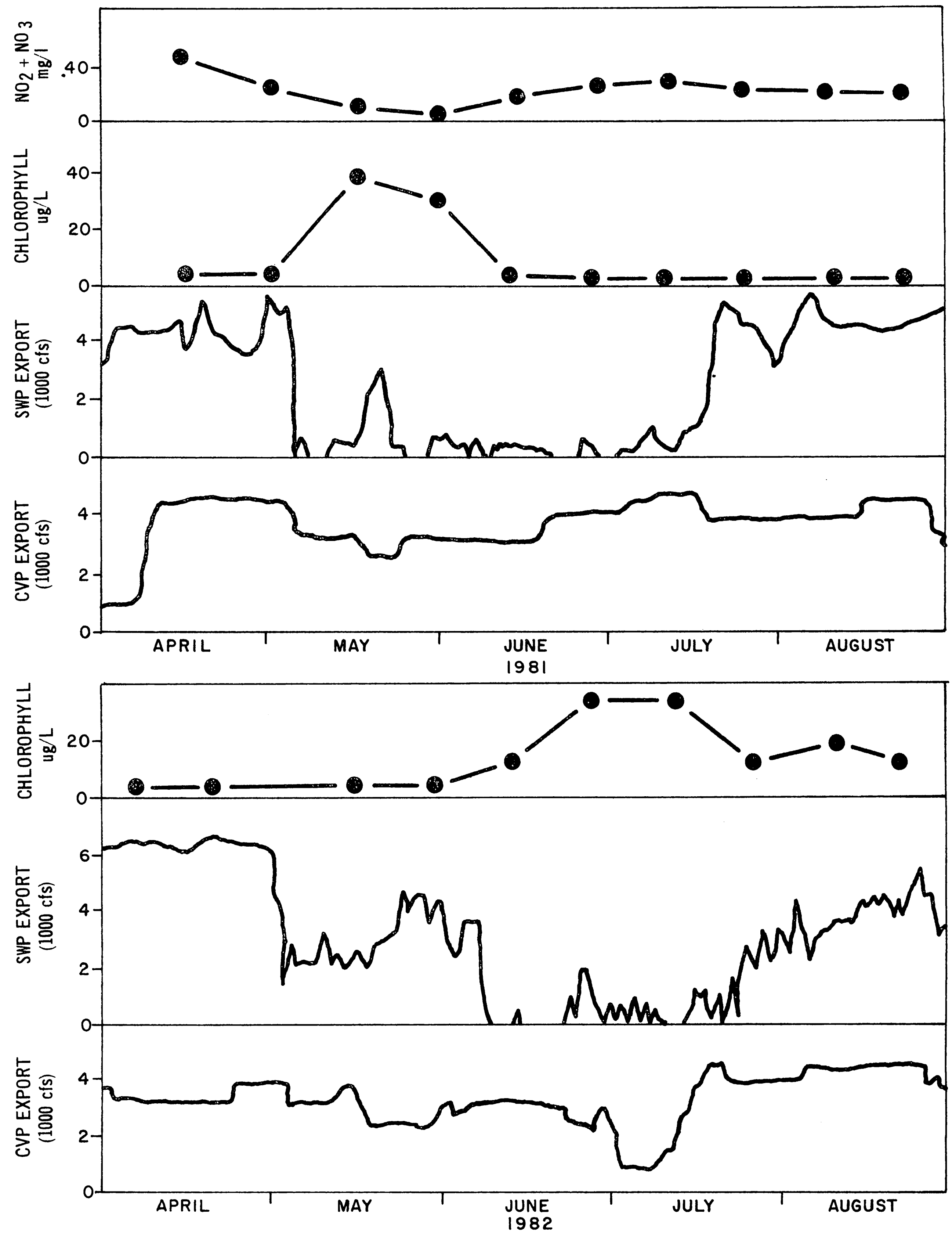

FIGURE 18. Comparison of chlorophyll a in the lower San Joaquin River from Antioch to the Mokelumne River with water exports at the CVP/SWP pumps from April to August in 1981 (above) and 1982 (below). Note the phytoplankton blooms following the reduction in export pumping for both years.

The Influence of Improved Waste Treatment

Improved waste treatment at point-source discharges in the Bay-Delta (in many cases directly into Suisun Bay and the western Delta, where larval striped bass are concentrated) during the first half of the 1970s, has reduced the contribution of organic material to the system and may have contributed to a decline in the production of microorganisms that are eaten by small zooplankton. It is hypothesized that the reduction in organic loading could have contributed to a subsequent reduction in the abundance of small zooplankton. Zooplankton are required in high densities to support the growth and survival of larval striped bass.

Figure 19 is a comparison of an index of organic loading (BOD) from point-source discharges in Suisun Bay and the western Delta with an index of zooplankton abundance at the times and places where larval striped bass are concentrated. The figure suggests that during the early 1970s, when organic discharge was relatively high, zooplankton were abundant. After waste treatment was improved in the mid-1970s and organic discharge was reduced, the zooplankton that larval bass eat were less abundant. The same general pattern exists for the relationship between organic discharge and the abundance of *Neomysis*, an important food item for juvenile striped bass. In a multiple regression analysis, the combination of May outflow and this index of organic loading in Suisun Bay and the western Delta accounted for 80% of the variability in the striped bass index over the past decade.

These preliminary results suggest that changes in waste treatment *may* have contributed to reduced production of zooplankton and striped bass in the Bay-Delta and *may* be an important factor in the striped bass decline. Our assessment is that this hypothesis is worthy of a more detailed examination. That examination will require more careful assessment of organic input to the system, probably using some measure other than BOD. Using BOD as a measure of the value of organic detritus as an energy source to the ecosystem may exaggerate the contribution of waste water discharge.

The Effect of Reduced Food on Young Striped Bass

We have shown that since 1976 there was a major decline in phytoplankton and *Neomysis* populations in both Suisun Bay and in the western Delta. Since then, Suisun Bay has partially recovered but the western Delta has not. How important is this to fish?

The Department of Fish and Game has collected data which demonstrate rather conclusively that year class size is

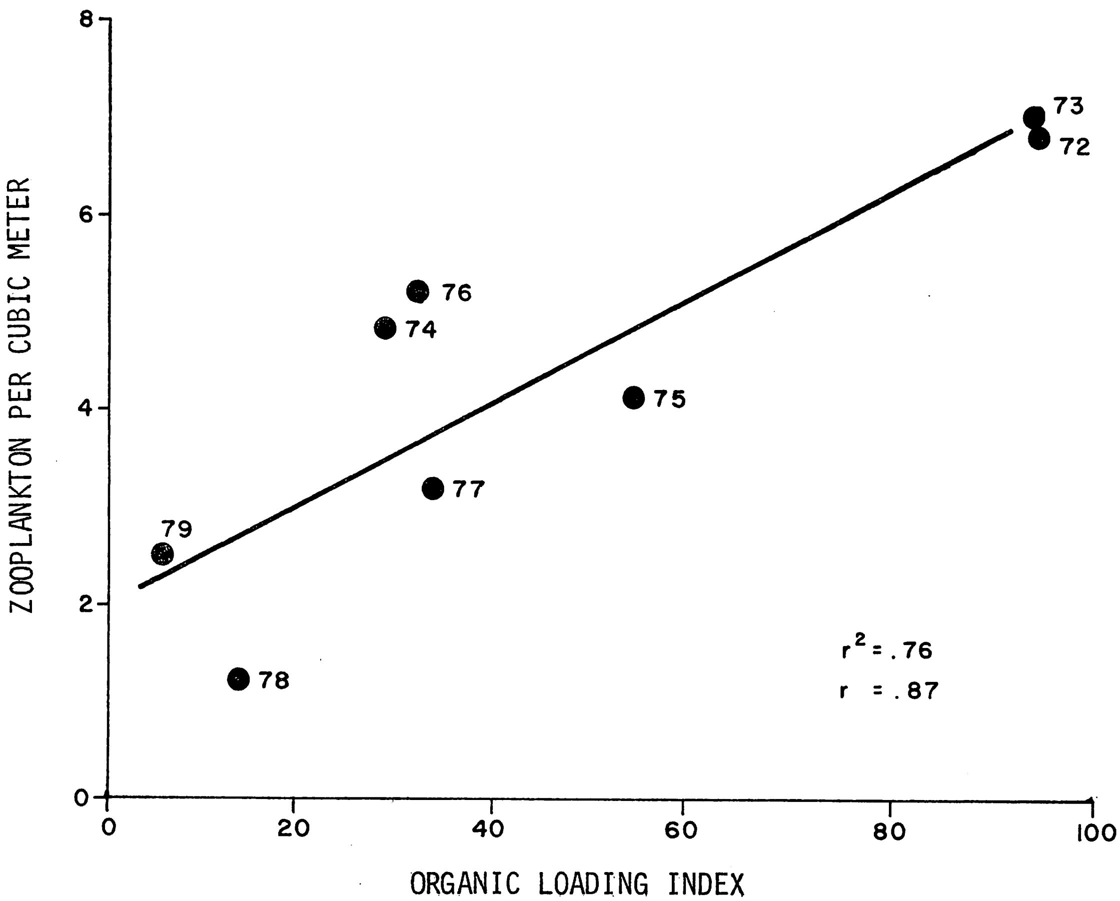

FIGURE 19. Relationship between zooplankton concentration at time and place of initial striped bass feeding compared with an index of organic loading (BOD) from point-source discharges in Suisun Bay and the western Delta. See next section for time and place of initial feeding.

is set by the time the bass reach 10 mm in length. Except for 1972, there is a significant relationship between the young bass after they first begin feeding, and the numbers that exist in midsummer (Figure 20) and in the fall (Figure 21).

The possible reason for the discrepancy in 1972 was that Andrus Island flooded in June. We speculate that a large amount of water was drawn from the nursery area in the western Delta causing very high mortalities of the young bass that had reached the 10 mm stage.

The size of the new year class of striped bass, i.e., the young-of-the-year index, may depend on the zooplankton densities when the larval fish first start feeding and some other outflow-related factor. The larval bass begin feeding on small crustacean zooplankters when the bass are 4 to 7 mm long. As these larval fish grow they eat more and larger food organisms. Laboratory studies have shown that larval fish survival is directly related to the number of food organisms available to them and that good survival requires localized concentrations of food greater than are found in average field measures. The fish that survive are those that find themselves in dense patches of zooplankton.

Where the young bass will be when they begin feeding depends largely upon Delta outflow. When they begin feeding depends largely upon water temperatures which control the time of spawning. In years of high outflow water temperatures are cooler, spawning is delayed, and larvae are carried downstream to begin feeding in Suisun Bay. In years of low outflow, more of the larvae begin feeding in the Delta and do so earlier.

Figure 22 is a comparison of the midsummer young-of-the year striped bass index with the phytoplankton and zooplankton densities 60 days earlier at the place where most of the bass began feeding. Delta outflow in May is also included on the graph to give an indication of the location of most larval fish for that particular year. When outflows are below 10,000 cfs, most of the bass begin feeding in the western Delta; at moderate outflows up to 30,000 cfs, they are spread throughout upper Suisun Bay and the western Delta; and, at high outflows over 30,000 cfs, most of them begin feeding in Suisun Bay and San Pablo Bay.

The figure illustrates that the young-of-the-year index has been at a very low level since 1976, and in all of those years there was very little phytoplankton or zooplankton where the bass needed it when they began feeding. Relatively high outflows since the drought have not produced even modest levels of zooplankton/phytoplankton at the right time and place for young bass.

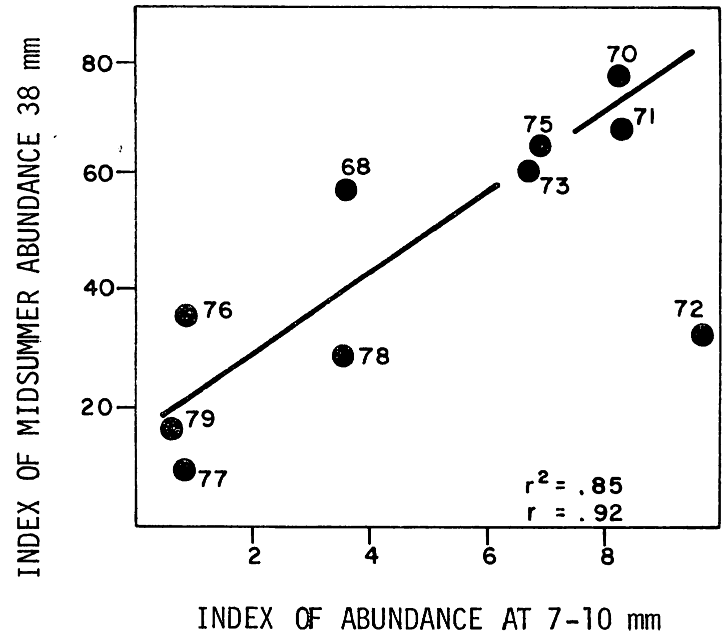

FIGURE 20. Relationship between number of 7-10 mm striped bass in spring, and number of 38 mm striped bass in mid-summer. No estimates of 7-10 mm bass available for 1969, 1974, 1980, 1981. Data point for 1972 not included in correlation calculation.

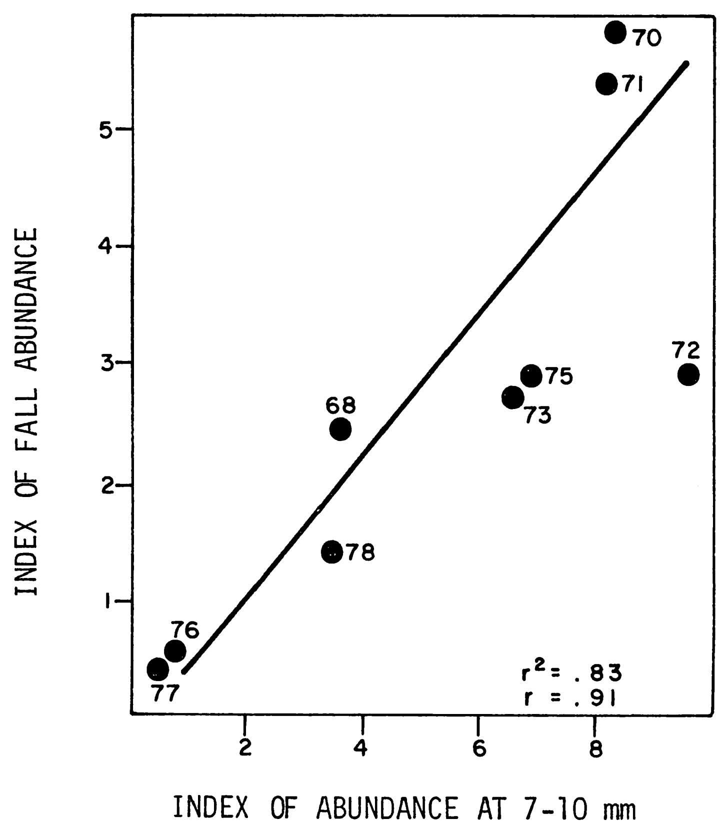

FIGURE 21. Relationship between number of 7-10 mm striped bass and number of striped bass in fall. Data point for 1972 not included in correlation calculation. See text for explanation.

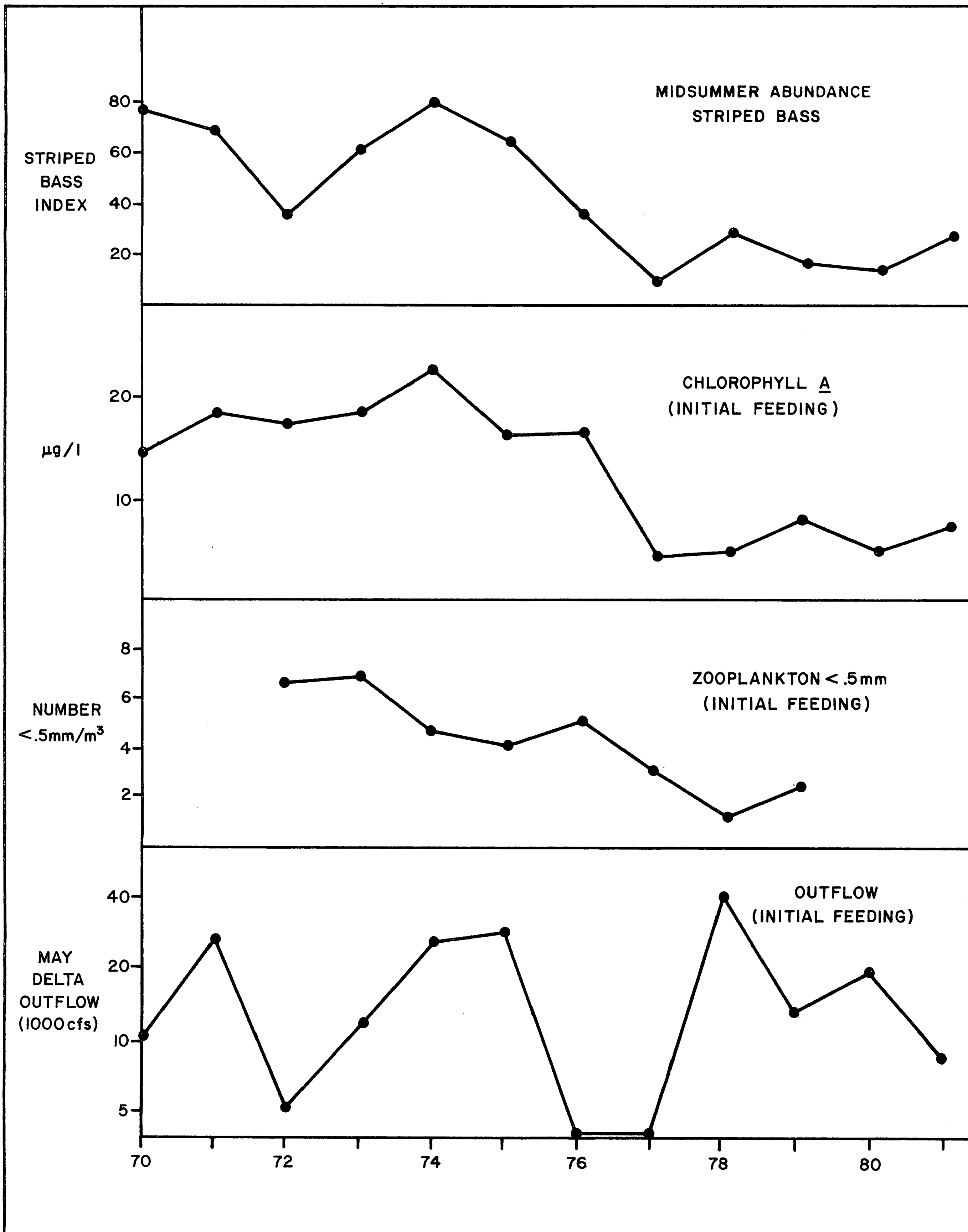

FIGURE 22. Concentration of chlorophyll a, zooplankton <.5 mm, and outflow at the time and place of initial feeding compared with striped bass abundance the following midsummer (CF&G, 1982). Since 1976, very little plankton has been available when and where most young bass begin to feed.

There also is evidence that phytoplankton population development has been delayed in recent years. Prior to 1977, the phytoplankton concentrations where most of the bass began feeding reached 10 µg/l from three to ten weeks before the young bass began feeding (Figure 23). This should be a long enough period of time for high zooplankton populations to develop from feeding on the phytoplankton. In 1977, chlorophyll concentrations in the Delta never reached 10 µg/l. And, in all the years since then, phytoplankton development where the young bass first begin feeding, whether in the Delta or in Suisun Bay, has been delayed beyond the time that it is needed by the larval fish.

A comparison of the mean chlorophyll *a* levels between the western Delta and Suisun Bay in April and May shows a significant relationship suggesting that in some years the very early phytoplankton blooms in Suisun Bay may be partially dependent on phytoplankton being washed downstream from the western Delta. As an example, note the late May 1982 bloom in both the western Delta (Figure 12) and Suisun Bay (Figure 15). The low concentrations of phytoplankton in the western Delta since 1977 may be responsible for lack of the early April-May peak in Suisun Bay. This would explain the delayed phytoplankton development where the young bass first begin feeding whether in the western Delta or Suisun Bay.

The abundance of young bass was closely related to outflow in the early 1970s but has been more closely related to available food since 1977. A multiple regression analysis, using small zooplankton concentrations at initial feeding as one variable and May-July outflow as a second variable, can explain 88% of the variation in young striped bass abundance that has occurred from 1972 to 1979 (Figure 24).

ENTRAINMENT AND THE LOSS OF SMALL BASS BY DIVERSION

Striped bass eggs, larvae, and juveniles are lost via entrainment at Delta water diversion facilities of Pacific Gas and Electric Company (PG&E), Central Valley Project (CVP), State Water Project (SWP), and Delta agriculture (DA). Fish losses are a function of the density of organisms at the pump intakes, the pumping rate at the time and, in the case of PG&E, mortality during passage through the facility and back into the Delta. Recent estimates are that 100 million young bass are lost annually at PG&E plants and approximately 200 million are lost each year to the CVP/SWP pumps. Even more may be lost to the thousand or more small pumps and siphons used in Delta agriculture. Could such losses have caused the recent young bass decline?

All of the estimates are debatable and, except for the PG&E estimates of losses to their diversions, are based on what most of us agree are inadequate measures of the

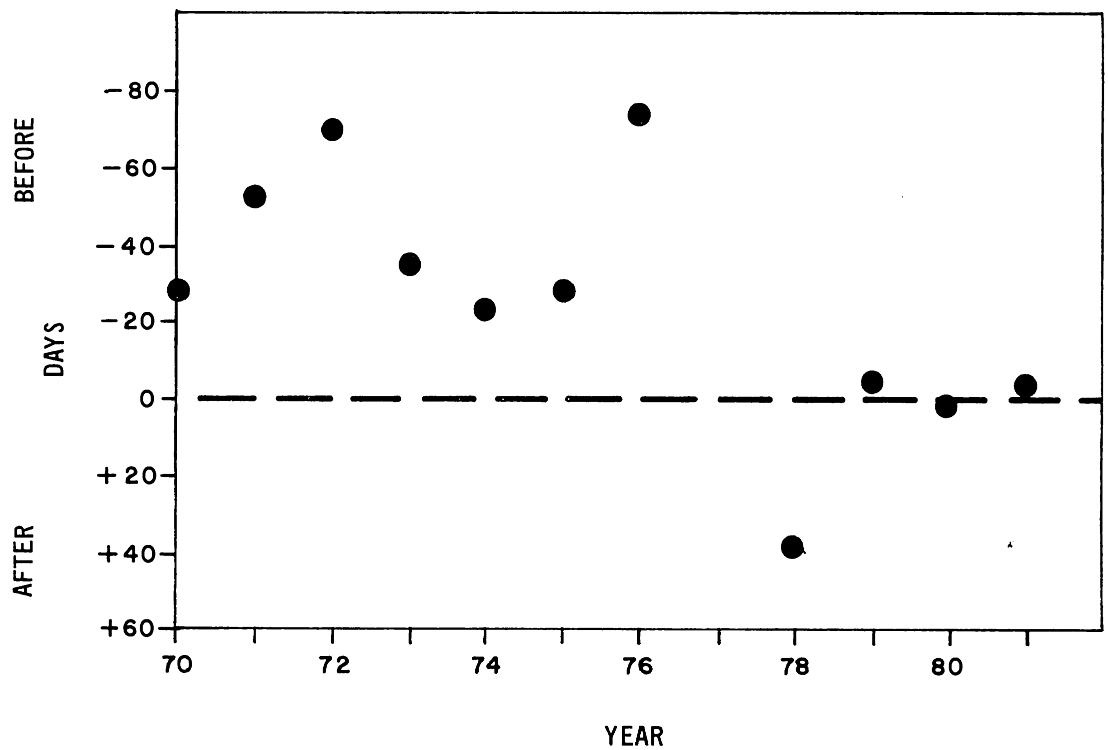

FIGURE 23. Number of days prior to or after initial feeding of larval bass that chlorophyll a levels reached 10 μg/l in the region of most bass larvae. Since 1976, development of phytoplankton has been seriously delayed.

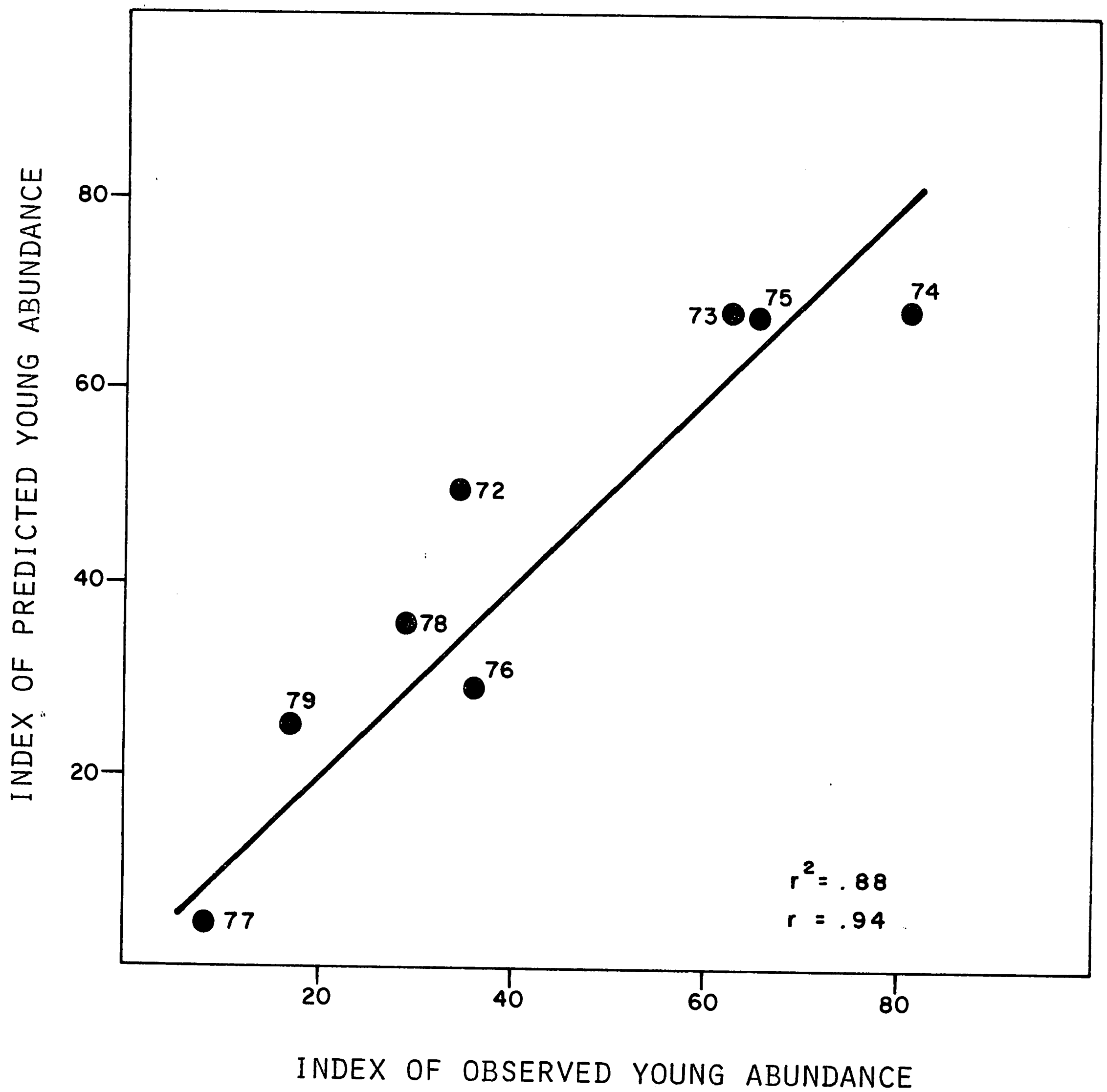

FIGURE 24. Relationship between observed and predicted young striped bass abundance based on crustacean zooplankton densities at time of first feeding and May - July Delta outflows (CF&G, 1982).

distribution and abundance of smaller fish at different times of the year. Yet, the data is adequate to convince us that large and probably significant numbers are being lost from the population.

Our analysis provides no evidence of a direct relationship between entrainment losses over the past several years and the decline of larval bass since 1976. A daily loss rate was calculated for the CVP/SWP pumping plants based on an estimate of the proportion of the total population in the southern Delta, the volume of water in the southern Delta, and the combined monthly water exported at the pumps. The daily loss rate was then used to estimate an index of reduction in the total population based on a 65-day growth period from egg to 38 mm young bass. These indexes of annual loss oscillate dramatically over the time period from 1959 to 1981, but there was no evidence of a dramatic entrainment loss since 1976.

A similar type of analysis was conducted for the PG&E power plants where estimates of larval bass entrainment losses were made based on the bass population in the adjoining river and the amount of cooling water pumped. Even though the annual losses were significant, there did not appear to be any unusual increase in the losses since 1976.

We could find nothing to suggest that there had been an increase in agricultural diversions since 1977. Therefore, we concluded that agricultural diversions did not appear to be responsible for the recent decline in the young striped bass index.

However, we cannot ignore the possibility that the long-term losses from the combined entrainment at the PG&E plants, CVP/SWP pumps, and Delta agricultural diversions, may be responsible for the long-term reduction in young striped bass (Figure 3) which has caused the decline in the adult fish population. Because of the decline in the adult population, CF&G has calculated that striped bass egg production is only about 10% of what it was in the late 1960s. This reduction in egg production might have caused the recent decline in the young striped bass index. This is discussed in detail in a later section of the report.

Our group believes that, because of the difficulties of assessing the meaning of large losses of the very young fish, it is better to investigate and determine ways of simply reducing these losses. All existing fish screens should be improved to the best extent possible, and investigation on the many Delta agricultural diversions should try to identify changes in design or operation that would minimize their losses. Reducing losses in some will require screening. Experimental screens for such pumps and diversions should be tried in the Delta.

TOXIC SUBSTANCES - POSSIBLE EFFECTS ON YOUNG BASS

Although most of the major waste treatment facilities discharging into the Bay and Delta have been much improved in the last decade, there are still large quantities of potentially toxic substances discharged into the system. Many are not routinely monitored. Much of the Central Valley is treated with pesticides each year. There is runoff from industrial and urban areas whenever it rains, and, of course, accidental spills of all sorts commonly occur. The possible effects of such toxic substances on adult striped bass has been previously discussed. In this section we will discuss the possible effects on eggs and juvenile bass.

Striped bass no longer migrate far up the San Joaquin River to spawn, but many migrate in the Sacramento as far upstream as Colusa, and some as far as Red Bluff. The CF&G egg and larval surveys provide good evidence that striped bass eggs and larvae are drifting down the Sacramento River during April, May, June, and even in July of some years.

In the Sacramento River Basin, rice farming uses the major portion of irrigation water in the spring. In general, water is diverted from the river or from reservoirs through irrigation canals, fields are flooded, pesticides are applied, and eventually the pesticide laden water is drained into sloughs and subsequently flows back into the river. Major irrigation drains, such as Sacramento Slough, Butte Slough, and the Colusa Basin drain, discharge into the river in regions where striped bass eggs and larvae are found in high densities.

From streamflow records, we have estimated that from April through July the five major sources of return irrigation water contribute between 5% and 20% of the total Sacramento River flow at or near Sacramento (Table 2). Pesticides and herbicides used in rice agriculture (molinate, ethyl parathion, methyl parathion, MCPA-DMA, bencarbthio) are applied extensively during April to July in the rice culture. Also of concern, are toxaphene and xylene (a common pesticide carrier/solvent) which are not used specifically on rice, but are extensively applied elsewhere. Detectable levels of several of these pesticides have been found in the Sacramento River and its tributaries during this period.

Concentrations of molinate found have been high enough to kill fish, but those of the other pesticides have generally been found at sublethal levels. Yet, spring kills of resident fish in irrigation discharge drains of the

Table 2. Irrigation return water as a percent of total Sacramento River flow.

DATE	1972	1973	1975	1976	1977	1980	1981
April	8.0	7.7	--	6.8	4.7	8.7	12.8
May	20.0	12.7	7.6	13.5	15.2	22.2	16.4
June	9.6	11.6	8.6	13.1	4.9	10.0	13.4
July	7.4	9.9	11.1	8.0	2.8	10.9	--

Sacramento basin and in the Sacramento River itself, are not infrequent. They are usually associated with pesticides.

While there is insufficient data to test the hypothesis that mortalities of striped bass eggs or larvae are being caused by these, or any other toxic substances, the indirect evidence is great enough to warrant concern.

Eggs and larvae of striped bass may be more sensitive to pesticides and other toxic substances than the current bioassay tests on other species have suggested. Eggs and larvae may also suffer chronic effects from concentrations below lethal levels. The evidence that we have seen suggests that toxic substances may be damaging the health of striped bass. It is not possible to determine the degree to which they are responsible for the striped bass decline. A pesticide monitoring program and toxicity testing are necessary to critically evaluate the current role of pesticides and to prevent problems from becoming more serious.

THE EFFECT OF REDUCED ADULT STOCKS ON THE YOUNG-OF-THE-YEAR

We have previously presented evidence that the adult population of striped bass has now been reduced to about one-quarter of its size two decades ago. CF&G biologists have hypothesized that the lower number of eggs being produced by this lower adult population may have contributed to the declining number of young-of-the-year.

Using estimated age class composition of the adult population and knowledge of how many eggs are produced by fish of different ages, CF&G calculated that egg production in 1980 was only about 10% of what it was during the late sixties and seventies (Figure 25). Could the reduction in number of eggs produced have caused the rapid decline of the young-of-the-year index from the mid- to late seventies and be preventing its recovery?

At first glance, a 90% reduction in egg production would seem an obvious reason for the bass decline. But with the average female striped bass producing nearly a half million eggs, it is hard for some biologists to envision there not being a surplus of eggs. This is because we are accustomed to believing that if fewer are produced, a greater proportion will survive to maintain the population. There is evidence to suggest that this principle does not presently apply to the striped bass population.

To test the hypothesis that the reduction in egg supply over the years has contributed to the declining number of young-of-the-year, we proposed two ways in which the young-of-the-year index might have been influenced by egg production

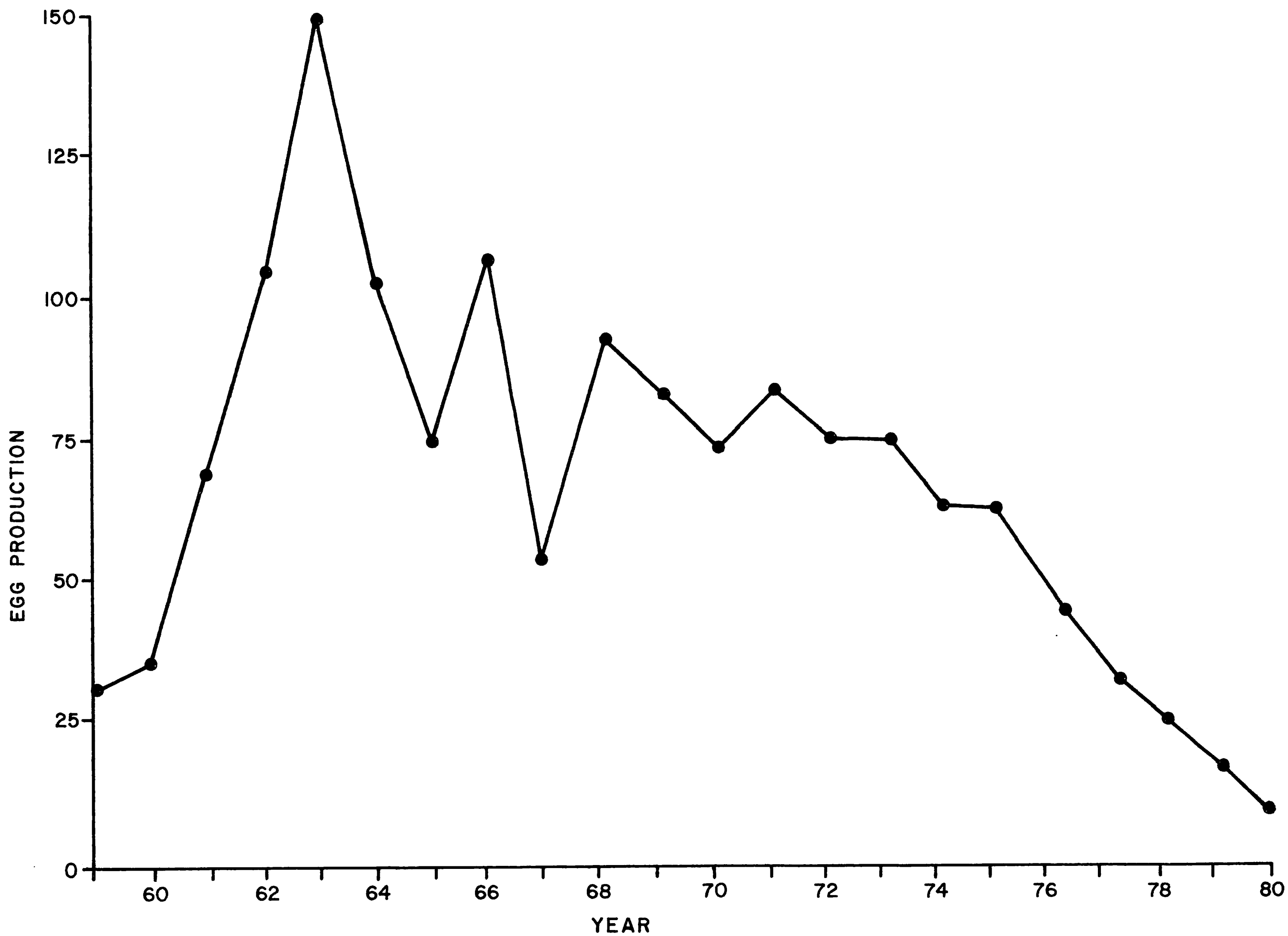

FIGURE 25. Egg production index for striped bass in the Sacramento-San Joaquin Estuary from 1959 to 1980.

and ran them through our model of the bass populations to see if the observed decline could be duplicated.

First, we assumed that above a certain number, there were surplus eggs and the young-of-the-year index would be determined by the spring outflow and Delta diversion rate, i.e., the relationship developed by CF&G which explained the variations in young-of-the-year abundance from 1959 to 1976. But, if a surplus number of eggs was not produced by the adult population, the number of young bass would be reduced. For this first test, we set the threshold at the number of eggs produced in 1977 because that was the first year in which abundance of young declined far below the level expected from CF&G's relationship using outflow and diversions. In this test the model output did not depict the decline of the young-of-the-year that actually occurred; thus, we concluded that the decline was not caused by egg production suddenly dropping below a threshold level in 1977.

Our second scenerio assumed there was not a surplus of eggs produced since the very high level of the 1960s. Thus since 1970, egg production, along with outflow and diversions, has always influenced the abundance of young. This scenerio depicted the decline reasonably well (Figure 26). Thus, our modeling effort indicates that low egg production could be responsible for the recent decline of young bass.

An important implication of this modeling and the early work by CF&G is that survival from eggs to the young-of-the-year stage could depend on flows and diversions. Indeed, an evaluation by CF&G revealed that survival was correlated with the amount of Delta outflow in the spring and early summer from 1959 all the way to the present (Figure 27). Survival is estimated by dividing abundance of the young in summer by the number of eggs produced in the spring.

After 1976, because egg production and young abundance were both very low the survival estimates did not decline severely. Thus, young bass abundance may be influenced by a combination of both flow and the number of eggs.

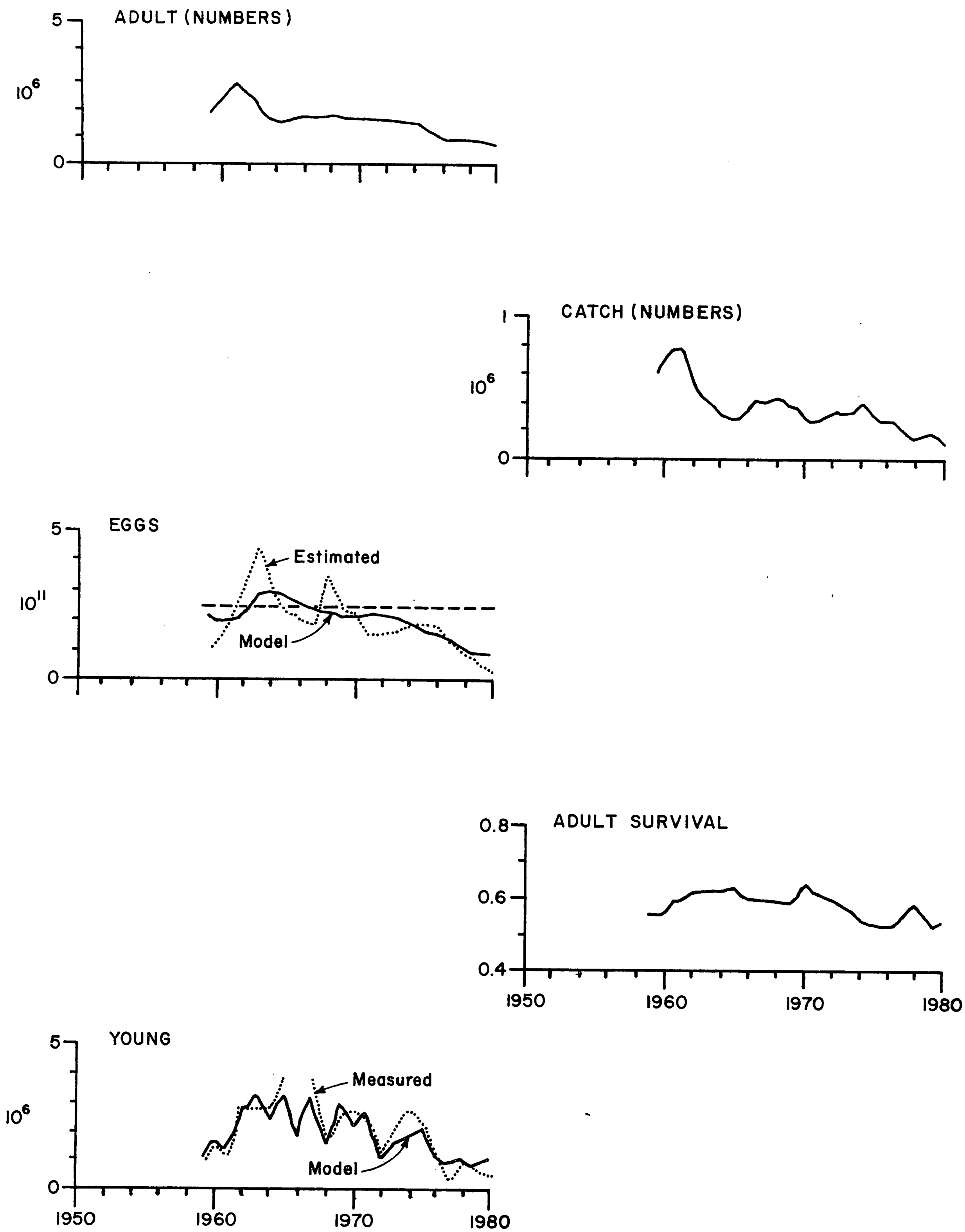

FIGURE 26. Model simulation run illustrating how the reduction in adult survival rate could have combined with the reduction in adult stocks caused by reduced young to simulate a rapid decline in the young-of-the year index in the mid-1970s.

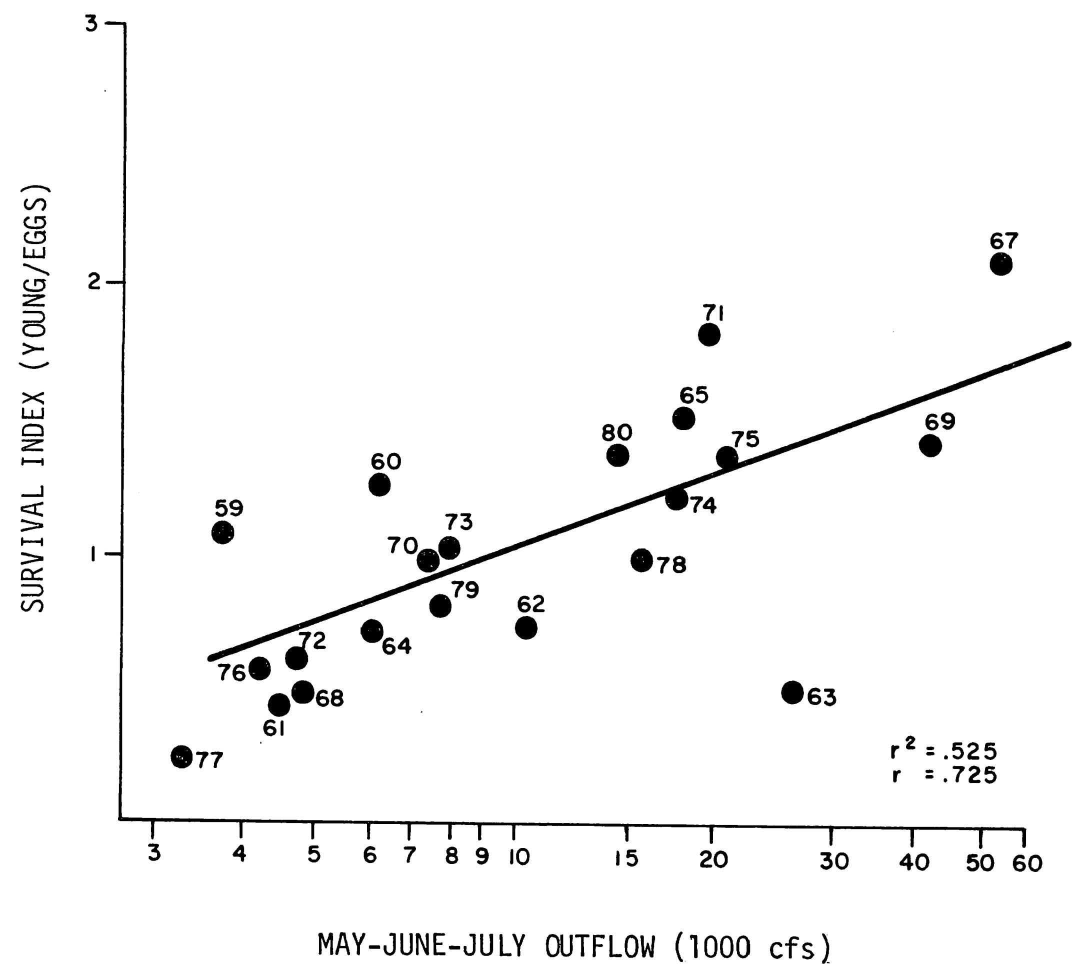

FIGURE 27. Relationship between survival index for striped bass from egg to young in midsummer and mean May-July outflow at Chipps Island.

CHAPTER V. CONCLUSIONS AND RECOMMENDATIONS

The production of young striped bass has suffered an unsteady but persistent decline from the population levels that were high in the middle 1960s. The decline was particularly severe in 1977 and production of young bass has been low since then. In the last decade the decline became apparent in the adult population. The adult population is now about one-quarter of its former size and there is little sign of recovery.

We believe the bass population and the fishery which it supports is in serious danger. The cause is most likely one or more of the following four factors:

1. The plankton food supply of young striped bass in the western Delta and Suisun Bay has been greatly reduced each spring. Export pumping of water by the CVP/SWP is a prime suspect.

2. Large numbers of young fish are lost by entrainment in diversions.

3. Additional stresses are placed on the population by toxic substances such as petrochemicals and pesticides.

4. The adult population is now so low that egg production may be inadequate.

REDUCED PLANKTON FOOD SUPPLY FOR YOUNG BASS

The plankton food supply required by young bass in the western Delta has been extremely low and that in Suisun Bay has been seasonally delayed in its development since 1977. We have presented evidence that the reduced and delayed production may be related to the use of Delta channels to convey water to the CVP/SWP export pumps in the South Delta. There is also evidence that this movement of water across the Delta may be a significant cause of the accelerated striped bass decline, and the failure of the bass population to recover.

We recommend that careful experiments involving the reduction of total export pumping to about 2500 cfs for several weeks in late April and early May, be designed and executed. The idea is to try to increase the spring development of phytoplankton and zooplankton in the western Delta and Suisun Bay by this reduction in export pumping. Enough outflow must be provided through June to carry the young bass downstream into Suisun Bay where they will be less susceptible to problems associated with cross-Delta flows when pumping increases again. It is extremely important during this time to intensively sample phytoplankton, zooplankton, striped bass eggs and larvae. Otherwise, the results of the field experiment cannot be evaluated.

ENTRAINMENT LOSSES OF YOUNG BASS

Our group has concluded that, while there is no evidence that entrainment has been the cause of the striped bass decline, entrainment losses of young fish in the diversions are large enough so that over a long period of years they could significantly reduce the bass populations. The risk is greater if there is inadequate food or in years of low Delta outflow. We believe that the current high estimates of losses at the PG&E, CVP, SWP, and numerous small agricultural diversions are sufficiently accurate to warrant major concern. The difficulties of interpreting what those losses mean to the adult population lessen the value of more precise estimates.

Our recommendations on entrainment are to do work aimed at reducing the losses instead of trying to provide better estimates or prove that they are or are not significant. We understand that PG&E is planning to reduce losses in their Pittsburg and Antioch Plants, and that some changes in design or operation are being considered for the CVP/SWP diversions.

Entrainment loss estimates for the many small agricultural pumps and siphons in the Delta are the least accurate of all, and in some ways are the hardest to make because they probably vary so much. We recommend a program of sampling of small fish to determine why losses in some agricultural diversions are higher than in others and what might be done to reduce them. We also recommend a pilot program of designing and testing simple fish screens to protect both the fish and the Delta farmer's water supply.

TOXIC SUBSTANCES

Even though the water quality of the Estuary has been greatly improved over the years, toxic substances may be affecting the health of striped bass and that may have contributed to the population decline. Whether or not this is true, the risk of toxic substances will always be with us, and the continuation of programs to monitor and understand their effects on the striped bass and the Estuary is essential. It was not our group's assignment to critique any existing program but we do believe that the following specific studies will be needed.

For eggs and larvae, onsite bioassays should be made to define the concentrations and durations of exposure to agricultural drain water that may damage striped bass eggs and larvae in the Sacramento River. The results of these bioassays should be compared with the actual exposure regimes experienced by striped bass eggs and larvae in the Sacramento River. If actual exposure regimes appear sufficient to cause damage, studies to determine which constituents of the drain water are causing mortality should be made. Action should be taken to eliminate such constituents from the Sacramento River.

The high levels of various toxic substances (petrochemicals, pesticides, and heavy metals) in the tissues of field collected striped bass have been correlated with poor health of individual bass in the population. We suggest that more intensive toxicant monitoring be carried out, with particular emphasis on the concentrations, persistence, and distribution of suspect toxic substances from point discharges including periodic oil spills.

We also suggest the additional work be done on the tissue concentrations and organ condition of striped bass killed during the annual spring die-off. If the results of that analysis suggest a relationship between the suspected toxic substances and these deaths, bioassays on returning spawners will tell if they are more sensitive than the other segments of the striped bass population.

EGG PRODUCTION

Because adult populations have been reduced and now consist of younger and smaller female bass, total egg production has declined by about 90%. Like the other hypotheses, we do not know if this is or is not the cause of the decline, but our striped bass model indicates that it could be. The saving of more eggs by reducing the catch of female bass is one quick way of attempting to mitigate the problem.

We recommend that, until the base cause of the decline is more clearly defined and solved, angling regulations should be designed to reduce catch. The regulations adopted last year should be evaluated annually, and if they have not succeeded in increasing egg production, more restrictive regulations should be temporarily implemented. Striped bass fishermen are more concerned about the future of this resource than anyone else, and, we believe they will do more than their share to help solve it.

Hatchery production may also be useful, provided that large numbers of fish are planted. It is essential that the stocking programs be planned and executed in a way that can be evaluated.

A DELTA TRANSFER FACILITY

Our group did not directly address the advantage or problems of any facility to transfer water around or through the Delta. A decision to build or not to build such a facility, and the choice among alternatives, however, will have a major effect upon man's ability to restore the Delta habitat and the striped bass nursery area.

There is good evidence that current use of the Delta channels to convey water to the CVP/SWP export pumping plants has been a major contributor to the long-term decline of the striped bass. Most of our group believe that in recent years the accumulation of those effects, combined with the reduced outflow, can explain the more rapid decline of the striped bass stocks. There is good reason to believe the planned increases in export pumping will exacerbate the problems of reduced food production and entrainment unless a properly designed and operated Delta transfer facility is built. That is likely to reduce the numbers of young-of-the-year produced each year and in turn will reduce adult stocks. A further decline in adult stocks will reduce the number of eggs produced and, thus, the striped bass population would continue to spiral downward.

DATA ANALYSIS AND EVALUATION

A very large amount of information relevant to the striped bass decline and how to solve it has been gathered over the years by the Department of Fish and Game, the Department of Water Resources, the US Bureau of Reclamation, the National Marine Fisheries Service, the State Water Resources Control Board, and others. But, because of administrative bottlenecks, much of the data that is key to understanding the problem was not available to us, and, in fact, has not been available to the scientists of those organizations. This problem must be solved. All data should be tabulated and made available for analysis within six months after it has been collected--or, in some cases, even sooner. There is simply no excuse for long delays with data inaccessible in computers or left unprocessed. The bass population and the fishery is in very serious trouble. Complete and timely analysis of the relevant information must receive high priority.

Our group also recommends that the State Board review the existing monitoring program required by Decision 1485. Some of the information collected over the years has not been subjected to the analysis and interpretation necessary to determine the effect of the water projects on the Estuary. That analysis should be completed and the program changed to reflect the new understanding.

COMMUNICATION

Our group was organized because its members, scientists from different agencies and organizations, had vastly different concepts of what was happening, both to the striped bass and to the environment of this Estuary. Working toward the very specific goal of trying to understand each other's work and viewpoints, to explore old and new ideas objectively and critically, and, finally, to describe what we agree and disagree about in an understandable fashion, has been very helpful to us. We think the results of our analysis and the improved communication it has achieved, will also help the Board and other agencies and organizations concerned with the striped bass problem.

We feel that we have only just begun. There is a particular need for faster and deeper analysis on the four hypotheses that we have described as being probable contributors to the striped bass decline, and there is a need for rapid, critical, and objective peer review of all that analysis.

We are, however, not recommending that the Striped Bass Working Group be continued. Our success has been largely due to a clear definition of our task by the Board and its staff, and by time constraints that often seemed impossible. We do recommend the organization of similar working groups to address specific problems within strict time limits. Members of such groups should, of course, be selected for their interest and expertise in the specific problem. We believe the method is a good one.

FIGURE REFERENCES

Arthur, J. 1982. The striped bass decline as influenced by food supply in the postyolk sac larval life stage. Rept. Striped Bass Working Group MS 38 pp.

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Whipple, J. A., et.al. 1982. The impact of estuarine degradation and chronic pollution on populations of anadromous striped bass (*Morone saxatilis*) in the San Francisco Bay-Delta, California. Res.Rept. NOAA 352 pp.

Yocom, T. G. and R. S. C. Wolcott, Jr. 1982. The condition of adult striped bass in the Bay-Delta Estuary. Rept. Striped Bass Working Group MS 8 pp.

APPENDIX

Following is a list of working papers prepared by various members of the Striped Bass Working Group. Copies will be on file with the California State Water Resources Control Board, after January 1, 1983.

Arthur, James F. The striped bass decline as influenced by food supply in the postyolk sac larval life stage.

Botsford, Louis W. Possible influence of adult striped bass on young-of-the-year; modeling results.

Hansen, Stephen R. Conceptual model: Factors affecting the striped bass population in the San Francisco Bay-Delta system. 5 pp.

Hansen, Stephen R. Evaluation of the role played by toxic substances in the decline of the striped bass population in the San Francisco Bay-Delta system. 61 pp.

Hanson, Charles H. A conceptual model of mechanisms and factors affecting striped bass year class strength. 48 pp.

Kohlhorst, David. Comparison of adult striped bass survival rates estimated by several methods.

Kohlhorst, David. Comparison of natural mortality rates of striped bass tagged in the Sacramento River and in the Delta.

Kohlhorst, David. Trends in striped bass harvest rates.

Miller, Lee. A partial analysis of trophic relationships between chlorophyll *a*, zooplankton, *Neomysis*, and young striped bass in the Sacramento-San Joaquin Estuary. 41 pp.

Miller, Lee. Hypothesis: Increased Ordram (molinate) use could account for the decline in abundance of striped bass.

Sitts, Richard M. Recommended courses of Board action to fight the decline in striped bass.

Sitts, Richard M. Monthly flows in the Delta as indicators of residence time, a potential cause of the striped bass decline.

Sitts, Richard M. Increased secondary waste treatment as the cause of the striped bass decline.

APPENDIX (continued)

Sitts, Richard M. Entrainment impacts on young striped bass of combined operation of southern Delta export facilities over the years 1959-1981.

Sitts, Richard M. Striped bass entrainment at Delta water diversion intakes.

Sitts, R. M. and C. H. Hanson. Conclusions and recommendations on entrainment and point-source organic wastes.

Sitts, R. M. and C. H. Hanson. Entrainment and the loss of small bass by diversions. 7 pp.

Stevens, Donald Recent trends in water transparency in the Sacramento-San Joaquin Delta.

Stevens, Donald Increased predation responsible for decline in young striped bass?

Stevens, Donald Decline in striped bass due to competition from threadfin shad?

Stevens, Donald Relationships between abundance and survival of young striped bass and crustacean zooplankton densities in the striped bass nursery area. 18 pp.

Turner, Jerry L. Possible sudden decline in adult striped bass population of the Delta-San Francisco Bay Estuary based on Petersen tagging results. 7 pp.

Turner, Jerry L. Chlorophyll _a_ and _Neomysis_ concentration in the Suisun Bay/Delta from 1970 to 1980. 6 pp.

Yocom, T. G. and R. S. C. Wolcott, Jr. The condition of adult striped bass in the Bay-Delta Estuary.