FWQ/BIO-4ATR/89-20

FACTORS AFFECTING STRIPED BASS ABUNDANCE in the SACRAMENTO-SAN JOAQUIN RIVER SYSTEM

Exhibit 25, entered by the
California Department of Fish and Game for the
State Water Resources Control Board
1987 Water Quality/Water Rights Proceeding on the
San Francisco Bay and Sacramento-San Joaquin Delta

Technical Report 20
August 1987

Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary

A Cooperative Study By:

California Department of Water Resources
State Water Resources Control Board
U.S. Fish and Wildlife Service
California Department of Fish and Game
U.S. Bureau of Reclamation
U.S. Geological Survey

C—045453

C-045453

FWQ/BIO-4ATR/89-20

FACTORS AFFECTING STRIPED BASS ABUNDANCE in the SACRAMENTO-SAN JOAQUIN RIVER SYSTEM

Exhibit 25, entered by the
California Department of Fish and Game for the
State Water Resources Control Board
1987 Water Quality/Water Rights Proceeding on the
San Francisco Bay and Sacramento-San Joaquin Delta

Technical Report 20
August 1987

Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary

A Cooperative Study By:

California Department of Water Resources
State Water Resources Control Board
U.S. Fish and Wildlife Service
California Department of Fish and Game
U.S. Bureau of Reclamation
U.S. Geological Survey

C—045454

C-045454

PREFACE

Interagency staff representing the California Department of Fish and Game had lead responsibility in preparing this report. Drafts have been reviewed by members of the fisheries/water quality committee of the Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary.

The report reflects the fisheries/water quality committee members' agreement on most points. Committee members will provide direct testimony on areas of disagreement.

Agency management was not part of the review process and may differ on how study results can be used in managing striped bass resources.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Sacramento-San Joaquin Estuary is habitat for a striped bass population which supports one of California's most important sport fisheries. Some 100,000 to 400,000 striped bass, depending upon current stock size, are caught by anglers each year. The annual recreational value of this fishery has been estimated at 45 million dollars.

Principal spawning areas are in the San Joaquin Delta and in the Sacramento River from the City of Sacramento upstream to the town of Princeton.

Eggs drift with water currents after spawning and hatch in 2-3 days into larvae that soon require food but have little swimming ability. They are distributed by flows in the Sacramento and San Joaquin rivers, in the Delta channels, in Suisun, Grizzly, and Honker bays and, in wet springs, even farther downstream.

The adult population, now less than 1 million fish, has declined to about 1/3 of its former level. Juvenile bass production has fallen even more. Major investigations of probable causes have been done and serious efforts made to mitigate the damages with fish screens; water quality, flow, and project operation standards; and, more recently, stocking. While all have undoubtedly been beneficial, none have prevented the decline or have yet restored the stocks.

This report describes the decline and what is known of its causes. Important points are:

1. Annual adult striped bass mortality rates have increased from about 40% in the early 1970s, when the population was higher, to 53% in recent years, thus contributing to the decline in abundance. Angling harvest rates have ranged from 12 to 24% of the annual population with a trend upward in the early 1970s, downward in the late 1970s and back up in the early 1980s. These rates are not considered too high for a healthy striped bass stock. Adult mortality from causes other than fishing increased after the mid-1970s, but no reason has been identified. It has been observed that the tissues of some adult bass contain heavy metals, various petrochemicals, and pesticides including DDT.

2. Growth rates of adult bass have not changed, suggesting that their food supply has not been significantly damaged.

3. A mid-summer index of striped bass young of the year (the 38 mm index) declined from high levels, which sometimes exeeded 100 in the mid-1960s, to an all time low of 6.3 in 1985. Year-to-year annual differences in this index from 1959-1970 were well explained by fluctuations in spring outflow and the percent of the Delta inflow that was being diverted. When outflows were high and the percent of inflow being diverted was

C-045459

low, the 38 mm index was high. When outflows were low and the percent of inflow being diverted was high, the 38 mm index was low.

Beginning in 1971, the 38 mm indices were always lower than expected. Since 1977 they have been very much lower. The single exception was the 1986 index which fit the relationship between outflow, diversions, and bass that existed before 1977.

Even though the indices have been lower in recent years, they have always remained correlated with outflow -- but at lower abundance levels.

This decline in the production of young bass is the principal cause for the decline in the adult bass population.

4. Part of the reason why the annual index of 38 mm bass has remained low is that since the adult population is now low, fewer eggs are being produced. This reduction in egg production cannot fully explain the decline in young fish but it may have accelerated it and does make recovery more difficult. Evidence suggests that there is no surplus of eggs.

5. There is no evidence that spawning habitats have been damaged. SWRCB standards have protected them and should be maintained.

6. The rate at which bass survive their first few months is critical. Larval bass survival varies greatly

from year to year but, in years with similar Delta flows, has been lower since 1975. The cause is not yet known.

7. <u>Large numbers of eggs and young bass too small to be screened are pumped from the Delta by diversions</u> for Delta agriculture, the Central Valley Project (CVP), the State Water Project (SWP), and Pacific Gas and Electric Company (PGE) power plants. Modifications of operations by PGE have cut their losses by 75% in recent years. The magnitude and consequence of these losses depends upon spring flows. In 1985, with an average spring Delta outflow of 6,495 cfs most larvae were left in the Delta. Diversion from the CVP/SWP plants alone reduced the population of 20 mm bass by 3/4. In 1986, with an average spring Delta outflow of 21,190 cfs, many larvae were washed down into Suisun Bay. The 20 mm population was reduced 31% by CVP/SWP entrainment. High correlations between abundance of striped bass at various life stages from eggs and larvae to adults strongly suggest that such larva losses have severely reduced the adult bass population and the fishery that it supports.

Evidence indicates that the significance of entrainment was underestimated when Decision 1485 was formulated. The May-July export restrictions in Decision 1485 did, however, place a ceiling on exports approximately at the average levels of the early 1970s.

Hence, current entrainment losses are probably not the major factor causing poorer survival of young bass since 1975.

The Departments of Fish and Game and Water Resources have signed an agreement to mitigate for entrainment losses at the Harvey O. Banks pumping plant. A mitigation effort is needed at the U.S. Bureau of Reclamation Delta pumping plant and discussions of the subject have started.

The report recommends that responsible agencies seek ways of moving eggs and larvae past the Delta into Suisun, Grizzly, and Honker bays where food is usually more abundant and the dangers of entrainment are less.

8. The level of several contaminants in striped bass are higher in this estuary than in bass at several other locations and may be causing harm, including the resorption of eggs. Controlled laboratory experiments are needed to evaluate cause and effect relationships for likely toxicants.

LIST OF TABLES

LIST OF FIGURES

Page

INTRODUCTION

This report will describe the importance of striped bass, *Morone saxatilis*, that depend upon the environment of the Sacramento-San Joaquin River Estuary, changes in their population that have taken place in the last 25 years, and what is known of the causes of these changes. We will emphasize the major decline in the population that became most evident after 1976.

We describe the adult population and the factors that affect it; followed by information on juveniles; and finally, a summary of what we believe has happened to the stock.

The last part of the report is a list of some past efforts to protect striped bass in the estuary, with major emphasis on the Central Valley and State Water Projects.

A short list of recommendations at the end is meant to direct all agencies toward an active program that can be developed and presented to the State Water Resources Control Board (SWRCB) before these hearings are completed.

This report has been prepared by Department of Fish and Game (DFG) staff with the assistance of staff from the U.S. Fish and Wildlife Service, California Department of Water Resources, U.S. Bureau of Reclamation, and an independent panel of fishery experts. This panel consisted of Don Kelley of D. W. Kelley and Associates (William Mitchell and John Reuter of Kelley's staff also participated); Jerry Turner, ECOS Consultants; Louis Botsford

and Robert Kope, University of California; Joseph Loesch, Virginia Institute of Marine Science; and Jeannette Whipple and Paul Smith, National Marine Fisheries Service.

THE STRIPED BASS FISHERY

The striped bass sport fishery is the most important fishery in the Sacramento-San Joaquin Estuary and is one of the most important fisheries on the west coast. The annual catch ranges between 100,000 and 400,000 fish and the annual recreational value of the fishery has been estimated to exceed 45 million dollars (Meyer Resources 1985).

Striped bass anglers fish from the Pacific Ocean beaches near San Francisco upstream through the estuary into the Sacramento River more than 125 miles above the Delta (Figure 1). Angling occurs the year around, but fishing localities vary seasonally in accordance with the striped bass migratory pattern. The fall migration of striped bass upstream from San Francisco Bay to the Delta is marked by good fishing in San Pablo and Suisun bays. Fishing in the Delta also improves gradually with the movement of bass into that area and then declines as the water temperature drops in the winter.

Fishing success improves as the water warms up in March when those striped bass that have wintered in the bays start moving upstream to fresh water for spawning. During the spring adults are spread throughout the Delta and over 100 miles north in the Sacramento and Feather rivers. Good fishing can be expected in the river spawning area at this time and occasional good catches are made in the bays.

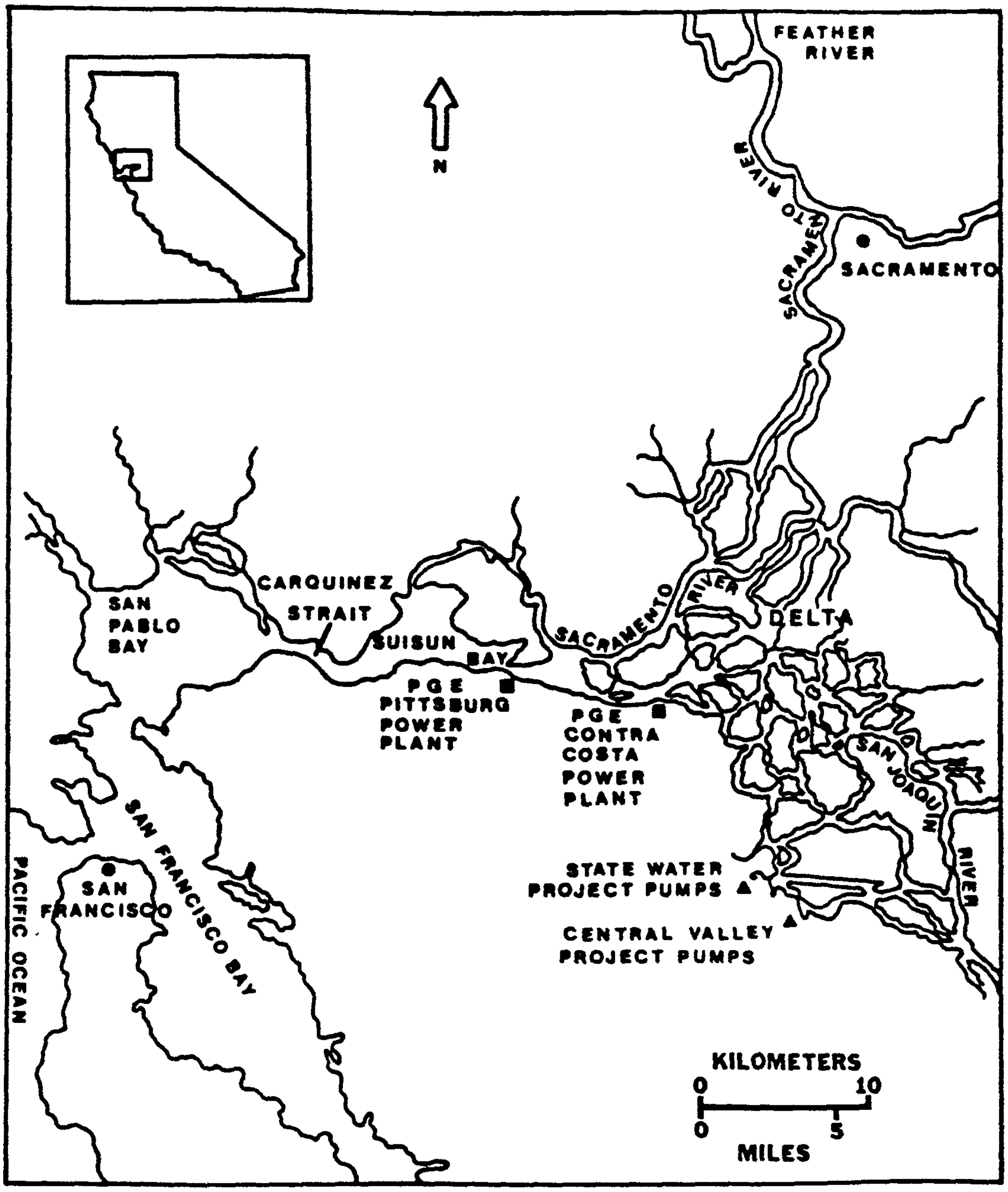


Figure 1. The Sacramento-San Joaquin River system. The principal striped bass nursery areas are the broad channels of the western Delta and Suisun Bay.

C-045473

By mid-June most adult striped bass have left freshwater and returned to brackish and salt water. During summer and early fall, fishing reaches its peak in Carquinez Strait, San Pablo Bay, and San Francisco Bay. Sometimes large numbers of striped bass migrate into the Pacific Ocean where many are caught by surf-casters.

Although most fishing is from shore and private boats, charter boats are an important component of the fishery in the San Francisco-San Pablo Bay area and provide us with a useful index of long term catch trends. Charter boat operators are required to report catches to DFG. These boats generally have taken only 10-15% of the total catch and their fishing locations and methods have changed over the years, but their reports are the best long-term striped bass catch records available (Stevens 1977a). From 1958 to 1985, the reported annual catch by charter boats declined from 48,900 to 9,700 striped bass (Figure 2). Catches have been particularly low since 1976 with the lowest catch of only 1,400 bass occurring in 1980. The catch per angler-day on charter boats is available from 1958 to 1982. It decreased from 1.96 to 0.49 during this period, although the general downward trend in the fishery was interrupted by good fishing in 1966, 1972, 1974, and 1979.

Total catches on charter boats are affected by the number of anglers willing to pay for a day's fishing, and fishing effort declines when fishing is poor (Miller 1974). Thus, low angler success has caused charter boat effort to drop off sharply in

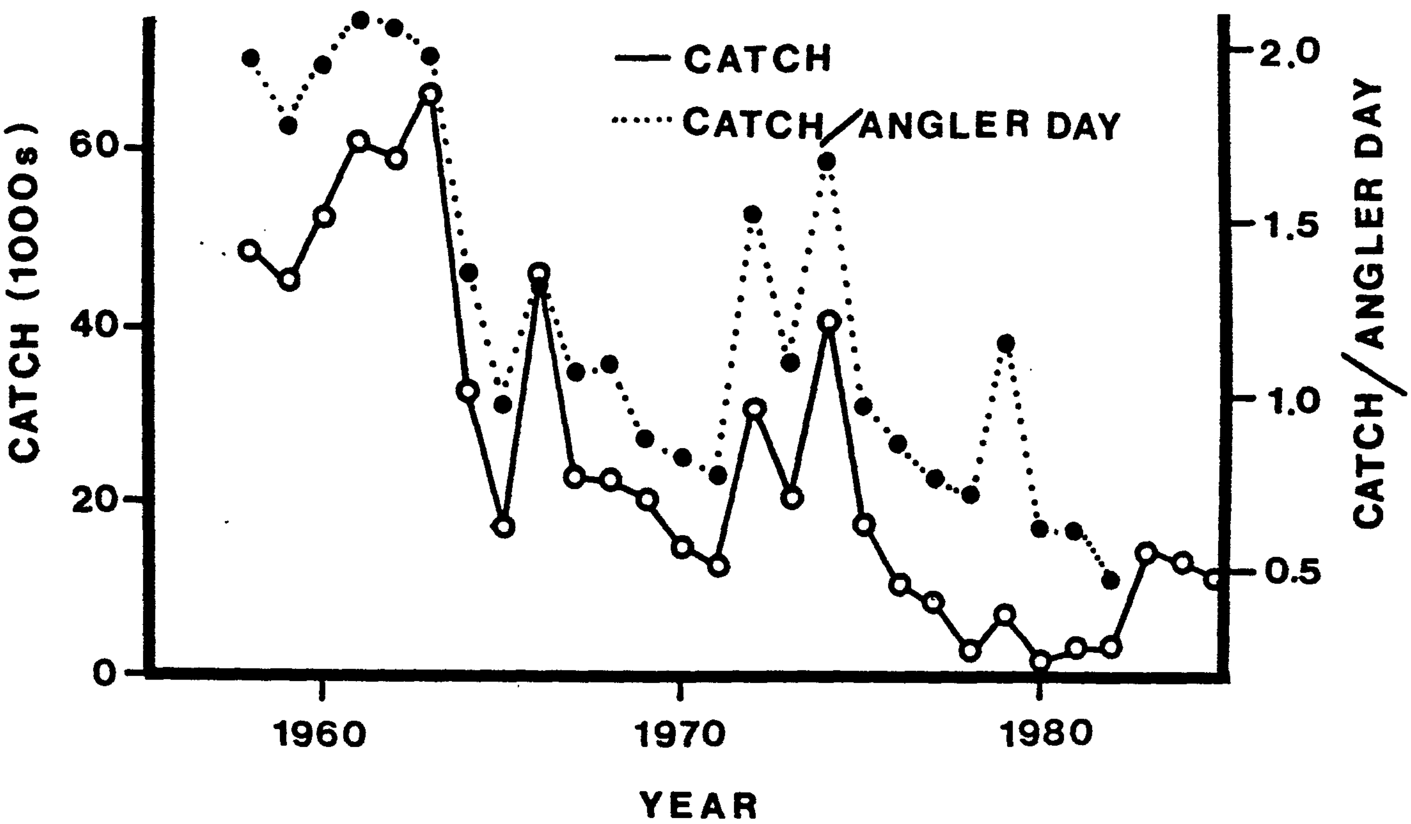


Figure 2. Trends in striped bass catch and catch per angler-day reported by charter boats in the San Francisco Bay area. Catches have been particularly low since 1976 reflecting a decline in angler success and decreased fishing effort associated with the generally poor fishing. While reduced effort may have caused the total catch on charter boats to decline more severely than the catch for the striped bass fishery as a whole, there is no question that the decline in the charter boat fishery reflects the seriousness of the decline in striped bass fishing in general.

recent years. While this reduction in effort has caused total catch on charter boats to decline more severely than the catch for the striped bass fishery as a whole, there is no question that the decline in the charter boat fishery reflects the seriousness of the decline in striped bass fishing in general. The entire fishery has been very badly damaged.

DECLINE OF THE ADULT STRIPED BASS POPULATION

The decline of the striped bass fishery is a direct result of a substantial decline in the striped bass population.

DFG has measured adult striped bass abundance with Petersen mark-recapture population estimates and the catch-per-effort (CPE) of adult (total length at least 16 inches) striped bass captured in large gill nets and traps during tagging studies.

Modified Petersen population estimates (Bailey 1951) were calculated annually from 1969 through 1985. Striped bass were tagged with disc-dangler tags (Chadwick 1963) during their spring spawning migration to the Delta and Sacramento River. The ratio of tagged to untagged fish in the population was estimated during annual summer-fall creel censuses in the San Francisco Bay area and subsequent spring tagging operations (Stevens 1977b).

According to the Petersen estimates, the striped bass population was a relatively stable 1.4 to 1.8 million adults between 1969, when the estimates began, and 1976 (Figure 3). In the next 2 years abundance declined to about one million adults and has remained at this level or below.

Our second assessment of adult striped bass stocks is a simple catch per unit of effort (CPE) of striped bass in gill nets and fyke traps (Hallock et al. 1957) during tagging operations in the Delta and Sacramento River. This CPE index is the sum of catches in the fishing gears after annual effort was standardized

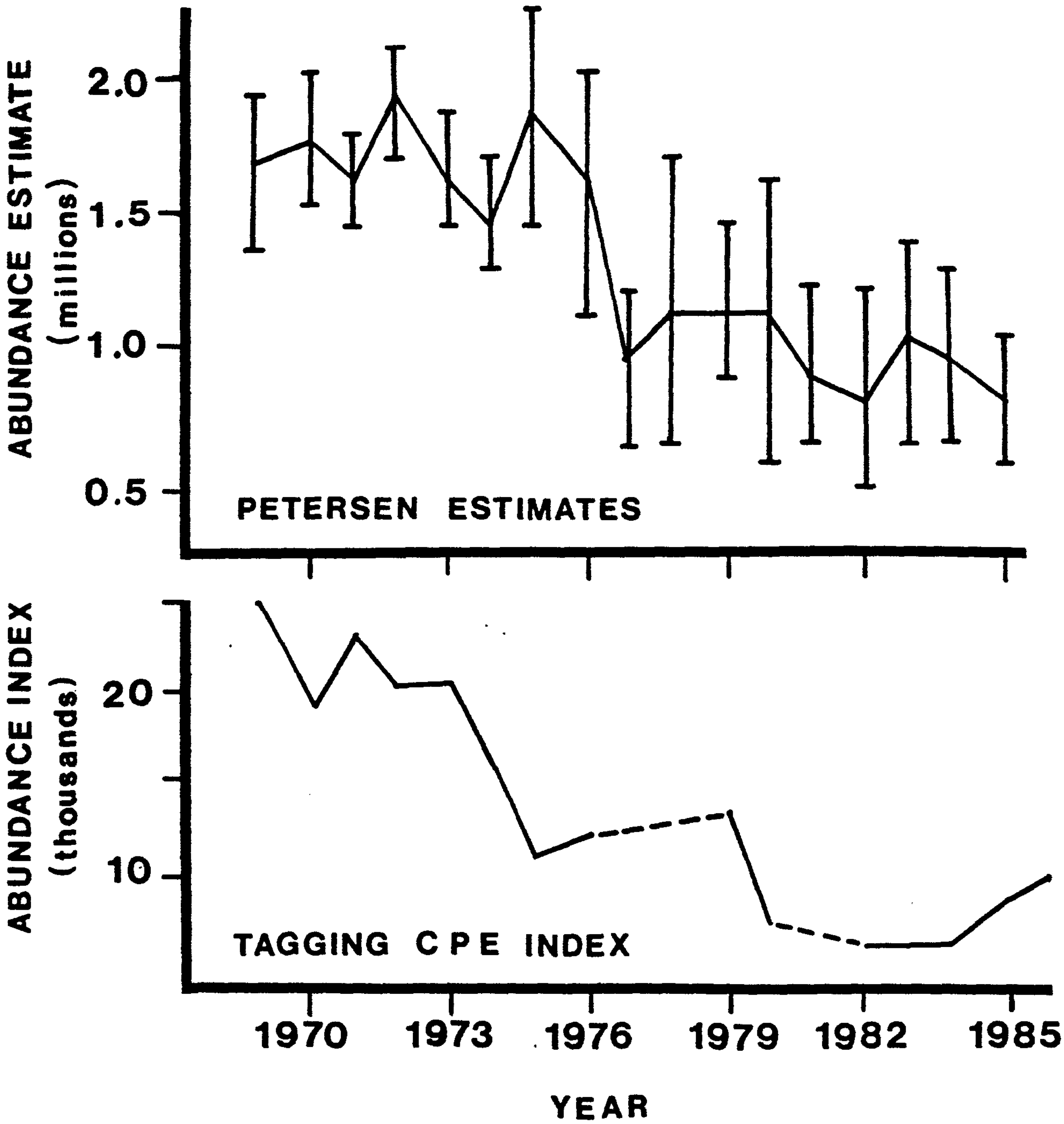


Figure 3. Trends in abundance of adult striped bass (at least 16 inches total length) in the Sacramento-San Joaquin Estuary. Direct measures of precision for the Petersen estimates in the form of 95% condfidence intervals are depicted by vertical bars. From 1969 to 1974 these confidence intervals averaged only ± 13% of the estimated value indicating that the Petersen estimates were quite precise. Thereafter, as the numbers of tagged fish released and recaptured decreased, the estimates became less precise; confidence intervals averaged ± 34% of the estimated value from 1975 to 1985. No direct measure of the precision of the CPE index is available, but correlations between indices for adjacent ages of the same year classes suggest that it is the more reliable of these population measures (Appendix 1).

C-045478

to 4 gill-netting boat-months and 36 fyke-trap-months. A boat-month is 20 8-hour days of fishing a 600 foot long drift gill net (4 to 5-1/2 inch stretched mesh). A trap-month is 30 24-hour days of fyke trap fishing. In years when fishing occurred, effort ranged from 2 to 4.5 boat-months and from 11 to 42 trap-months.

Tagging began in 1958 (Chadwick 1968), but the fyke netting started in 1969. No CPE index is available for 1977, 1978, or 1981 because fyke traps were not fished in those years.

Like the Petersen estimates, the CPE index indicates that the bass population was stable from 1969 to 1973, declined by some 40% between 1973 and 1975, and remained at that level through 1979. By 1983 this index had declined to one-third of what it was a decade earlier. This index rose somewhat in 1985 and 1986.

We have done an analysis (Appendix 1) which suggests that the CPE index is more reliable than the Petersen estimates and that conclusions based on it should be given more weight where only an index rather than an absolute measure of abundance is needed.

Overall, there is no question that the population of adult striped bass in the estuary has fallen to a low level -- much lower than when estimates were first available 20 years ago. This reduction in adult stock is the result of both increased adult striped bass mortality and lower recruitment from the juvenile population.

Increased Adult Mortality Rate

Measures of adult striped bass mortality are based on tag returns from anglers. The returns allow us to use standard fishery text book techniques (Ricker 1975) to calculate annual mortality rate A.

Annual mortality rate A is the complement (A=1-S) of annual survival rate S (Ricker 1975). Survival rate was estimated using Ricker's (1975) equation 5.1:

$$S_1 = \frac{R_{12}\, M_2}{M_1\, R_{22}},$$

where: S_1 = estimated survival rate in year 1,

M_1 = number of fish tagged at the start of year 1,

M_2 = number of fish tagged at the start of year 2,

R_{12} = returns of tags in year 2 that were applied at the start of year 1, and

R_{22} = returns of tags in year 2 that were applied at the start of year 2.

To determine whether trends in mortality of young and old fish differed, we estimated mortality for ages 3 and 4 combined and ages 5 and older in addition to estimating annual mortality for all ages combined.

The results indicated that annual mortality of all of these age groups increased slightly in the last 15 years (Table 1, Figure 4).

Table 1. Number of tagged fish released, response rate, and mortality rates for striped bass in the Sacramento-San Joaquin Estuary.

Year	Number Released	Response Rate1/	Exploitation Rate	Expectation of Natural Death	Annual Mortality Rate Ages 3&4	Annual Mortality Rate Ages ≥5	Annual Mortality Rate All Ages	Source
1958	3,891		0.372	0.309			0.681	Chadwick 1968
1959	2,965		0.247	0.219			0.466	"
1960	3,358		0.243	0.156			0.399	"
1961	1,609		0.190	--			--	"
1965	3,889		0.142	0.203			0.345	Miller 1974
1966	2,996		0.179	--			--	"
1969	16,416	0.658	0.171	0.224	0.477	0.399	0.395	
1970	14,373	0.618	0.121	0.309	0.504	0.366	0.430	
1971	18,127	0.498	0.171	0.198	0.383	0.352	0.369	
1972	18,377	0.512	0.170	0.275	0.527	0.364	0.445	
1973	15,385	0.512	0.167	0.267	0.469	0.351	0.434	
1974	13,785	0.459	0.229	0.142	0.473	0.220	0.371	
1975	8,852	0.407	0.240	0.265	0.578	0.419	0.505	
1976	10,511	0.473	0.208	0.223	0.553	0.462	0.431	
1977	4,955	0.431	0.170	0.242	0.425	0.508	0.412	
1978	4,253	0.354	0.163	0.389	0.579	0.494	0.522	
1979	11,055	0.412	0.155	0.299	0.515	0.385	0.454	
1980	6,405	0.493	0.123	0.365	0.502	0.486	0.488	
1981	7,402	0.498	0.111	0.460	0.660	0.368	0.570	
1982	3,437	0.372	0.159	0.148	0.300	0.383	0.307	
1983	3,094	0.456	0.237	0.328	0.562	0.606	0.565	
1984	4,829	0.363	0.223	0.278	0.544	0.475	0.501	
1985	7,404	0.409	0.198	--				

1/ Estimated fraction of recovered nonreward tags that anglers actually return. The estimation assumes all recovered $20 reward tags were returned. Because $20 tags were not released every year and response generally decreased annually as catches of tagged fish became more common through the mid-1970s, we calculated linear regressions of return rate ratio on year for (1) nonreward:$5 tags, (2) $5 tags:$10 tags, and (3)$10 tags:$20 tags. Response for each year before $20 tags were first used (1978) was estimated as the product of observed and predicted ratios. Response from 1978 to 1985 is the observed return rate ratio for nonreward:$20 tags.

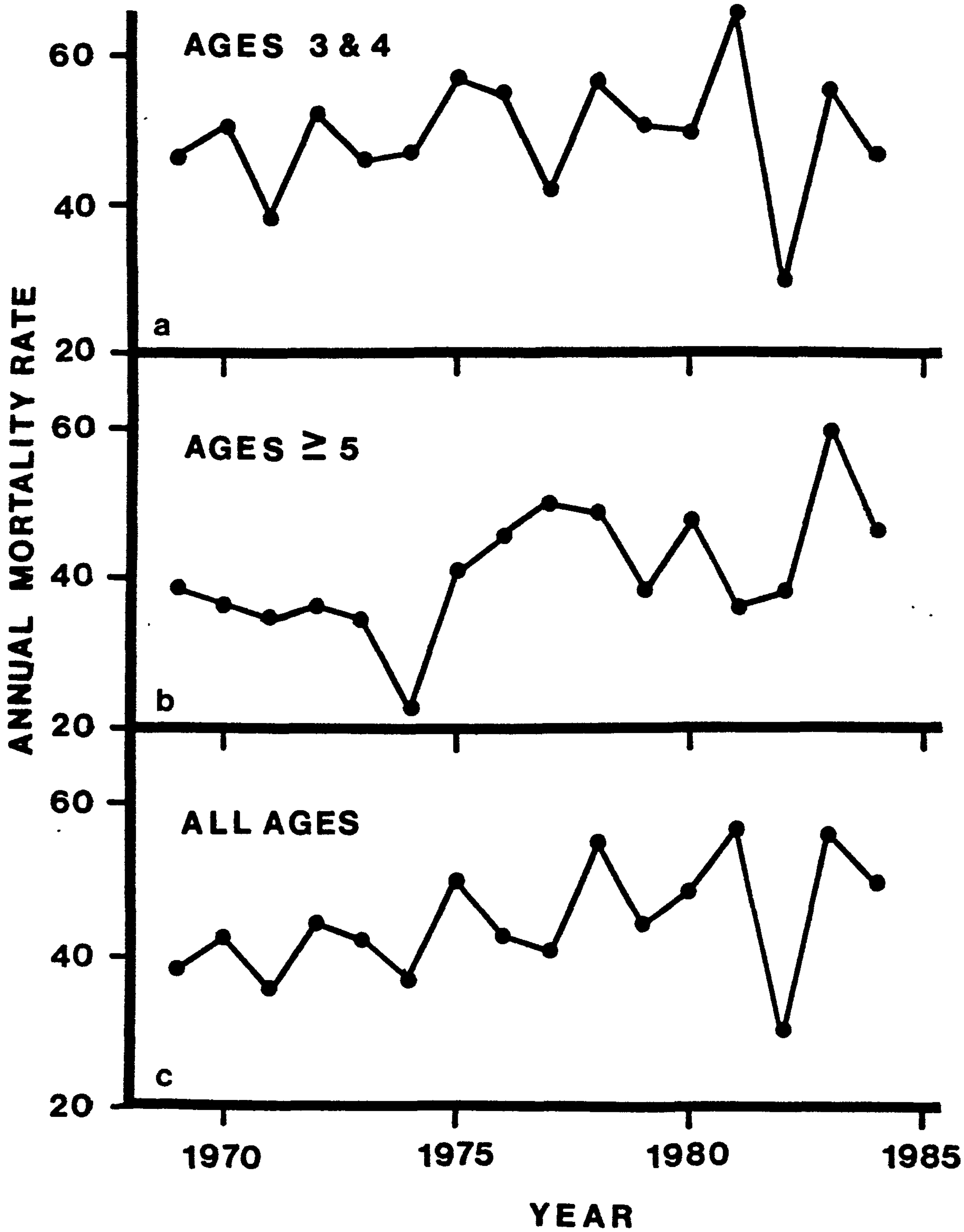


Figure 4. Estimates of annual mortality rates for striped bass in the Sacramento-San Joaquin Estuary from 1969 to 1984. The upward trend from 1969 to 1984 is most apparent if the unusually low 1982 estimates in a) and c) are omitted. Those estimates may be affected by imprecision associated with the small number of bass tagged in 1982 and 1983.

C-045482

Estimates of mortality rates for the overall population in earlier years are available for comparison with the estimates for years since 1969 (Table 1) (Chadwick 1968; Miller 1974). Annual mortality rate was very high in 1958 (0.681). The mean for 1959, 1960, and 1965 (0.40) is similar to the 1969-1973 mean (0.41) and lower than the means from 1974-1979 (0.45) and 1980-1984 (0.49). The total adult mortality rate has increased from around 0.40 in the early 1970s to 0.53 in most recent years.

Angler Harvest and "Natural" Mortality

Angler harvest exploitation rate (u) was estimated from returns of nonreward tags as:

$$u = \frac{R}{M},$$

where: R = number of tags recovered in the first year after tagging and

M = number of tags released at the start of the tag-return year.

Exploitation rate varied between 1969 and 1985, but showed no overall trend (Figure 5). Estimated exploitation ranged from 0.111 to 0.240, increasing from 1970 to 1975, then decreasing through 1981, and finally, increasing again. These exploitation rates are not too high for a healthy bass population.

The decrease in exploitation from 1975 to 1981 probably reflected reduced angler effort in response to the declining population (Figure 3) and poor fishing (Figure 2). The subsequent

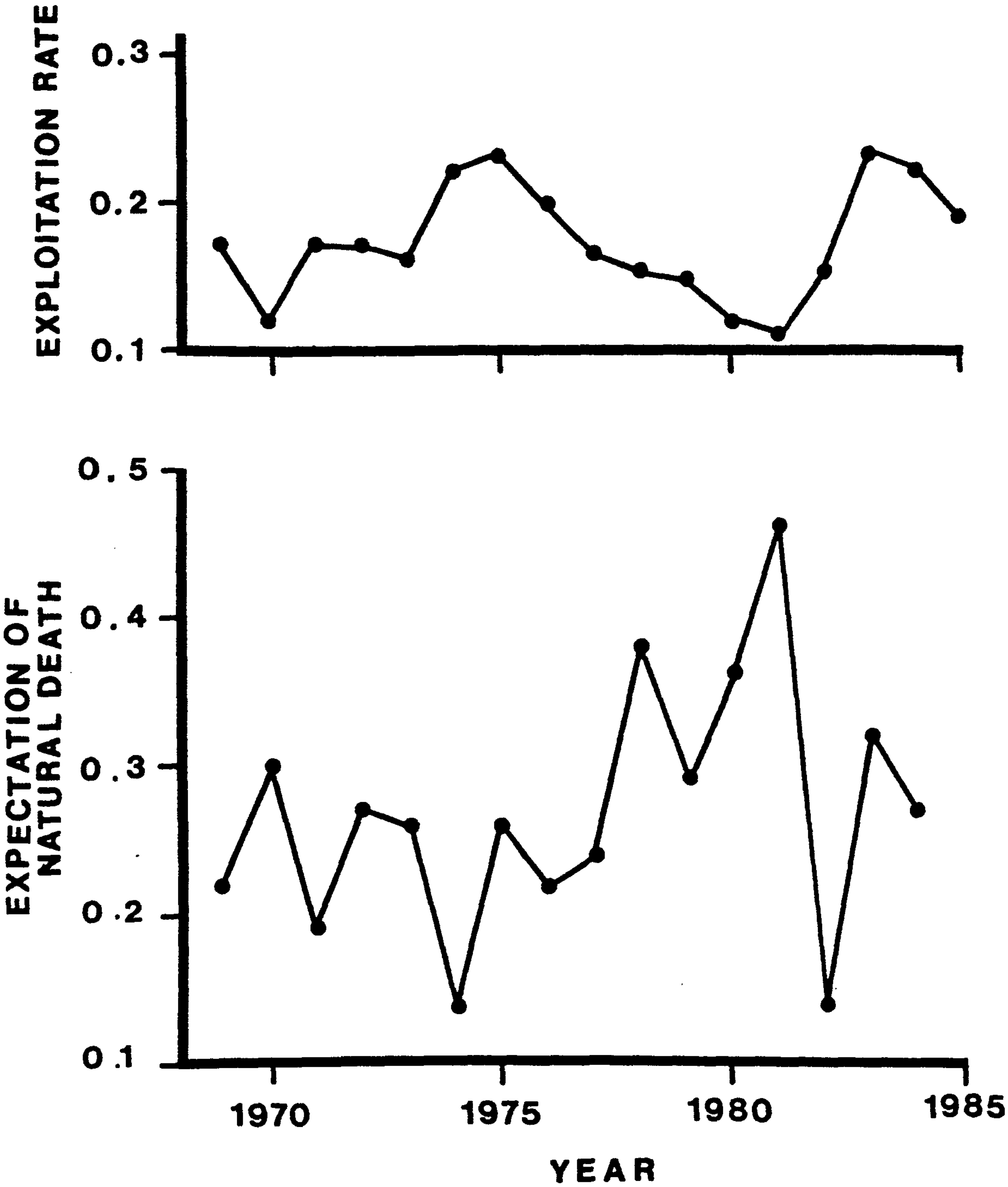


Figure 5. Estimates of exploitation rate and expectation of natural death for striped bass in the Sacramento-San Joaquin Estuary from 1969 to 1985. The decrease in exploitation from 1975 to 1981 probably reflects reduced angler effort in response to the declining striped bass population and poor fishing. The pattern of subsequent increase in exploitation reflects an increase in availability of bass to the fishery despite continued low population levels. Most high values and the greatest variability in "natural mortality" occurred in the late 1970s and 1980s.

pattern of increased exploitation, although more acute than the uptrend in catch on the charter boats, closely mimicked it. Presumably, the higher harvest reflected an increase in availability of bass to the fishery despite continued low population levels.

Expectation of natural death ("natural mortality rate") calculated by subtracting exploitation rate from total annual mortality (A-u) varied substantially from 1969 to 1984. The estimates ranged from 0.142 to 0.460. Most high values and the greatest variability occurred in the late 1970s and early 1980s (Figure 5).

We compared exploitation and natural mortality rates in earlier years (Chadwick 1968; Miller 1974) with estimates of these mortality rates since 1969 (Table 1). Exploitation rate in 1958 was higher than any subsequent estimate, but exploitation in 1959 and the early 1960s (mean=0.20) was similar to recent estimates (1969-1985 mean=0.18). Again omitting 1958, Chadwick and Miller's estimates of expectation of natural death (mean=0.22) are lower than the mean value (0.28) since 1969.

The increase in total mortality from 1969-1984 cannot be ascribed solely to either exploitation or natural mortality since neither component of mortality alone showed an overall trend during this period. For example, from 1978-1981, high natural mortality estimates led to greater total mortality estimates in spite of low exploitation. Conversely, in 1983 and 1984, the estimated exploitation rate had increased to keep the total

C-045485

mortality estimates higher at the time when estimates of natural mortality had decreased.

Effect of Toxic Substances

Toxic substances and the health of striped bass from the Sacramento-San Joaquin system have been studied by the National Marine Fisheries Service (NMFS), Tiburon Laboratory (1978-1983) (Whipple et al. 1981; Jung et al. 1984; Whipple et al., MS) and DFG (1984-1985) (Knudsen and Kohlhorst 1987, Appendix 2) (Tables 2 and 3). Whipple and her staff found that gonads, liver, and muscle of adult striped bass accumulated toxic substances, including petrochemicals, pesticides, and heavy metals and exhibited symptoms of physiological stress such as parasite infestations, parasite-induced lesions, and egg resorption. Striped bass collected on spawning grounds near Antioch from 1978 through 1985 showed no overall trend in condition, parasite load, or pollutant burden (Table 4), except for decreases in alicyclic hexanes (petrochemicals) and chromium.

Simple correlations between pollutant levels and health measurements (Table 5) lead us to the following broad generalizations:

1. Skeletal abnormalities (usually misshapened gill rakers) are associated with high burdens of trace elements in liver tissue, specifically with mercury, selenium, zinc, and chromium.
2. Older fish have higher levels of trace elements in the liver.

Table 2. Annual summary showing means and ranges of pollutant concentrations in liver tissue and relative health measurements of female striped bass collected from the San Joaquin River near Antioch during the April and May spawning period. Concentrations of trace elements are in ppm (ug/g) dry weight; other pollutants are in ppm wet weight. NM = not measured. ND = not detected.

	1978	1979	1980	1981	1982	1983	1984	1985
POLLUTANTS:								
MAHs 1/	0.33	0.17	0.05	2.10	0.22	0.46	ND	0.41
	0.0 - 3.29	0.0 - 6.61	0.0 - 0.25	0.43 - 5.24	0.0 - 1.47	0.0 - 6.53		0.0 - 2.24
AHs 1/	0.14	0.41	ND	0.02	ND	0.73	ND	ND
	0.0 - 1.19	0.0 - 2.22		0.0 - 0.15		0.0 - 8.73		
DDT & Metabolites	NM	NM	NM	0.72	NM	NM	0.25	0.49
				0.06 - 1.57			0.11 - 0.59	0.06 - 3.93
Other Pesticides 4/	NM	NM	NM	NM	NM	NM	0.04	0.08
							0.02 - 0.10	0.01 - 0.44
PCB-1260	NM	NM	NM	1.51	NM	NM	0.47	0.40
				0.0 - 5.00			0.20 - 0.83	0.07 - 1.40
Copper	NM	NM	30	66	NM	NM	76	67
			0 - 122	27 - 220			8 - 338	9 - 154
Zinc	NM	NM	81	159	NM	NM	175	147
			10 - 175	28 - 250			85 - 272	64 - 213
Cadmium	NM	NM	NM	2.62	NM	NM	2.90	3.69
				0.29 - 9.40			0.28 - 8.40	0.20 - 8.60
Chromium	NM	NM	NM	1.42	NM	NM	0.12	0.08
				0.61 - 3.30			0.05 - 0.23	0.04 - 0.15
Mercury	NM	NM	NM	3.4	NM	NM	1.7	1.1
				0.8 - 10.0			0.6 - 3.3	0.1 - 2.7
Selenium	NM	NM	NM	8.5	NM	NM	7.3	7.2
				3.5 - 12.9			3.2 - 17.0	1.8 - 12.7
HEALTH MEASURES:								
All Parasites 5/	10.5	18.5	15.2	15.0	30.4	10.6	14.5	14.9
	0 - 45	0 - 107	2 - 42	0 - 45	6 - 86	0 - 28	2 - 43	0 - 31
Tapeworm Larvae 5/	2.6	4.6	6.7	4.3	16.0	4.4	5.4	7.5
	0 - 8	0 - 15	2 - 16	0 - 9	4 - 48	0 - 10	0 - 14	0 - 17
Tapeworm Rafts 5/	2.0	7.4	3.5	4.2	0.3	4.9	3.4	4.1
	0 - 22	0 - 99	0 - 13	0 - 19	0 - 2	0 - 16	0 - 13	0 - 10
Roundworm Larvae 5/	5.8	5.0	4.8	6.5	11.6	1.2	4.6	3.0
	0 - 20	0 - 36	0 - 22	0 - 24	0 - 32	0 - 4	0 - 20	0 - 12
% Eggs Resorbed	35.8	24.9	13.4	24.5	0.0	18.6	1.8	6.3
	1.6 - 100.0	0.0 - 100.0	0.0 - 100.0	0.0 - 100.0		0.0 - 100.0	0.0 - 11.6	0.0 - 69.6
Mesenteric Fat 6/	NM	2.5	1.9	1.3	1.9	2.6	2.4	3.0
		1 - 4	1 - 4	1 - 3	1 - 4	1 - 4	1 - 4	1 - 4
% Fat in Liver	NM	NM	9.2	NM	NM	NM	3.3	8.2
			8.3 - 10.4				1.1 - 10.0	2.0 - 36.0
Skeletal Abnormalities 5/	0.2	1.7	1.6	4.1	1.6	2.4	1.0	1.0
	0 - 4	0 - 17	0 - 11	0 - 13	0 - 9	0 - 7	0 - 5	0 - 4
Age	5.6	5.4	5.0	8.1	5.4	5.0	5.2	4.9
	4 - 8	4 - 11	4 - 7	4 - 13	5 - 6	3 - 6	4 - 8	1 - 6
MINIMUM SAMPLE SIZE:	52	39 7/	19 8/	12	7 9/	15	20	21

1/ Monocyclic aromatic hydrocarbons (volatile petrochemicals) analyzed were: benzene, toluene, ethylbenzene, para-, meta-, and ortho-xylene.
2/ Alicyclic hexanes (volatile petrochemicals) analyzed were: cyclohexane; methylcyclohexane; 1,1-, 1,2-, 1,3- and 1,4-dimethylcyclohexane; and ethylcyclohexane.
3/ Includes p,p'-DDT; o,p-, p,p'-DDD; o,p-, p,p'-DDE.
4/ Includes toxaphene, chlordane, nonachlor, oxychlordane, hexachlorabenzene and aldrin.
5/ Mean severity rank for a given parasite or abnormality type was calculated by summing the severity rank (slight=2 to heavy=5) for all occurrences of the type and dividing by the number of fish examined.
6/ Mesenteric fat abundance was ranked from none=1 to abundant=4.
7/ Sample size for mesenteric fat abundance is 11.
8/ Sample size for percent fat in liver is 3.
9/ Sample size for percent of eggs that are resorbing is 3.

C-045487
C—045487

Table 3. Annual summary showing means and ranges of pollutant concentrations in liver tissue and relative health measurements of female striped bass collected from the Sacramento River near Clarksburg during the April and May spawning period. Concentrations of trace elements are in ppm (ug/g) dry weight; other pollutants are in ppm wet weight. NM = not measured. ND = not detected.

	1979	1980	1984	1985
POLLUTANTS:				
MAHs 1/	0.12 0.0 - 3.59	0.17 0.0 - 1.41	0.05 0.11 - 0.43	0.09 0.0 - 1.68
AHs 1/	0.67 0.0 - 3.51	0.27 0.0 - 5.04	ND	ND
DDT & Metabolites	NM	NM	0.39 0.10 - 1.02	1.52 0.02 - 13.42
Other Pesticides 4/	NM	NM	0.08 0.02 - 0.24	0.11 0.02 - 0.64
PCB-1260	NM	NM	0.66 0.19 - 1.20	0.44 0.0 - 1.40
Copper	NM	16 1 - 55	43 12 - 146	65 8 - 384
Zinc	NM	70 9 - 204	145 104 - 204	155 91 - 211
Cadmium	NM	NM	2.18 0.97 - 5.20	3.94 0.10 - 12.40
Chromium	NM	NM	0.16 0.04 - 0.61	0.07 0.05 - 0.09
Mercury	NM	NM	1.3 0.5 - 3.7	3.0 0.3 - 19.8
Selenium	NM	NM	6.9 4.0 - 21.0	8.6 2.9 - 35.1
HEALTH MEASURES:				
All Parasites 5/	12.5 0 - 39	14.0 0 - 60	16.8 2 - 35	19.4 6 - 46
Tapeworm Larvae 5/	3.5 0 - 14	4.6 0 - 13	5.8 2 - 13	8.4 0 - 26
Tapeworm Rafts 5/	3.8 0 - 30	6.0 0 - 34	4.9 0 - 25	3.7 0 - 15
Roundworm Larvae 5/	5.2 0 - 34	3.4 0 - 38	5.6 0 - 20	6.7 0 - 22
% Eggs Resorbed	30.2 0.0 - 100.0	3.6 0.0 - 23.3	2.5 0.0 - 17.5	3.5 0.2 - 16.9
Mesenteric Fat 6/	3.1 1 - 4	2.4 1 - 4	2.6 1 - 4	2.5 1 - 4
% Fat in Liver	NM	19.8 12.1 - 36.1	4.6 1.5 - 12.4	7.1 2.0 - 23.0
Skeletal Abnormalities 5/	1.3 0 - 9	1.1 0 - 5	1.5 0 - 4	0.7 0 - 4
Age	6.1 4 - 12	5.3 3 - 9	5.5 4 - 9	7.2 1 - 17
MINIMUM SAMPLE SIZE:	37	19 7/	19	20

1/ Monocyclic aromatic hydrocarbons (volatile petrochemicals) analyzed were: benzene, toluene, ethylbenzene, para-, meta-, and ortho-xylene.
2/ Alicyclic hexanes (volatile petrochemicals) analyzed were: cyclohexane; methylcyclohexane; 1,1-, 1,2-, 1,3- and 1,4-dimethylcyclohexane; and ethylcyclohexane.
3/ Includes p,p'-DDT; o,p-, p,p'-DDD; o,p-, p,p'-DDE.
4/ Includes toxaphene, chlordane, nonachlor, oxychlordane, hexachlorabenzene and aldrin.
5/ Mean severity rank for a given parasite or abnormality type was calculated by summing the severity rank (slight=2 to heavy=5) for all occurrences of the type and dividing by the number of fish examined.
6/ Mesenteric fat abundance was ranked from none=1 to abundant=4.
7/ Sample size for percent fat in liver is 8.

C-045488

C-045488

Table 4. Annual comparisons of pollutant concentrations in liver tissue and health measures in female striped bass collected from the San Joaquin River near Antioch 1978-1985. Years with letters in common were not significantly different ($p < 0.05$) based on an a-posteriori test. Asterisks indicate that the a-posteriori test was unable to determine which year(s) differed from others. nm = variable not measured.

Variable	Significant Difference Between Years?[1]	1978	1979	1980	1981	1982	1983	1984	1985
POLLUTANTS:									
MAHs[2]	yes	B	C	B	A	B	C	C	B
AHs[3]	yes	A	A	B	B	B	B	B	B
DDT and Metabolites[4]	no	nm	nm	nm		nm	nm		
Other Pesticides[5]	no	nm	nm	nm	nm	nm	nm		
PCB-1260[6]	no	nm	nm	nm		nm	nm		
Copper	yes	nm	nm	B	AB	nm	nm	AB	A
Zinc	yes	nm	nm	B	A	nm	nm	A	A
Cadmium	no	nm	nm	nm		nm	nm		
Chromium	yes	nm	nm	nm	A	nm	nm	B	C
Mercury	yes	nm	nm	nm	*	nm	nm	*	*
Selenium	no	nm	nm	nm		nm	nm		
HEALTH MEASURES:									
All Parasites[7]	no								
Tapeworm Larvae[7]	yes	B	A	A	A	A	A	A	A
Tapeworm Rafts[7]	yes	*	*	*	*	*	*	*	*
Roundworm Larvae[7]	yes	*	*	*	*	*	*	*	*
% Eggs Resorbed	yes	*	*	*	*	*	*	*	*
Mesenteric Fat[8]	yes	A	A	B	B	A	A	A	A
% Fat in Liver	yes	nm	nm	A	nm	nm	nm	B	A
Skeletal Abnormality[7]	yes	B	A	A	A	A	A	A	A
Age	yes	A	A	B	A	A	A	A	B

1/ Determined by ANOVA, ANCOVA, or nonparametric ANOVA, as appropriate.
2/ Monocyclic aromatic hydrocarbons (volatile petrochemicals) analyzed were: benzene, toluene, ethylbenzene, para-, meta- and ortho-xylene.
3/ Alicyclic hexanes (volatile petrochemicals) analyzed were: cyclohexane; methylcyclohexane; 1,1-, 1,2-, 1,3- and 1,4- dimethylcyclohexane; and ethylcyclohexane.
4/ Includes p,p'-DDT; o,p-, p,p'-DDD; and o,p-, p,p'-DDE.
5/ Includes toxaphene, chlordane, nonachlor, oxychlordane, hexachlorabenzene (HCB), and aldrin.
6/ PCB-1260 had been analyzed prior to 1984, so it was selected for statistical analysis.
7/ Mean severity rank for a given parasite or abnormality type was calculated by summing the severity rank (slight=2 to heavy=5) for all occurrences of the type and dividing by the number of fish examined.
8/ Mesenteric fat abundance was ranked from none=1 to abundant=4

C-045490

Table 5. Correlation matrix for variables measured from female striped bass collected in the Sacramento-San Joaquin Estuary in 1978-1985. ns = not significant, $p > 0.05$.

Variable	All Parasites	Tapeworm Larvae	Tapeworm Rafts	Roundworm Larvae	% Eggs Resorbed	Egg Color	Mesentric Fat Abundance	% Fat in Liver	Skeletal Abnormality Severity	Striping Pattern	Fork Length	Age	MAH's	AH's	DDT and Metabolites	Other Pesticides	PCB-1260	Copper	Zinc	Cadmium	Chromium	Mercury	Selenium
All Parasites		0.70	0.60	0.67	-0.26	ns	ns	ns	ns	ns	0.44	0.37	ns	-0.16	-0.25	-0.26	ns	0.20	0.18	0.50	ns	0.33	0.34
Tapeworm Larvae			0.38	0.28	-0.29	ns	ns	ns	ns	ns	0.18	ns	ns	-0.29	-0.23	ns	ns	0.25	ns	0.51	ns	ns	0.33
Tapeworm Rafts				ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-0.14	-0.13	ns	ns	ns	ns	0.35	ns	ns	ns
Roundworm Larvae					-0.19	ns	ns	ns	ns	ns	0.54	0.47	ns	ns	-0.22	-0.23	ns	ns	0.17	0.29	ns	0.40	0.28
% Eggs Resorbed						ns	0.15	ns	ns	ns	-0.26	-0.14	0.18	0.20	ns	ns	ns	ns	ns	ns	ns	ns	ns
Egg Color							ns	ns	ns	ns	ns	ns	-0.18	-0.15	ns	ns	ns	ns	ns	ns	0.21	ns	ns
Mesenteric Fat Abundance								0.46	-0.15	ns	-0.27	-0.34	-0.18	0.26	0.28	0.45	ns	ns	ns	ns	-0.39	-0.62	-0.34
% Fat in Liver									ns	ns	ns	ns	0.31	4/	0.76	0.77	0.44	ns	0.58	-0.26	-0.56	-0.46	-0.42
Skeletal Abnormality Severity										0.14	ns	ns	ns	ns	ns	ns	ns	ns	0.24	ns	0.40	0.35	0.24
Striping Pattern											ns	ns	ns	-0.19	ns	ns	ns	-0.24	0.18	ns	ns	ns	ns
Fork Length												0.71^	ns	ns	ns^	ns^	ns	ns^	0.24^	0.22^	ns	0.63^	0.29^
Age													ns	ns	ns^	ns^	ns	ns^	0.19^	0.29^	ns	0.60^	0.29^
MAHs 1/														0.22	0.26	0.26	0.22	ns	ns	ns	0.38	ns	ns
AHs 1/															ns	4/	ns	ns	0.21	ns	0.22	ns	4/
DDT and Metabolites 2/																0.93^	0.39	-0.33^	-0.36^	-0.29^	ns	-0.20^	-0.36^
Other pesticides 3/																	0.57	-0.34^	0.41^	-0.26^	-0.29	-0.39^	-0.39^
PCB-1260																		ns	ns	ns	ns	ns	ns
Copper																			0.72^	0.47^	ns	ns^	0.57^
Zinc																				0.43^	0.26	0.38^	0.43^
Cadmium																					ns	0.36^	0.61^
Chromium																						0.34	ns
Mercury																							0.52^
Selenium																							

^Parametric correlation. All others are nonparametric rank correlations (Spearman).
1/ See Appendix A for list of compounds included.
2/ Includes p,p'-DDT; o,p-, p,p'-DDD; o,p-, p,p'-DDE.
3/ Includes toxaphene, chlordane,nonachlor, oxychlordane, hexachlorabenzene (HCB) and aldrin.
4/ The two variables did not occur together in any of the fish collected.

C-045490

3. Egg resorption is lower in older fish, and is positively associated with petrochemicals (MAHs and AHs).
4. Parasites are more abundant in older fish and fish with higher levels of trace elements. Parasites are less abundant in fish with high levels of petrochemicals and pesticides.
5. If fish with high levels of body fat are in good condition, then those "healthy" fish tend to be young, have high levels of fat soluble pollutants (petrochemicals, pesticides, and PCB) and low levels of trace elements. Perhaps an advantage of being "fat" is that the lipophilic pollutants are bound in the fat and not mobilized into tissues where they might do damage.

Petrochemicals are of particular concern because they were found in the livers of 44% of the female bass sampled between 1978 and 1985 and are relatively toxic to fish (Benville and Korn 1977; Benville et al. 1985). As mentioned in #3 above, they are positively associated with egg resorption.

If tapeworm induced lesions and egg resorption are indicative of poor health, then striped bass in our estuary are in poorer condition than fish from other areas. Twenty-eight percent of female bass collected in the San Joaquin River from 1978 to 1984 had evidence of extensive tapeworm lesions; such lesions are not known to occur in striped bass from other estuaries (Whipple et al., MS; Jung et al. 1984). Also, the rate of egg resorption in our fish is higher than in fish from either the Coos or Hudson rivers.

These results suggest that toxic substances may increase adult striped bass mortality. The degree of damage to the bass population cannot be assessed because: 1) data is lacking from before the bass population declined to its present low level, so we only have a picture of fish health after the decline; 2) sample sizes for fish with a wide range of pollutant and condition variables recorded are still too small for meaningful multivariate analyses; and 3) controlled laboratory studies to test specific cause-effect relationships have not been done.

Inadequate Food Supply

The food supply for adult striped bass in the estuary has not been well measured, but any food shortage long and severe enough to cause mortality should affect growth. Collins (1982) studied the growth of adult bass from 1969 to 1978. He found that, although as adults, the 1970 to 1975 year classes averaged 0.75 inches smaller than the 1965 to 1969 year classes, the actual growth rates of adult fish had not changed. Instead, the size reduction was due to recent slower growth during the first year of life.

Poaching

Here, we use the term "poaching" to include all forms of illegal striped bass fishing. These include netting, overlimits, retention of undersized fish, and the illegal sale of fish no matter how taken.

C-045492

Mortality caused by poaching is included in our estimates of total mortality rates, but we do not know to what extent these poaching losses are apportioned between "exploitation" and "natural mortality". That apportionment depends on whether or not poachers return tags.

Striped bass poaching has been a persistent problem in the estuary, but there are no readily obtainable records which allow us to evaluate whether the magnitude of this problem has changed. Recently, there has been an increase in DFG's striped bass enforcement efforts due to a general perception that the problem is serious and the availability of increased funding from the sale of striped bass fishing license stamps. Currently DFG wardens spend about 2,000 hours annually enforcing striped bass regulations in the San Francisco Bay area. Additional time is spent in the Delta and upper river areas.

Coutant's Thermal Niche Hypothesis

Recent changes in the distribution of tag returns from adult striped bass tagged in the Sacramento-San Joaquin system have provided evidence that migrations into San Francisco Bay and coastal waters decreased after the high levels of 1959-1974 (DWR Exhibit 608). This change was accompanied by a concurrent increase in tag returns from Suisun Bay and the Delta. Fishing records from the 1930s and 1940s (Calhoun 1949) and tag returns from the early 1950s (Calhoun 1952) suggest a similar cycle of extensive migration into San Francisco Bay until 1944 and limited migration into the bay from the mid-1940s through the mid-1950s.

The cause of such changes in bass migration have never been satisfactorily defined.

Dr. Charles Coutant recently (1985) proposed a thermal niche hypothesis as a possible basis for explaining the observed patterns of distribution and declining abundance of striped bass in reservoirs and estuaries nationwide. This hypothesis states in part that the migrations and distribution of adult striped bass are strongly influenced by their requirement for temperatures within the range of 65-77°F, and that restriction of suitable habitat can affect survival and fecundity and thus population size. To test the applicability of this hypothesis to the Sacramento-San Joaquin population, Mitchell (DWR Exhibit 608) compared tag return data from 1969-1985 and earlier periods with long-term water temperature data from San Francisco Bay and the Delta.

Although Radovich (1963) provided evidence of greater downstream migrations of striped bass into bay and ocean waters in warmer years, there is no evidence that adult bass are avoiding water cooler than 65°F as suggested by Coutant. Average summer and fall water temperatures near the mouth of the bay at Fort Point between 1950 and 1982 seldom exceeded 60°F. Furthermore, Fort Point temperatures have generally been increasing since 1965 yet tag returns from San Francisco Bay have declined. In the eastern-central portion of the bay at Alameda, water temperatures during the summer and fall are within or near the lower limit of Coutant's "thermal niche" for adult bass. No clear relationship is apparent between Alameda water temperature and tag returns from the bay. In the Delta, no significant relationship between tag returns and water temperature was apparent except that there was a general association between warmer fall water temperatures and increasing fall returns after 1975.

The fact that temperature did not adequately explain overall migration changes or that we find no evidence that temperature is restricting suitable habitat is not, however, evidence that temperature is not important. The increasing Delta returns suggests a link between temperature and bass distribution during the fall. Conversely, higher water temperatures during this period may have coincided with other environmental changes which offer better explanations for increased utilization of the Delta in recent years.

Predation by Sea Lions

The California sea lion population has increased by more than 10 times from low levels in the 1930s and 1940s. All breeding is on the Channel Islands of Southern California or Mexico. Counts there ranged from 785 to 2,680 during the 1927-1947 period, and increased to 13,000 in 1958, 26,000 in 1975, and 51,000 in 1983 (Bonnell et al. 1978; Bonnell et al. 1983). This increase and more frequent sightings of sea lions in the bay have led to speculation that their predation on striped bass may increase the "natural" mortality rate. Although the number of juvenile sea lions remaining in Central California waters when the adults migrate to the Channel Islands has increased, those populations likely to come into contact with the adult bass population remain quite small. Their primary food is herring and other marine fishes. While some adult striped bass are occasionally taken, it seems unlikely that sea lion predation would have a significant effect on the bass stock.

YOUNG-OF-THE-YEAR STRIPED BASS PRODUCTION

Historical Changes

Production of juvenile bass has suffered a major decline since the peak level of the mid-1960s. Reduced juvenile production is the principal cause of the adult population decline.

Since 1959, DFG has sampled young-of-the-year striped bass each summer (except 1966). An extensive survey is conducted every second week from late June to late July or early August throughout the nursery habitat. The fish are measured and, when their mean fork length reaches 38 mm, a young-of-the-year index is calculated on the basis of catch per net tow and the volume of water in the areas where the fish are caught (Turner and Chadwick 1972). The indexing procedures were reviewed and judged sound by the Striped Bass Working Group appointed by the SWRCB in 1982 (Striped Bass Working Group 1982).

Sampling occurs primarily in the Delta and Suisun Bay, so the young-of-the-year index has a well-recognized bias in high flow years when a large proportion of the young are washed downstream into San Pablo Bay which is inadequately sampled by this survey. Hence, in very wet years, the index is an underestimate of the actual population (Stevens 1977a, 1977b).

Young-of-the-year striped bass abundance declined from high index levels sometimes exceeding 100 in the mid-1960s to the all time low of only 6.3 in 1985 (Figure 6). The decline was greatest in the Delta, but also occurred in Suisun Bay. In 1986, the

C-045497

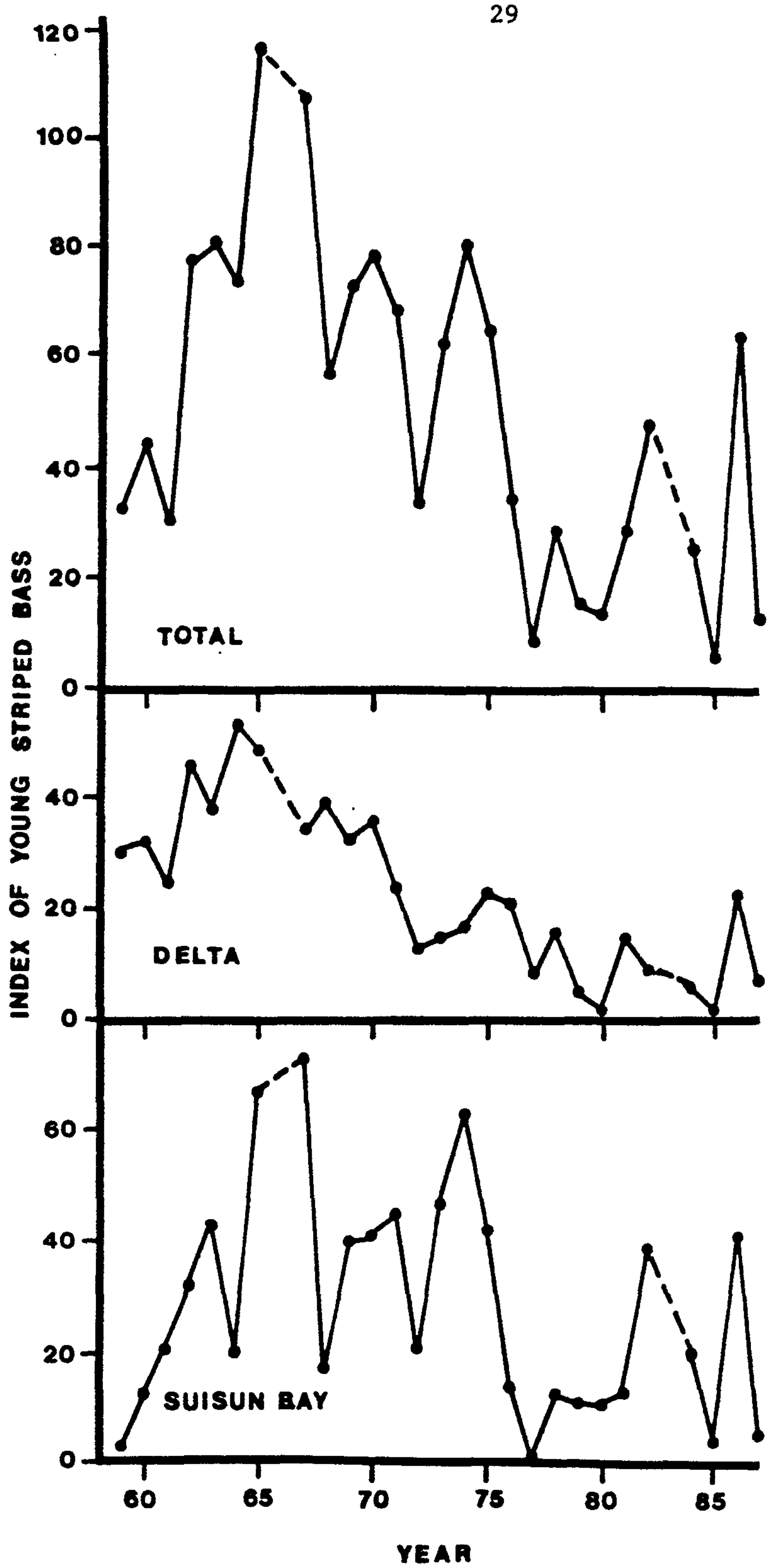


Figure 6. Annual index of young striped bass abundance by area in the Sacramento-San Joaquin Estuary. Young bass suffered an unsteady but persistent decline from the mid-1960s to 1985. The decline was most pronounced in the Delta, but also is clearly visible in Suisun Bay despite greater year-to-year fluctuations there. In 1986 young striped bass abundance rebounded to its highest level since 1975. No sampling was conducted in 1966 and the 1983 index was omitted because extremely high flows transported most young bass downstream from the area effectively sampled by the tow net survey.

abundance index rebounded to its highest level since 1975, but this was not the beginning of a recovery. The current year, 1987, produced a disappointingly low index of 12.6.

A close, long-term association between production of young bass and Delta outflow and diversion rates has been a fundamental reason for concern regarding water project impacts. During the years 1959-1970, the abundance of young striped bass was highly correlated with both freshwater outflow from the Delta and the percent of the river inflow diverted from the Delta channels during spring and early summer by the CVP, SWP, and Delta farmers (Figure 7). Flows during June and July provided the highest correlations but good correlations were also found between the number of young bass and May flows. In years when outflow was high and the 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 (Turner and Chadwick 1972).

In the early and mid-1970s, young striped bass abundance was lower than expected based on the 1959-1970 relationships (Figure 8). In particular, they began to decline in the Delta portion of the estuary (Figure 9). This decline coincided with higher diversion rates from the SWP and CVP export pumps in the south Delta in May and June of those years and the combination of May-June outflow and diversion rates accounted for the decline (Figure 10). Young bass abundance in Suisun Bay was best explained by June-July outflow throughout the 1959-76 period (Figure 11).

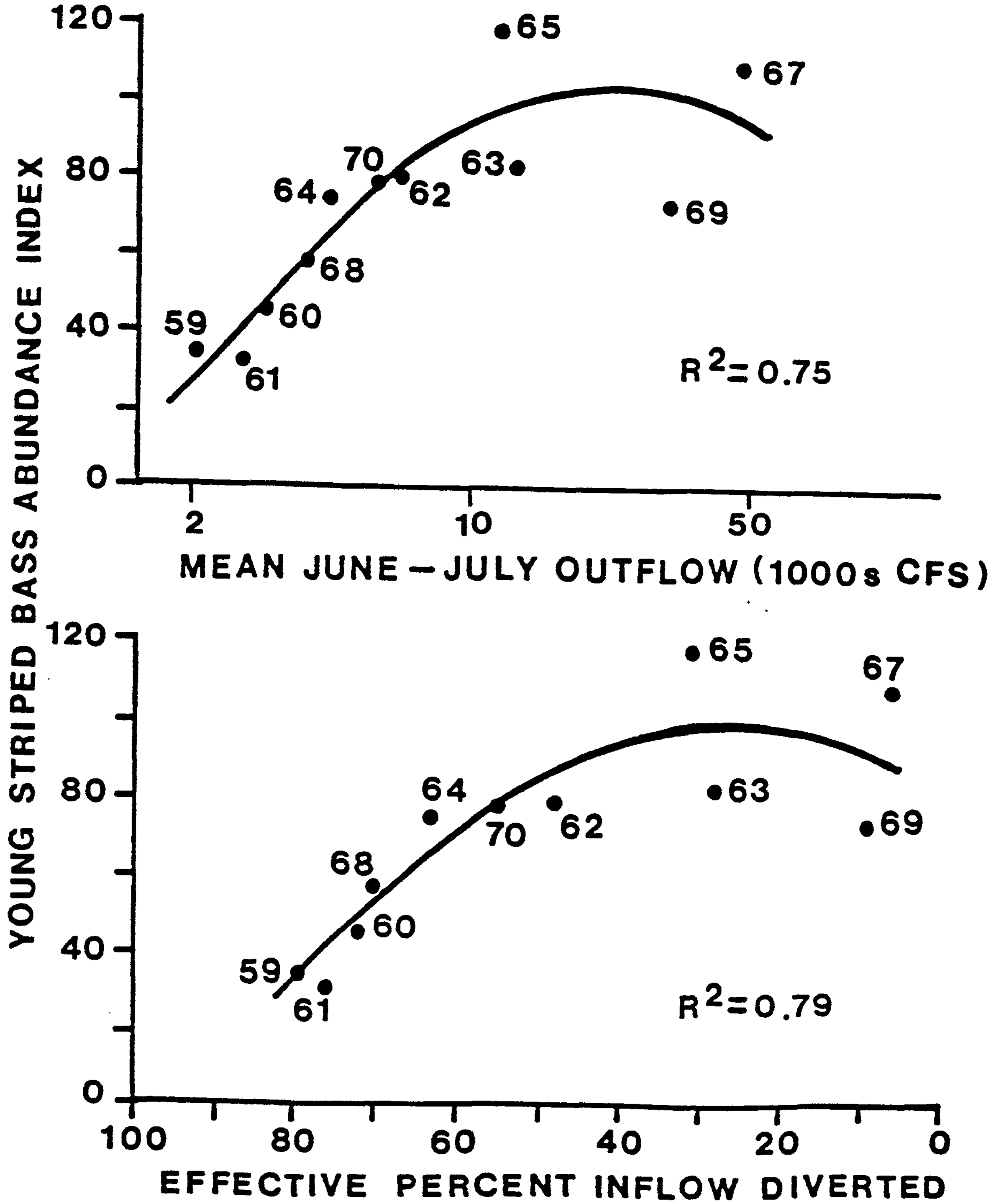


Figure 7. Relationship between total abundance of young striped bass in the Sacramento-San Joaquin Estuary and Delta outflow and diversions from 1959 to 1970. In years when outflow was high and percent of river inflow diverted was low, the striped bass index was high; conversely, when outflows were low 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.

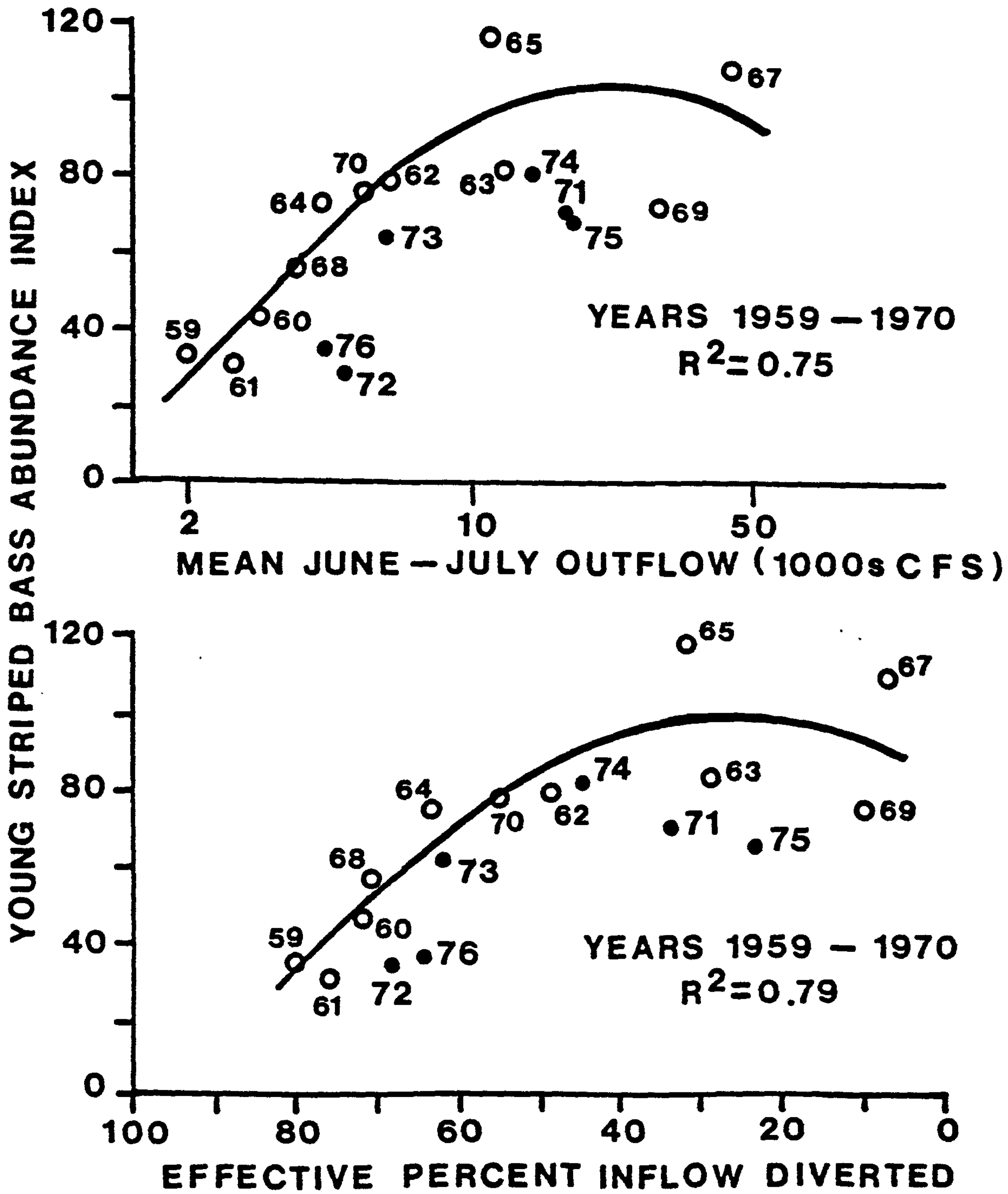


Figure 8. Relationship between total abundance of young striped bass in the Sacramento-San Joaquin Estuary and Delta outflow and diversions, 1959-1976. Curves are fits to 1959-1970 data. In the early to mid-1970's, young bass abundance was consistently lower than expected based on the 1959-1970 relationships 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.

C-045501

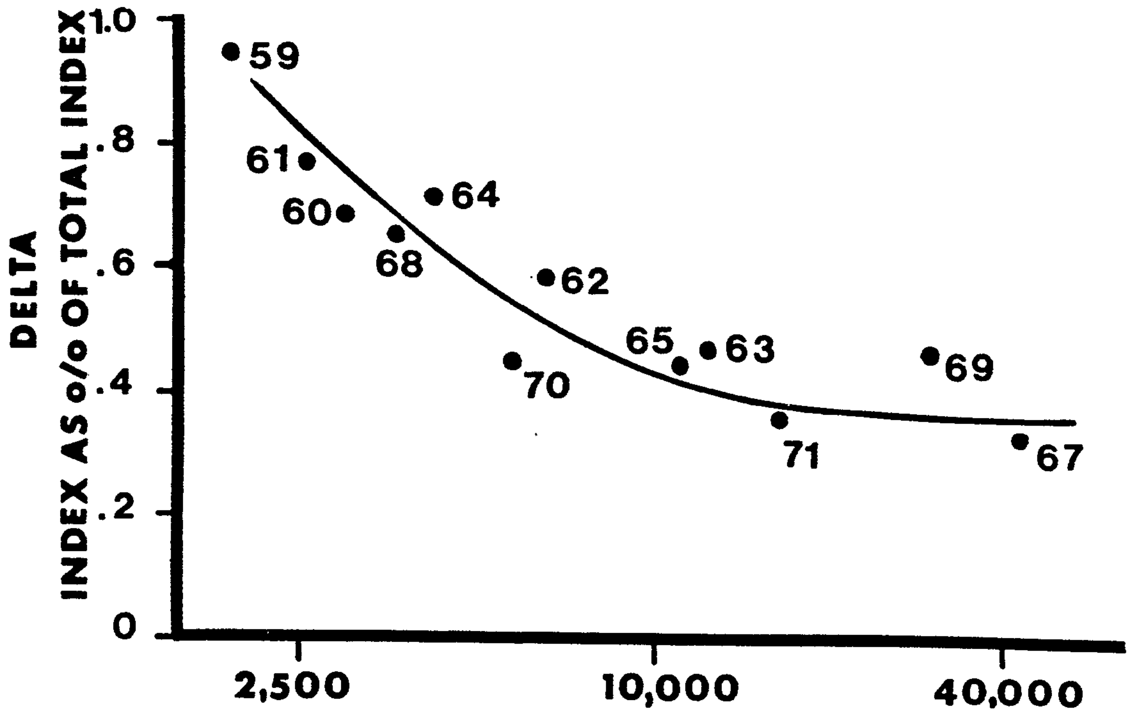


Figure 9a. Relationship between outflow past Chipps Island and the Delta index of young striped bass as a percent of the total index from 1959 to 1971. Line drawn by eye.

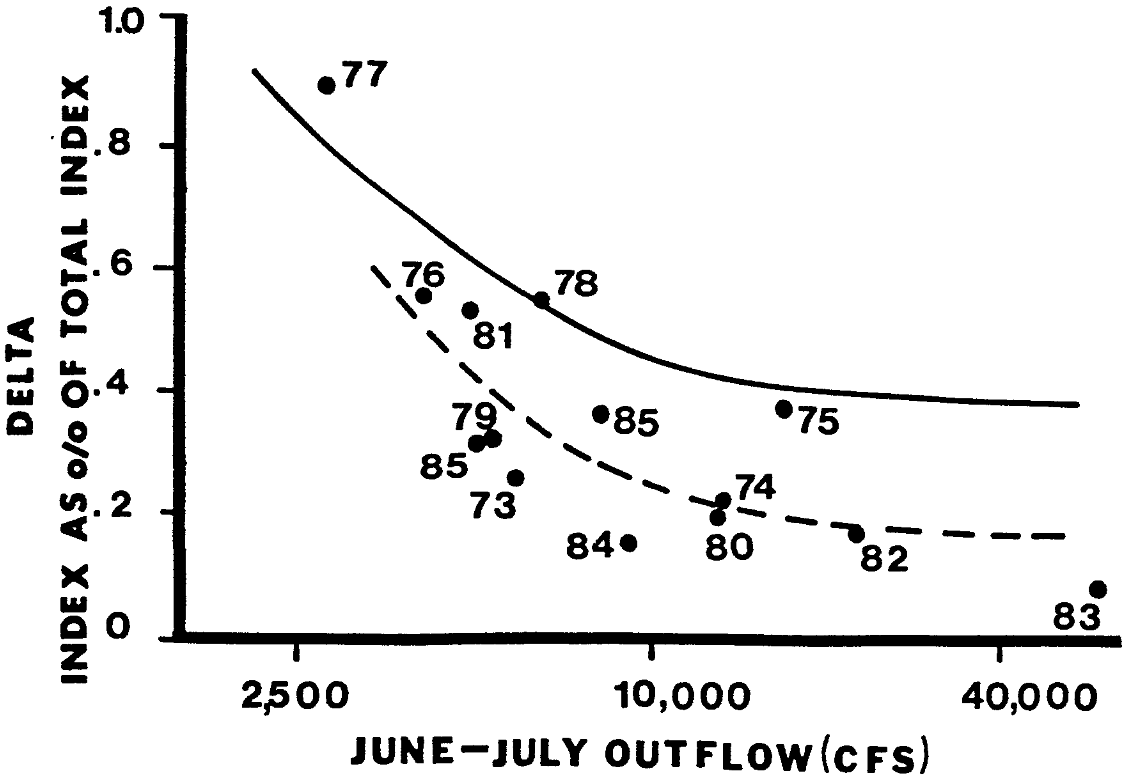


Figure 9b. Relationship between outflow past Chipps Island and the Delta index of young striped bass as a percent of the total index from 1973 to 1986. Solid line copied from (a). Dashed line drawn by eye from 1973 to 1986 data points. A smaller proportion of the population now uses the Delta as its nursery.

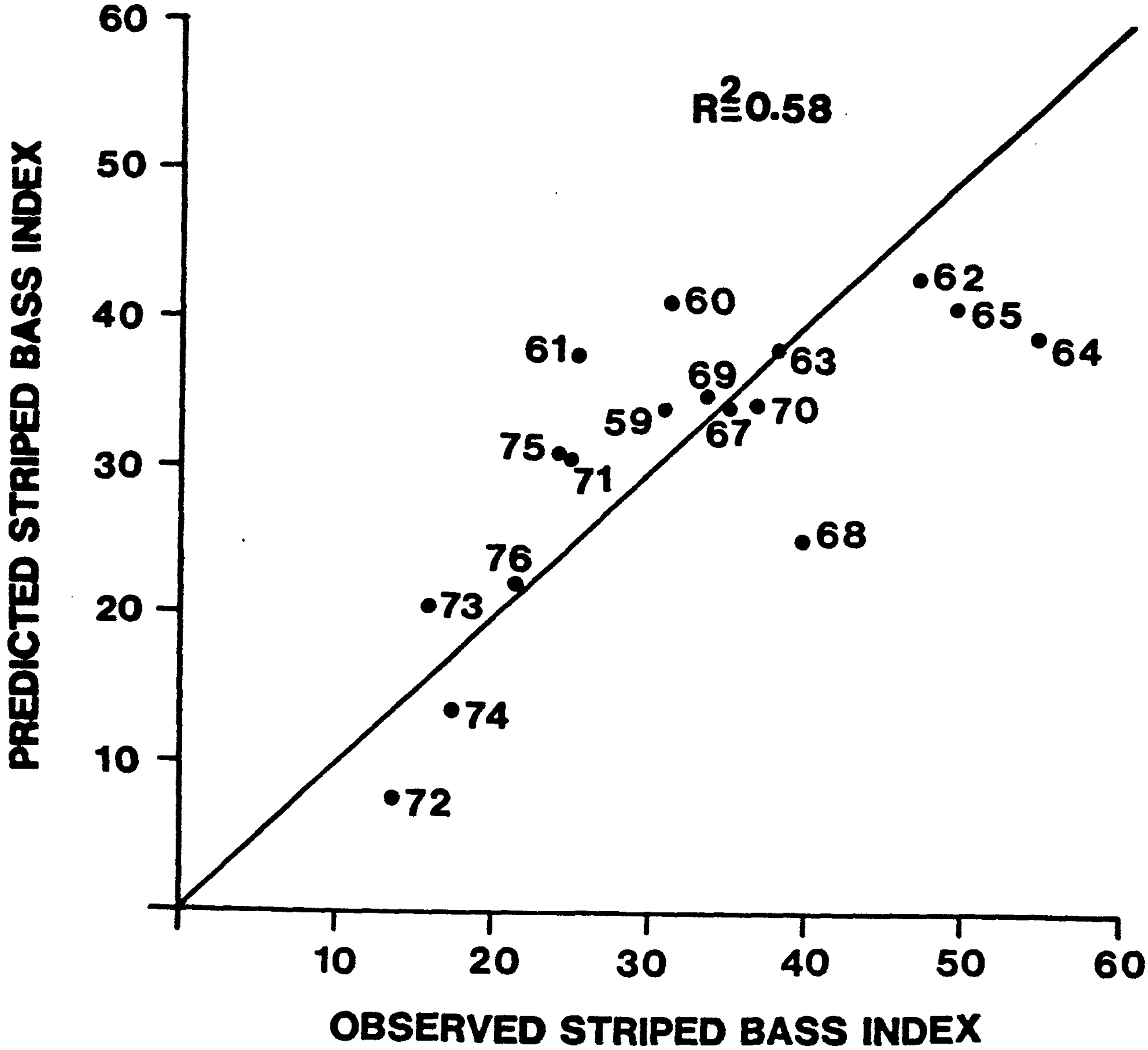


Figure 10. Relationship between actual and predicted young striped bass abundance in the Sacramento-San Joaquin Delta from 1959 to 1976. Predicted abundance = -507 - 0.00554(mean daily May-June water diversion rate by water projects and local agriculture) + 282($\log_{10}$ mean daily May-June Delta outflow) - 34.0($\log_{10}$ mean daily May-June Delta outflow)^2. All flows are in cubic feet per second. Increased water diversions in May and June explain the reduced abundance of young bass in the early and mid-1970s (See Figure 8).

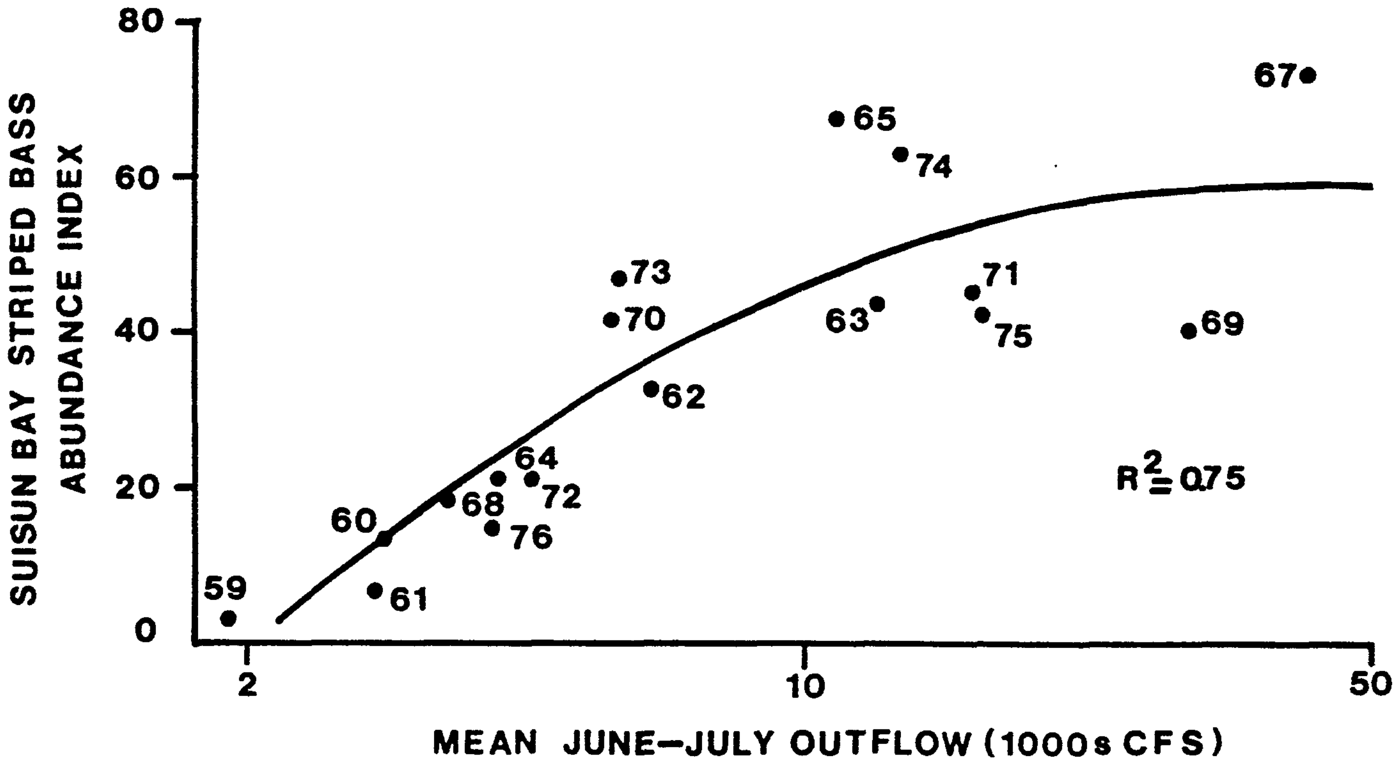


Figure 11. Relationship between young striped bass abundance in Suisun Bay and Sacramento-San Joaquin Delta outflow from 1959-1976. Predicted index = $-670 + 315(\log_{10}$ mean daily June-July Delta outflow$) - 33.9(\log_{10}$ mean daily June-July Delta outflow$)^2$. All flows are in cubic feet per second. No change in this relationship is apparent after 1970.

These correlations between the 1959-1976 38 mm indices and May-July outflows and the amounts of water diverted were used to develop standards for Decision 1485.

Decision 1485 placed constraints on the amount of water exported by the CVP and SWP during the spawning and early postspawning period. Outflow and export criteria established in Decision 1485 were designed to maintain the young-of-the-year index at levels which the SWRCB staff estimated would have existed without the project, assuming that outflow and diversions would affect young bass abundance as correlations (Figures 10 and 11) suggest.

However, from 1977 to 1985, the abundance of young striped bass was considerably lower than predicted by the regressions based on results from 1959 to 1976 (Figure 12). Both juvenile striped bass abundance and our ability to predict it was greatly reduced. This decline in young bass abundance occurred despite the CVP and SWP meeting the outflow and export standards set by Decision 1485. Since 1976, YOY abundance continues to be correlated with flow but at a lower level of abundance (Figure 13).

We believe that increasing outflows are inherently beneficial to striped bass because they enlarge the nursery area and increase the production of their food supply (Stevens et al. 1985), particularly of the oppossum shrimp (DFG Exhibit 28) which is the principal food for juvenile bass.

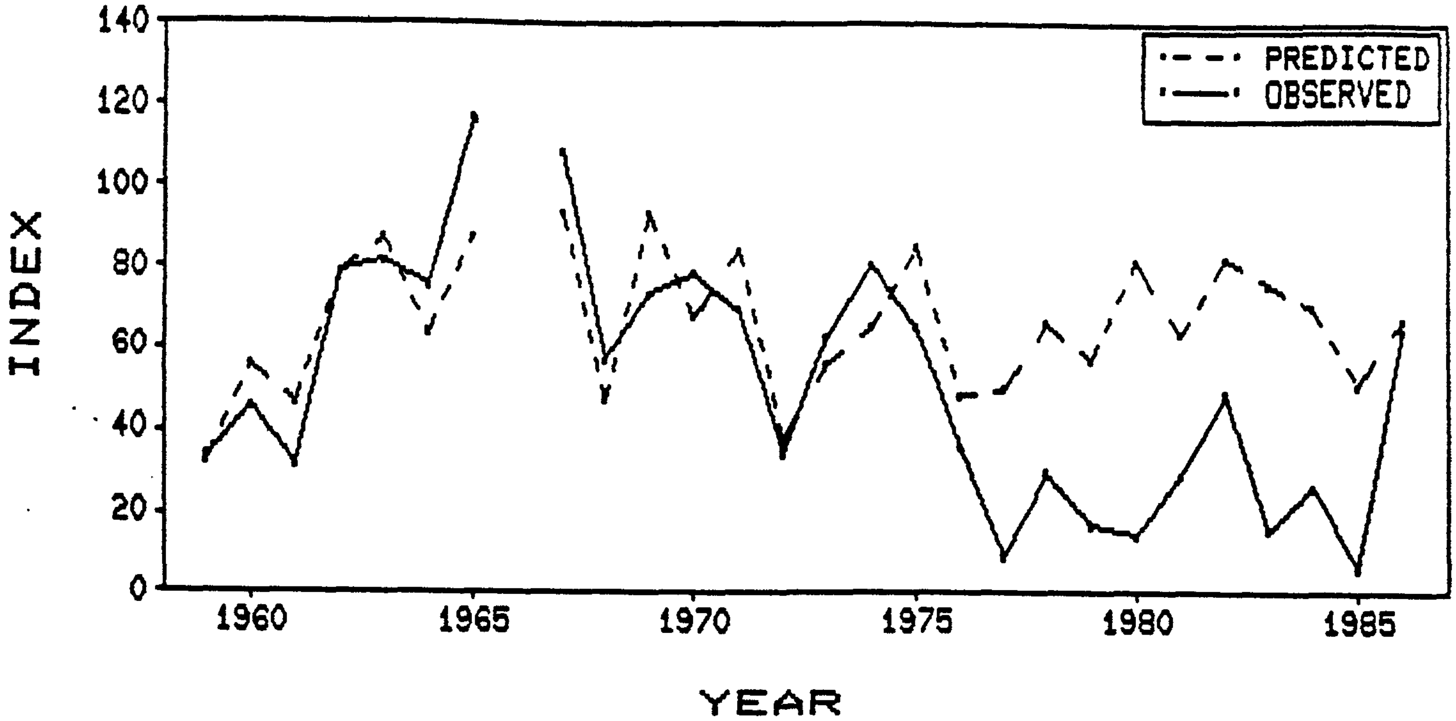


Figure 12. Trend in young striped bass abundance from 1959 to 1986. The predicted index is based on relationships between abundance and flow and diversion rates from 1959 to 1976 and is the sum of the predicted Delta index (Figure 10) and the predicted Suisun Bay index (Figure 11). From 1977 to 1985 the abundance of young bass was considerably below that predicted from the 1959 to 1976 results.

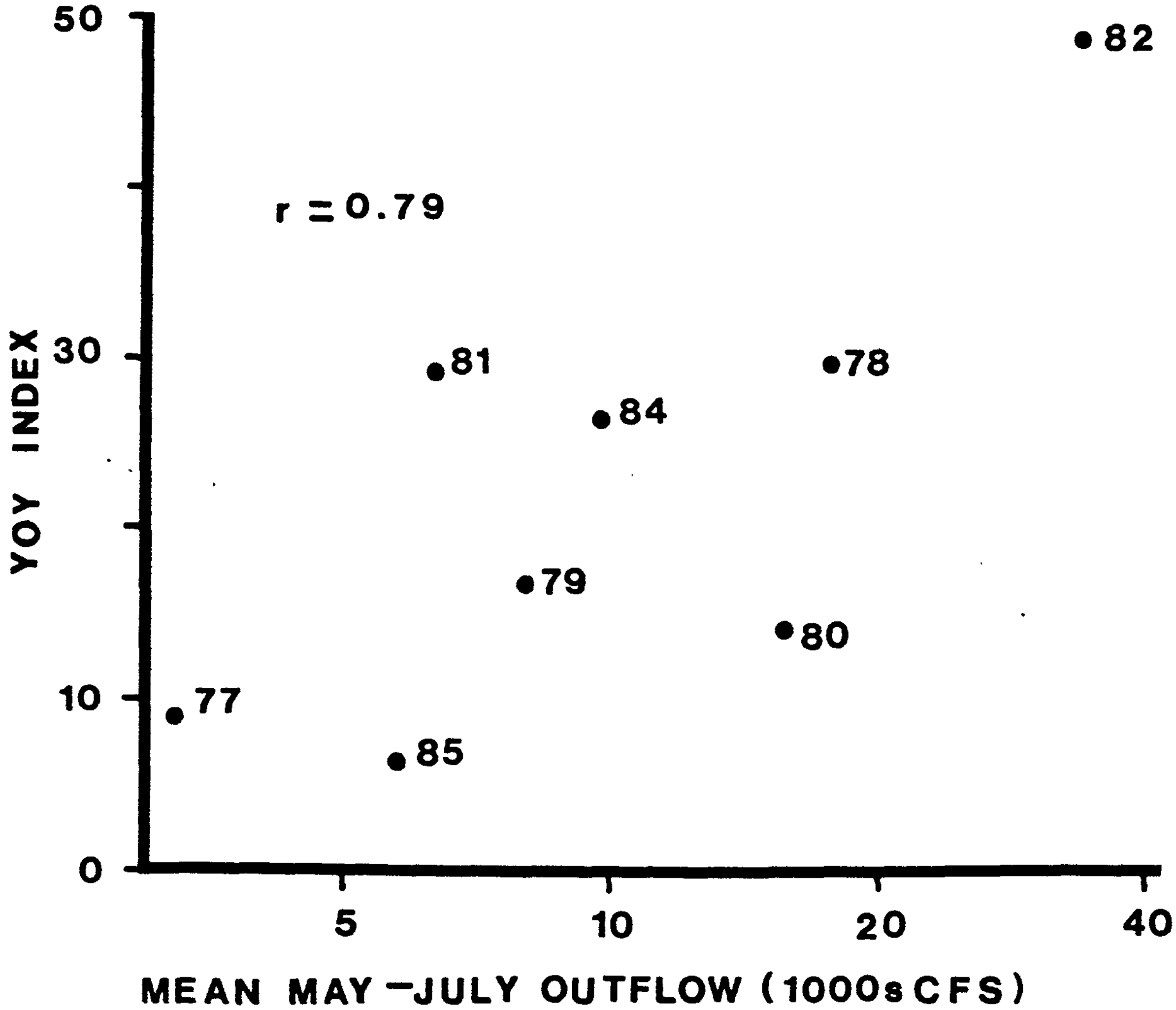


Figure 13. Correlation between abundance of young striped bass and $\log_{10}$ mean May, June, July outflow, 1977-1985. Data from 1983 were excluded because extremely high flows swept fish out of the sampling area. This correlation is similar to that for 1959 to 1976 except recent abundances are lower.

Reduced Egg Production

The number of eggs being produced declined with the reduction of the adult striped bass population. We calculated two separate indices of annual egg production. These are based on age-specific fecundity of adult bass and our best measures of adult bass abundance: 1) the Petersen estimates and 2) the tagging CPE indices. The Petersen estimates are available from 1969 to 1985 and the CPE indices from 1969 to 1986 (except 1977, 1978, and 1981 when the fyke traps were not fished in the Sacramento River).

The abundance measures for each age class were multiplied by the estimated fecundity for the appropriate age (Table 6). For both egg production indices, the annual index of total eggs spawned is the sum of these products.

Both indices indicate that egg production declined substantially from the late 1960s and early 1970s to the present (Figure 14). Based on the Petersen estimates, average egg production from 1981 to 1985 was only 29% of the 1969-1973 average. The CPE egg production indices declined even more precipitously to a 1982-1986 average value that was only 17% of the 1969-1973 index.

These estimates are based on the reduced numbers and size of female bass. NMFS data (Whipple et al., MS; Jung et al. 1984), as well as data from U.C. Davis (Crosby et al. 1986) and the USFWS (Columbia National Fisheries Research Laboratory 1984) suggests that female striped bass from this estuary had a much higher incidence of egg resorption than those from other areas. We do

Table 6. Fecundity of female striped bass in the Sacramento-San Joaquin Estuary.

Age	Estimated eggs/ mature female (1,000s)	Maturity correction[a/]	Estimated mean fecundity of females on spawning grounds (1,000s)[c/]	Migration correction[b/]	Estimated mean fecundity of all females (1,000s)
4	243	0.35	85	0.16	14
5	447	0.87	389	0.90	350
6	652	1.00	652	1.00	652
7	856	1.00	856	1.00	856
8	1,061	1.00	1,061	1.00	1,061
9	1,265	1.00	1,265	1.00	1,265
10	1,470	1.00	1,470	1.00	1,470
11	1,674	1.00	1,674	1.00	1,674
≥8	1,427	1.00	1,427	1.00	1,427
≥12	1,879	1.00	1,879	1.00	1,879

a/ Fraction of female striped bass that are mature on the spawning grounds (Scofield 1931).

b/ Fraction of all female striped bass that migrate to the spawning grounds (from the female:male ratio in spring tagging from 1969 to 1978).

c/ Used to calculate tagging CPE egg production index since these fish are captured on the spawning grounds.

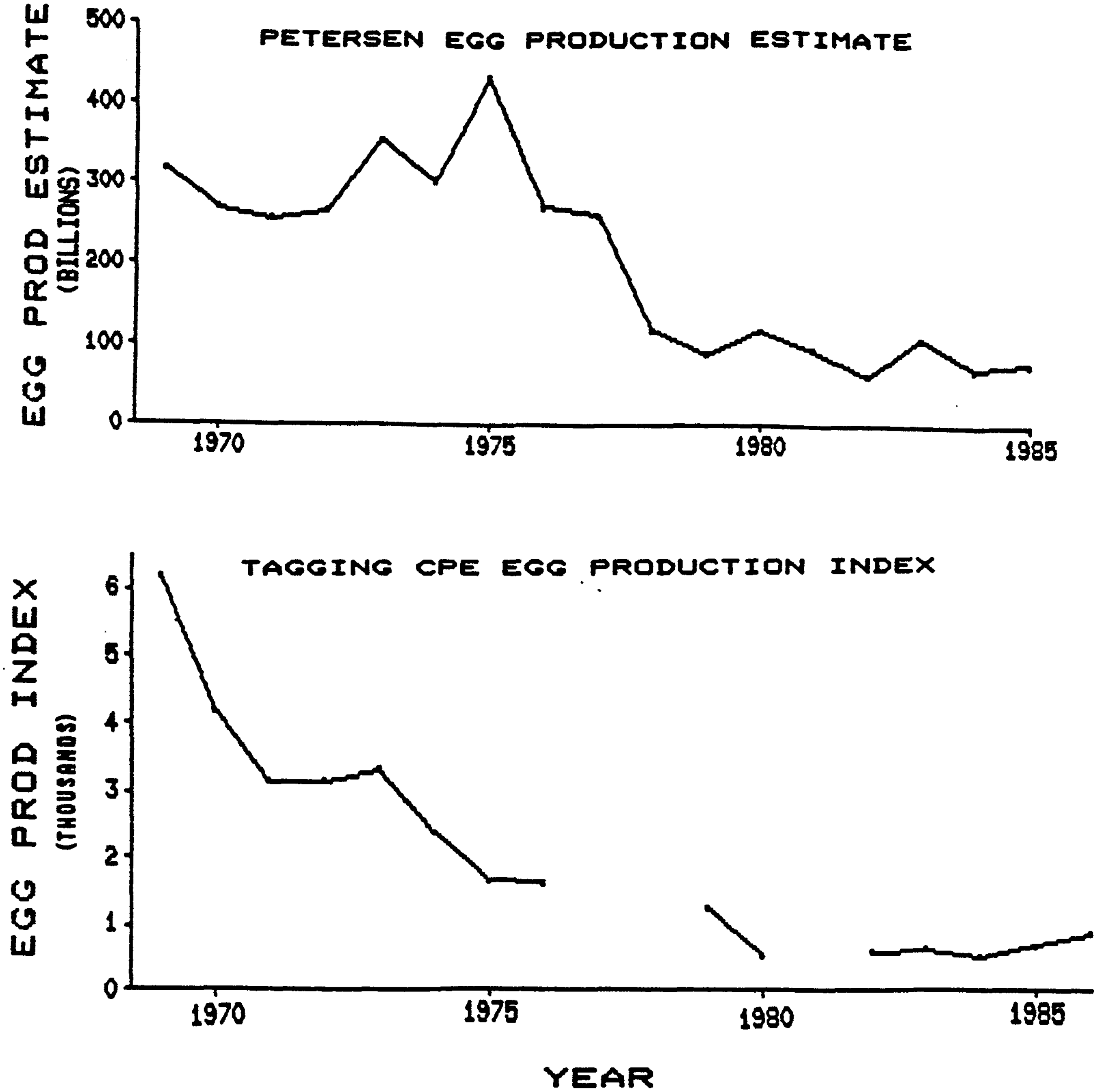


Figure 14. Annual indices of striped bass egg production based on age-specific fecundity (Table 6) and Petersen and CPE measures of adult bass abundance. Both indices indicate that egg production declined substantially from the late 1960s and early 1970s to the mid-1980s.

not know whether historical rates of resorption were different than those measured by the recent studies. Hence, we are unable to apply a correction for it in our estimates of egg production. If resorption has increased, the decline in egg production is more severe than we have shown.

Statistical analyses of data from 1978 to 1983 were used by NMFS to reach the conclusion that effective fecundity (the number of viable eggs) was directly affected by contaminant levels in prespawning females (Whipple et al., MS; Jung et al. 1984).

Annual estimates of fecundity reduction have been quite variable (0 to 50%), and we do not know if this variability is real or due to small sample sizes. Subsequent analyses by DFG of all data from 1978 to 1985 do not show strong relationships between reproductive condition, parasite burdens, and pollutant concentrations (Appendix 2). It is clear, however, that egg production has been reduced. Although the principal cause is the reduced adult stock, toxic substances may contribute to this reduction to an unknown extent.

Striped Bass Spawning

Striped bass spawn primarily in two general areas: the Sacramento River between Sacramento and Colusa and the western Delta in the San Joaquin River between Antioch and Venice Island. One-half to two-thirds of the eggs are produced in the Sacramento River and no change in this proportion is evident (Table 7). Turner (1976) described the location and season of spawning from

Table 7. Percent of egg catch from the Sacramento and San Joaquin rivers, by year.

Year	% Sacramento River	% San Joaquin River
1972	59.5	40.5
1975	66.4	33.6
1977	63.3	36.7
1984	52.7	47.3
1985	46.3	53.6
1986	62.7	37.3
Average	58.5	41.5

egg collections made from 1963 through 1969 and in 1972. He found that most spawning in the San Joaquin Delta occured between April 23 and May 25 except in 1965, when spawning was earlier. Spawning in the Sacramento River above the Delta occurred about 2 weeks later, from May 10 to June 12. Mitchell (DWR Exhibit 607) analyzed egg collections made in 6 years since 1972 and found that the time of spawning had not changed -- in spite of earlier warming in the Sacramento.

Striped bass always spawn in essentially fresh water; therefore, the salinity regime in the western Delta is important. Salinities on the San Joaquin side are lowest just downstream from the mouth of the Mokelumne River where fresh water from the Mokelumne and Sacramento systems dilutes the saltier (largely due to agriculture return flows) water flowing into the Delta from the upper San Joaquin River. Farther west, the river gradually becomes more saline due to the intrusion of ocean water.

Bass apparently react to this salinity regime while on their spawning migration. A study in 1966 indicated that bass did not migrate through the increasing salinities of the eastern Delta beyond the point where specific conductance (EC) exceeded 550 microsiemens (Radtke and Turner 1967). In relatively dry years, this salinity blockage occurs a few miles upstream from Venice Island. Typically spawning occurs between Antioch Point (river mile 53) and Venice Island (river mile 73) (Table 8). This reach generally is just upstream from the ocean salinity gradient.

C-045513

Table 8. Percentages of striped bass eggs between 0 and 8 hours old in 10 km (6.2 mile) segments of the Delta and Suisun Bay. River km (mile) 0 is at the Golden Gate. * = Not Sampled.

Area	River kilometer (Miles)	1968	1969	1970	1971	1972	1973	1975	1976	1977	1984	1985	1986
Suisun Bay[1/]	50-59 (31.1-36.7)	0	0.7	0	0	0	0	0	*	*	0.1	*	0.1
	60-69 (37.3-42.9)	0	2.5	0	0	0	0	0	*	*	0	0	0
	70-79 (43.5-49.1)	0	4.5	0.2	2.3	0	0	0.2	0	0	0.5	0	0.3
San Joaquin River[2/]													
Antioch	80-89 (49.7-55.3)	6.5	27.8	9.0	39.6	55.5	10.0	52.8	1.5	0.1	6.9	0.9	52.2
	90-99 (55.9-61.5)	43.9	13.3	16.6	46.9	37.6	66.2	43.9	32.4	52.8	22.9	20.3	22.8
	100-109 (62.1-67.7)	39.5	3.3	5.0	10.8	2.4	23.9	1.8	49.3	1.6	53.9	29.3	11.8
	110-119 (68.4-73.9)	8.3	0	59.8	0	2.7	0	0.2	16.2	45.5	15.0	44.2	10.7
Venice Island	120-129 (74.6-80.2)	0.5	1.9	3.2	0	0.2	0	0.1	0.6	0.1	0.5	3.0	1.1
Sacramento River[3/]													
Collinsville	80-89 (49.7-55.3)	0	43.5	0.1	0	0	0	0.3	0	0	0.1	0.1	0.2
	90-99 (55.9-61.5)	0.3	2.6	5.3	0.4	1.3	0	0.4	*	0	0.1	2.1	0.9
Rio Vista	100-109 (62.1-67.7)	0.9	0	0.9	0	0.3	0	0.2	*	0	0	0.1	0

1/ Based on sampling of DFG striped bass egg and larvae survey stations from Martinez to Collinsville.

2/ Based on sampling of DFG striped bass egg and larvae survey stations from Broad Slough to Mandeville Cutoff.

3/ Based on sampling of DFG striped bass egg and larvae survey stations from Collinsville to Rio Vista.

C-045514

During most striped bass spawning surveys in the Delta the majority of spawning occurred where EC was less than 300 microsiemens (Table 9). In several of the drier years such as 1968, 1972, 1976, and 1977, when salinity intruded into the Delta, spawning did shift several miles upstream, but this was not far enough to avoid higher than normal salinities (Tables 8 and 9). In fact, about one-quarter of the Delta spawning occurred in water of between 1,500 and 1,799 microsiemens in 1972 and between 3,000 and 5,999 microsiemens in 1977. The extent to which egg and larva survival was reduced by high salinity in these years is unknown. Laboratory studies have indicated ECs up to 1,500 microsiemens (approximately 1,000 ppm TDS) do not affect egg survival adversely (Turner and Farley 1971). However, the least abundant year classes are generally produced in the drier, high salinity years.

The long term effect of such salinities is unknown. Striped bass have a pronounced tendency to return to the same spawning area each year (Chadwick 1967), and thus might respond little to occasional high salinities. Yet, considering that striped bass everywhere spawn in essentially fresh water, it seems likely that regular occurrences of higher salinities would gradually reduce use of the Delta as a spawning area due to this inherent water quality preference.

<u>Increased Mortality of Larvae</u>

Obviously, the environmental conditions that control the abundance of 38 mm bass have their impacts before the index is

Table 9. Distribution of striped bass eggs between 0 and 8 hours old compared with specific conductance (EC), a function of salinity. Numbers are percentages collected in each EC range.

EC	Year											
	1968	1969	1970	1971	1972	1973	1975	1976	1977	1984	1985	1986
<299	8.7	96.6	89.6	100.0	4.8	100.0	100.0	51.9	52.7	82.5	71.3	99.8
300-599	46.7	3.4	7.4		5.6			19.2	14.1	16.1	26.7	0.1
600-899	40.8		0.4		44.8			11.6	0.1	1.2	1.5	
900-1199	0.8		2.5		8.7			11.2	6.8	0.2	0.4	
1200-1499	3.8		0.1		7.6			5.4				
1500-1799	0.1				25.7			0.2	0.1			
1800-2099					0.2			0.5				
2100-2499					2.5				1.3			
2500-2999					0.1				1.4			
3000-5999									23.6			
6000-7999												
8000-9999												
10000-14999										0.1		0.1
15000-35000												

"set" -- between the time of spawning and mid-summer. Major investigations have been conducted on the distribution and abundance of striped bass eggs and larvae and the factors which influence them. Analysis of these egg and larva surveys conducted annually from 1967 to 1977, except for 1974, and in 1984, 1985, and 1986 have produced some valuable insights.

The surveys consist of sampling with fine mesh towed nets during the striped bass spawning season in the spawning and nursery areas of the estuary and, in several years, the upper Sacramento River. Depending on the year, sampling occurred every second or fourth day at 32 to 43 stations. These stations were located at 2 mile intervals from Benicia in Suisun Bay to Rio Vista on the Sacramento River and to Medford Island on the San Joaquin River. In some years additional sites were sampled in Carquinez Strait, upper Suisun, Grizzly and Honker bays, and Montezuma Slough.

In the upper Sacramento River, eggs and larvae were sampled every second day, usually at 10 mile intervals from Isleton to Grimes, but in 1985 and 1986 stations were sampled every 5 miles.

A cone shaped net with 930 micron mesh was used for sampling from 1967-1973. It was replaced in 1975 with a more efficient cylinder-cone shaped net with smaller 505 micron mesh. Paired net comparison tests were made to determine the relative efficiencies of the two nets and in this report correction factors have been applied to the 1967-1973 data.

Simultaneous sampling of the food chain, chlorophyll a and zooplankton, became part of the egg and larva survey in the estuary in 1984.

The eggs are broadcast in open water, hatch in about 2 days, and the larvae drift with the river and tidal currents. When spring river flows are relatively high, such as in 1971, the larvae are soon found in Suisun Bay or even downstream from there (Figure 15). Conversely, during drier conditions, such as in 1968, the situation is dramatically different. The larvae become concentrated in the Delta, with only a few being washed downstream to eastern Suisun Bay (Figure 16). Under the extreme salinity and flow conditions of the 1977 drought, the few larvae that survived were all in the Delta at the eastern edge of their normal range (Figure 17).

Annual larva indices for the estuary demonstrate a wide range of bass abundance over the years (Table 10). The high indices were nearly all in the 1970-75 period when adult stocks and egg production were high (Figures 3 and 14). The index of 6-8 mm abundance was extremely low in 1977 and 1984; in spite of continuing low egg production, it recovered somewhat in 1985 and 1986. Obviously, the combination of egg production and larva survival rates is critical.

The very large reduction between the indices of 6-8 mm larvae and 12-14 mm larvae in 1985 is evidence of low survival that year. The smaller reduction in numbers between those size groups in 1986 is evidence of high survival.

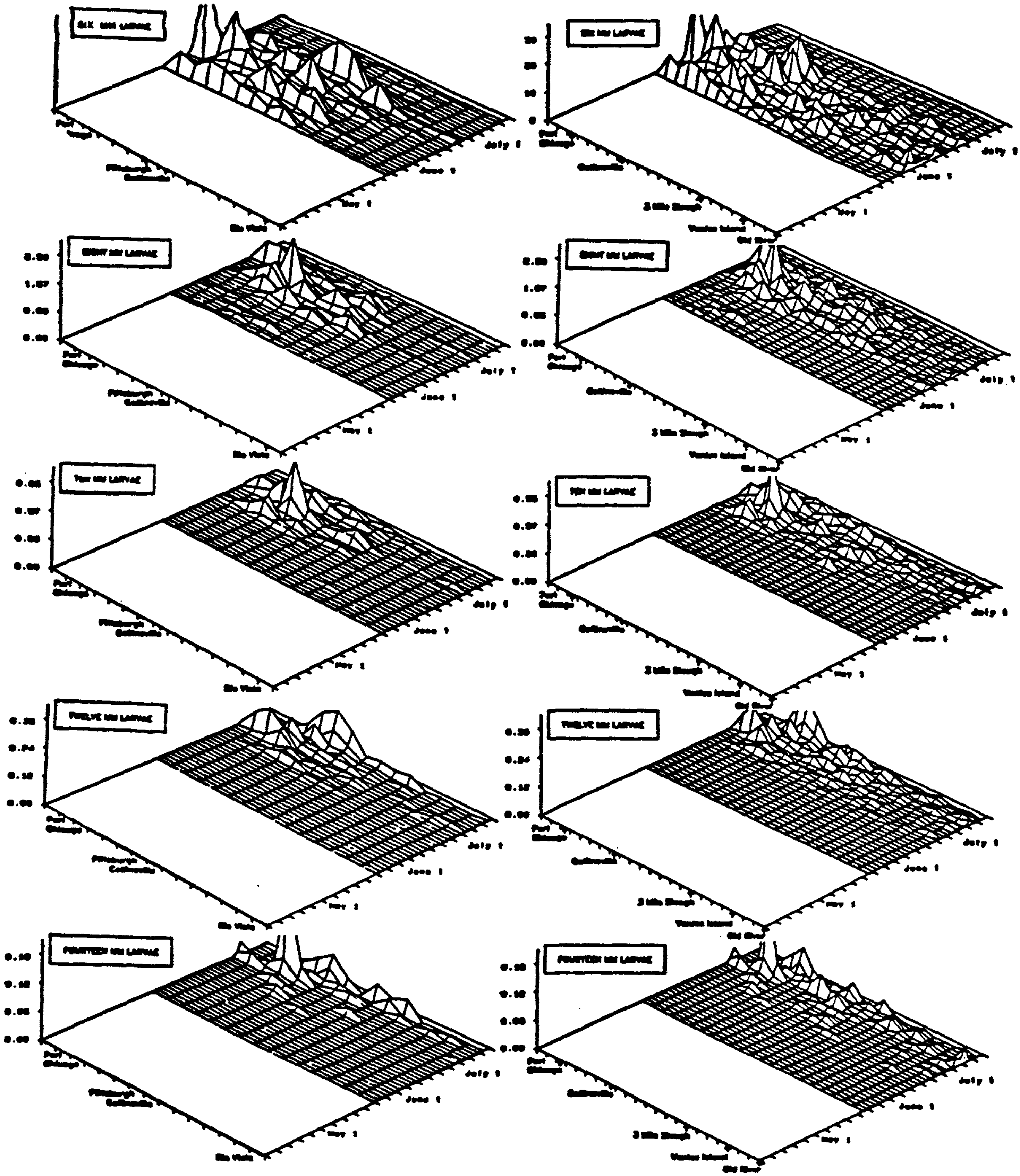


Figure 15. Concentration in 1971 of larval striped bass per cubic meter by: (1) millimeter size group, (2) location in the estuary, and (3) sampling time. River flows were relatively high (mean outflow was about 26,400 cfs in May) and larvae were soon found below Collinsville in Suisun Bay.

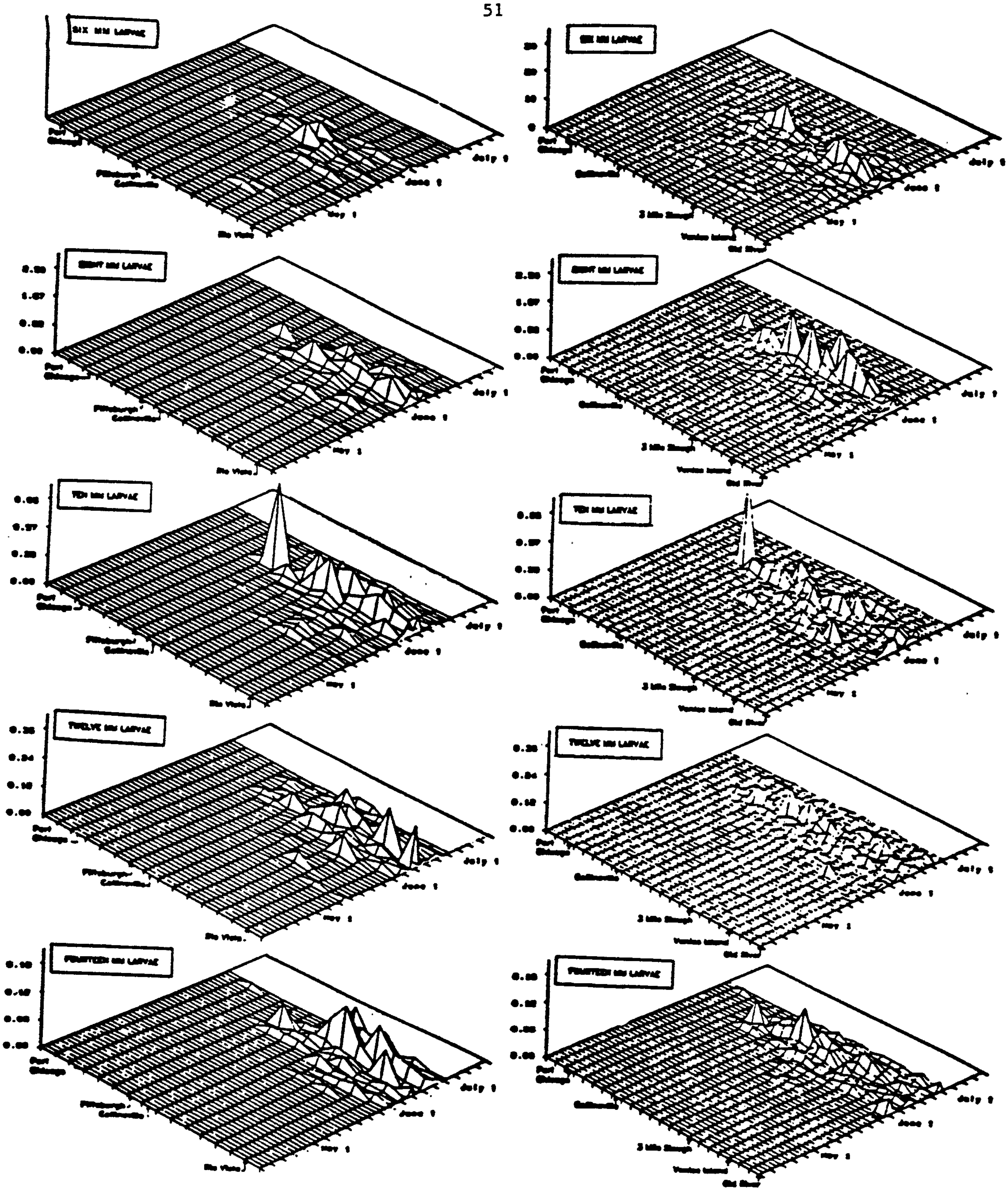


Figure 16. Concentration in 1968 of larval striped bass per cubic meter by: (1) millimeter size group, (2) location in the estuary, and (3) sampling time. The spring was relatively dry, outflows were low (mean outflow was about 6,700 cfs in May), and larvae were concentrated in the Delta.

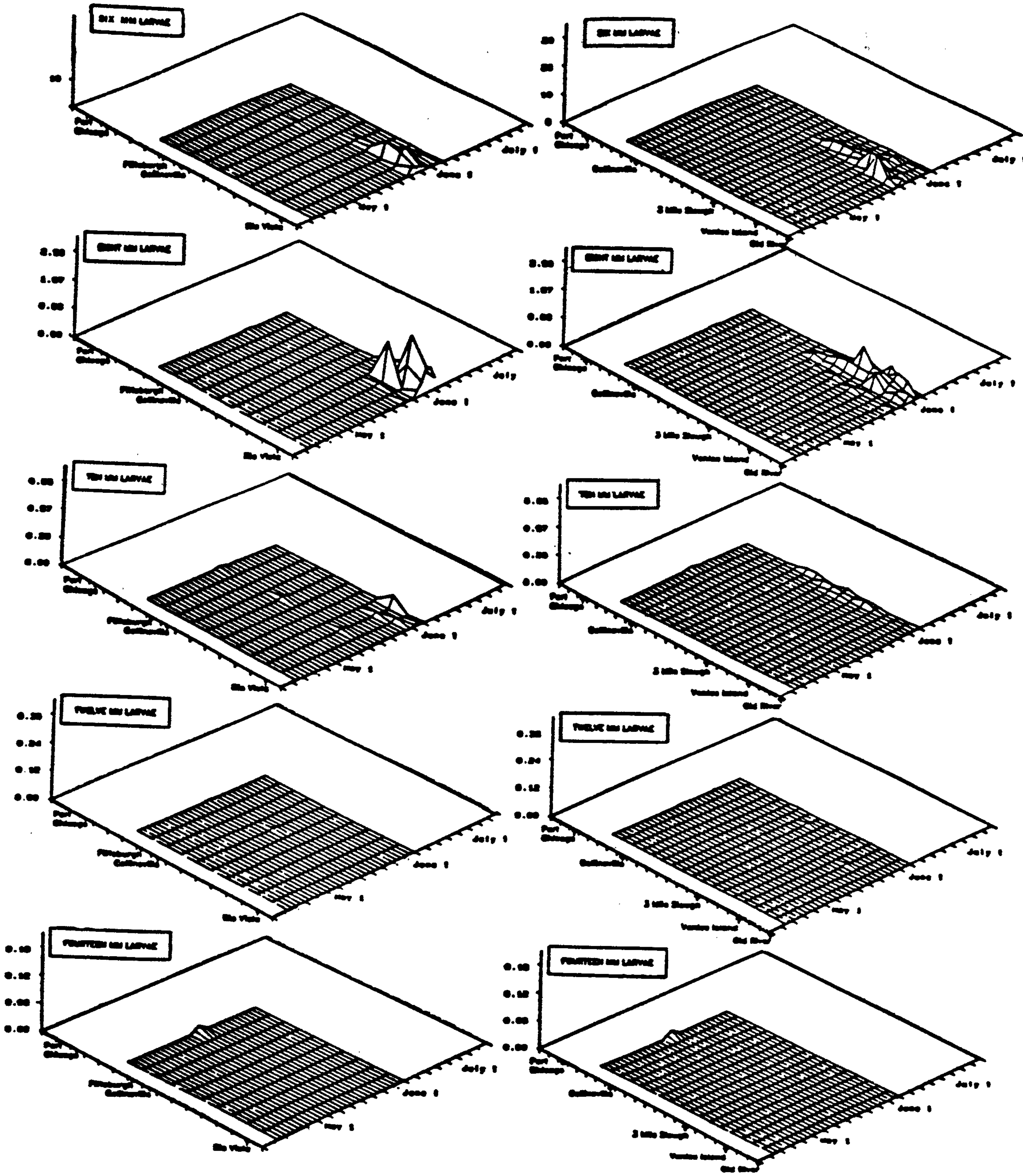


Figure 17. Concentration in 1977 of larval striped bass per cubic meter by: (1) millimeter size group, (2) location in the estuary, and (3) sampling time. This was a year of extreme drought (mean outflow was about 4,000 cfs in May) and the few larvae that survived were at the eastern edge of their normal range.

Table 10. Abundance indices for 6-8, 9-11, 12-14, and 6-14 mm striped bass larvae, 1968-1986. Indices calculated by summing weighted catches for Suisun, Grizzly, and Honker bays, the lower Sacramento River, and San Joaquin River. Data are in numbers of fish x 10^4. Data for 1968-1977 include time period extrapolations and extrapolations for upper Suisun Bay stations. Data for 1968-1973 corrected for differences in net efficiency.

Year	6-8 mm Index	9-11 mm Index	12-14 mm Index	6-14 mm Index
1968	872,828	132,177	28,535	1,033,540
1970	2,292,883	197,831	55,254	2,545,968
1971	5,008,934 1/	136,983	28,234	5,174,151
1972	2,381,722	219,189	50,350	2,651,261
1973	--	148,436	40,988	--
1975	5,815,994	113,847	29,965	5,959,806
1977	320,658	11,884	365	332,907
1984	588,415	43,220	7,694	639,329
1985	1,419,289	23,306	2,856	1,445,451
1986	1,778,712	107,462	24,118	1,910,292

1/ Actual weighted catch sum, no time period extrapolation.

Turner (USBR Exhibit 100) compared the distribution of larvae as they grew in length during a set of early and recent years when freshwater flows were similar and distribution also should be (Table 11). He paired years of similar flow to reduce the differences that might be due to larger numbers of larvae being washed downstream in years of higher river flow. In the more recent of these paired years, concentrations of bass larvae in the Delta portion of the estuary declined much more rapidly as they grew from 6 to 14 mm in length during May and June (Figures 18, 19, 20).

We analyzed the actual rate at which larval bass populations declined in all the years during which the larva surveys were made. A decline is, of course, natural and expected, but changes in the rate of decline can very quickly lead to lower or higher populations. These decline rates have increased substantially in recent years (Table 12).

In the years that were comparable, we calculated a 70% greater decline rate in the recent years in the Delta and a 65% increase in the decline rate in Suisun/Grizzly/Honker bay region (Table 13). The change was apparent in all paired years (Figure 21 and 22) but greatest in the driest pairs, 1968/1985 and 1972/1977 (Table 14).

To illustrate the significance of changes in these rates of larva population declines, we calculated the number of 14 mm bass that would remain from a hypothetical initial population of one billion 6 mm larvae at the decline rate estimated in the paired

Table 11. Mean monthly May/June flows (cfs) in years of comparable striped bass larva surveys.

	1968	1985	1970	1984	1972	1977
Sacramento River at Sacramento	13,316/11,353	13,432/13,310	14,265/11,787	15,406/14,990	12,848/13,827	7,597/6,86
San Joaquin River at Vernalis	891/592	2,134/1,751	2,393/2,737	3,240,2,297	744/587	400/11
Cross Channel & Georgiana Slough	5,992/5,416	5,553/5,371	6,270/5,543	5,482/6,482	5,855/6,144	4,316/4,02
Total Delta Exports	5,611/4,708	6,206/6,516	4,012/4,997	5,929/6,165	6,495/8,111	2,987/73
San Joaquin River at Jersey Point	164/-986	351/-1,483	3,561/1,202	2,068/804	-1,042/-3,569	1,082/99
Delta Outflow	6,737/3,666	7,176/5,411	10,761/6,214	11,204/8,038	5,140/2,891	3,999/2,52

NA = Data not yet available.

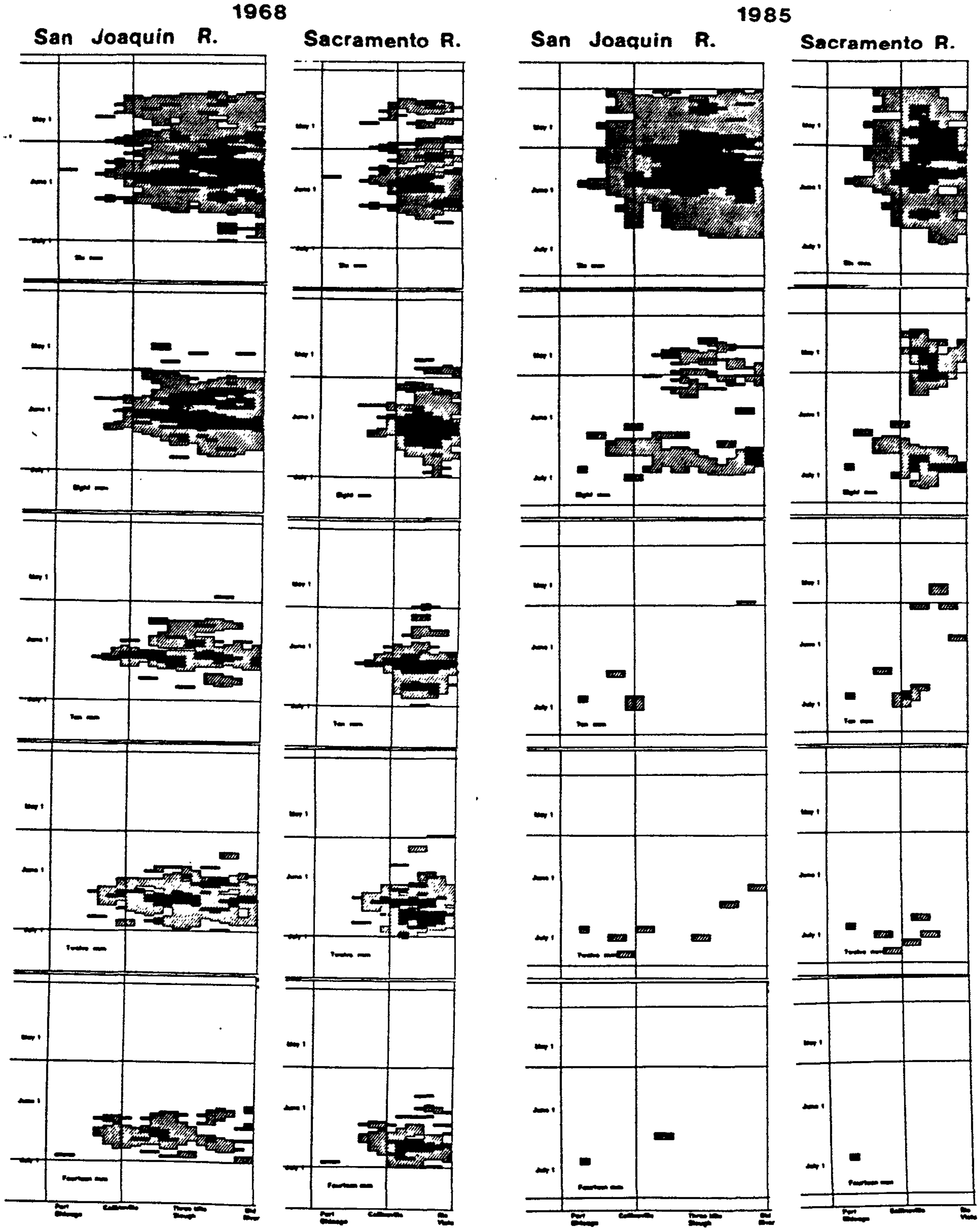


Figure 18. Comparison of the concentrations of 6 to 14 mm larval striped bass over time and space in 1968 and 1985, similar flow years. May outflow at Chipps Island was 6,737 cfs in 1968 and 7,176 cfs in 1985. June outflows were 3,666 cfs and 5,215 cfs, respectively. Mean San Joaquin River flows at Jersey Point were 164 cfs in May and -986 cfs in June 1968 and 351 cfs in May and -1,483 cfs in June 1985.

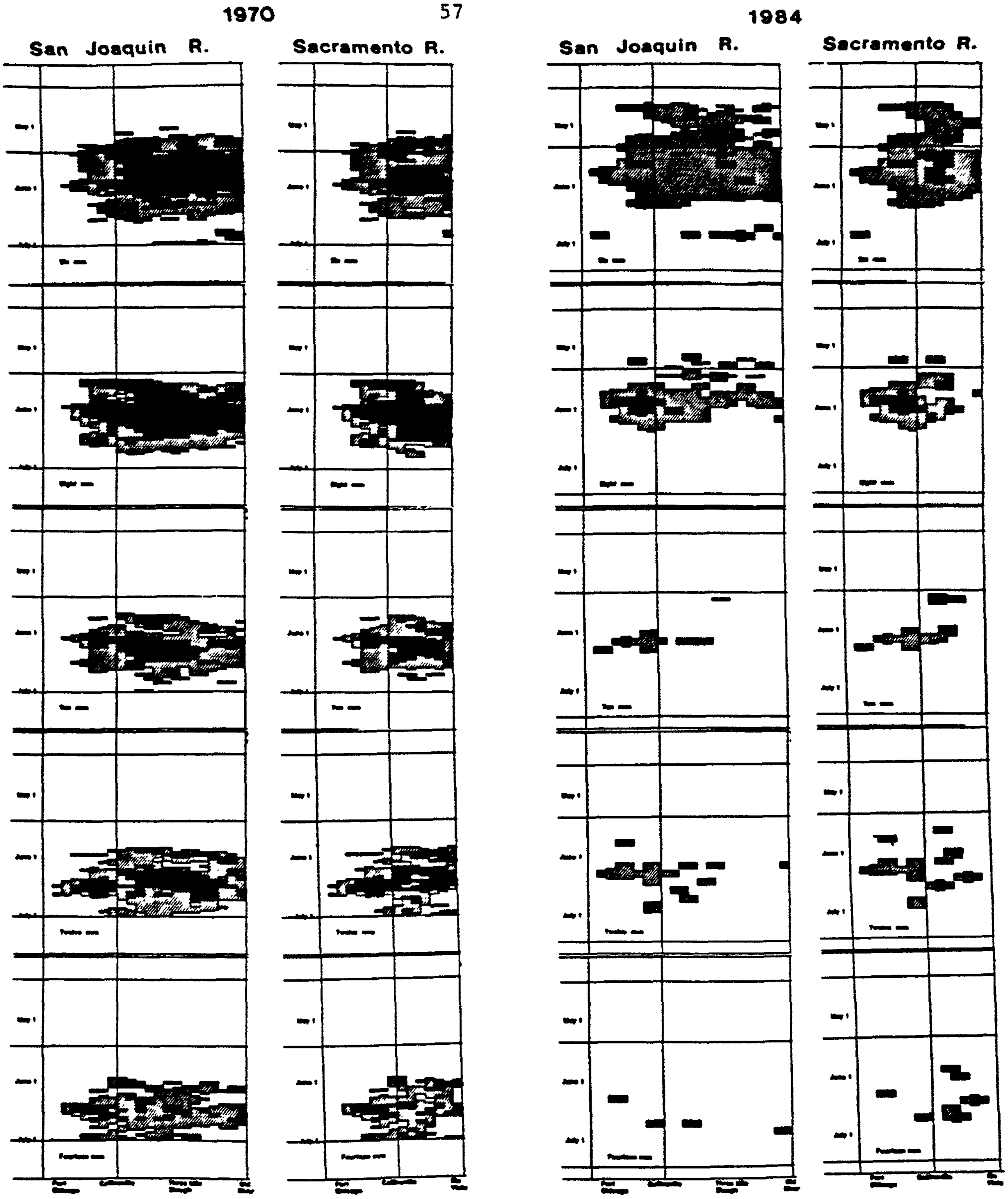


Figure 19. Comparison of the concentrations of 6 to 14 mm larval striped bass over time and space in 1970 and 1984, similar flow years. May outflow at Chipps Island was 10,761 cfs in 1970 and 11,204 cfs in 1984. Mean San Joaquin River flows at Jersey Point were 3,561 cfs in May and 1,202 cfs in June 1970 and 2,068 cfs in May and 804 cfs in June 1984.

C-045526

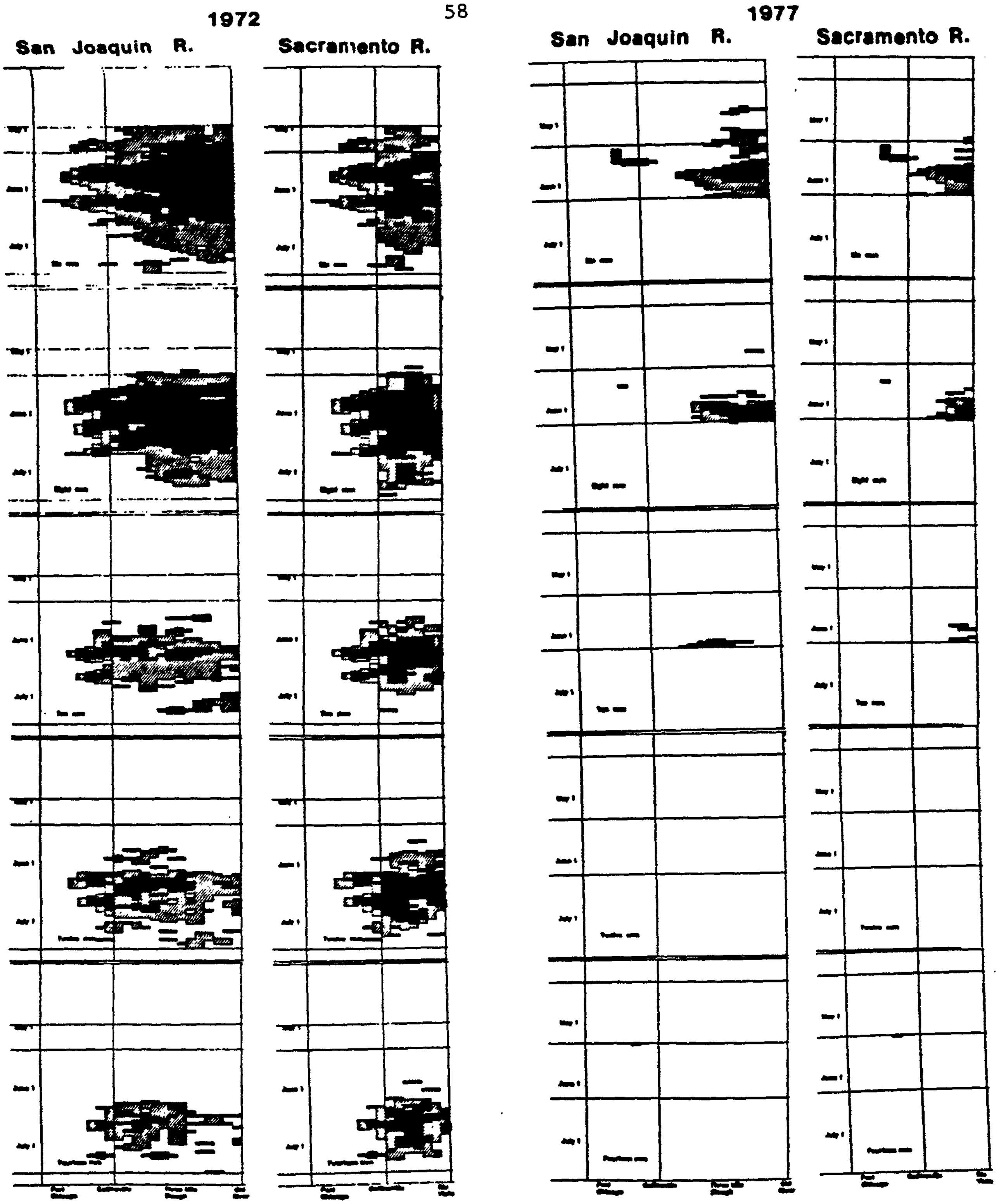


Figure 20. Comparison of the concentrations of 6 to 14 mm larval striped bass over time and space in 1972 and 1977, similar flow years. May outflow at Chipps Island was 5,140 cfs in 1972 and 3,999 cfs in 1977. Mean San Joaquin River flow at Jersey Point was -1,042 cfs in May and -3,569 cfs in June 1972 and 1,082 cfs in May and 992 cfs in June 1977.

Table 12 . Decline rates by area for 6-14 mm striped bass.

Year	Sacramento River	San Joaquin River	Delta Stations Above Collinsville	Suisun Bay	Grizzly-Honker	Suisun/ Grizzly-Honker
1968	-.454	-.600	-.540	-.379	-.439	-.386
1970	-.532	-.651	-.611	-.427	-.273	-.405
1971	-.833	-.77	-.773	-.768	-.727	-.748
1972	-.526	-.678	-.601	-.532	-.523	-.531
1973[1/]	-.430	-.448	-.443	-.397	-.388	-.393
1975	-.857	-.834	-.847	-.757	-.761	-.759
1977[2/]	-1.36	-1.083	-1.220	-1.079	-.831	-1.007
1984	-.654	-.817	-.716	-.610	-.603	-.607
1985	-1.01	-1.08	-1.048	-.545	-.781	-.577
1986	-.742	-.780	-.771	-.645	-.512	-.575

1/ 1973 data for 6-8 mm larvae were incomplete. The decline rates were calculated only for 9-14 mm abundances.

2/ 1977 data for 6-9 mm bass only.

Table 13. Mean decline rates of 6-14 mm striped bass. Early years (1968, 1970, 1972) are compared with recent years (1977, 1984, 1985). Years were paired on the basis of similar May-June flows.

	Sacramento River	San Joaquin River	Delta	Suisun Bay	Grizzly/ Honker Bays	Suisun/ Grizzly/ Honker Bays
Mean Early Years	-.504	-.643	-.584	-.446	-.412	-.441
Mean Recent Years	-1.008	-.993	-.995	-0.745	-.738	-.730
Percent Increase in Recent Years	100.0	54.4	70.4	67.0	79.1	65.5

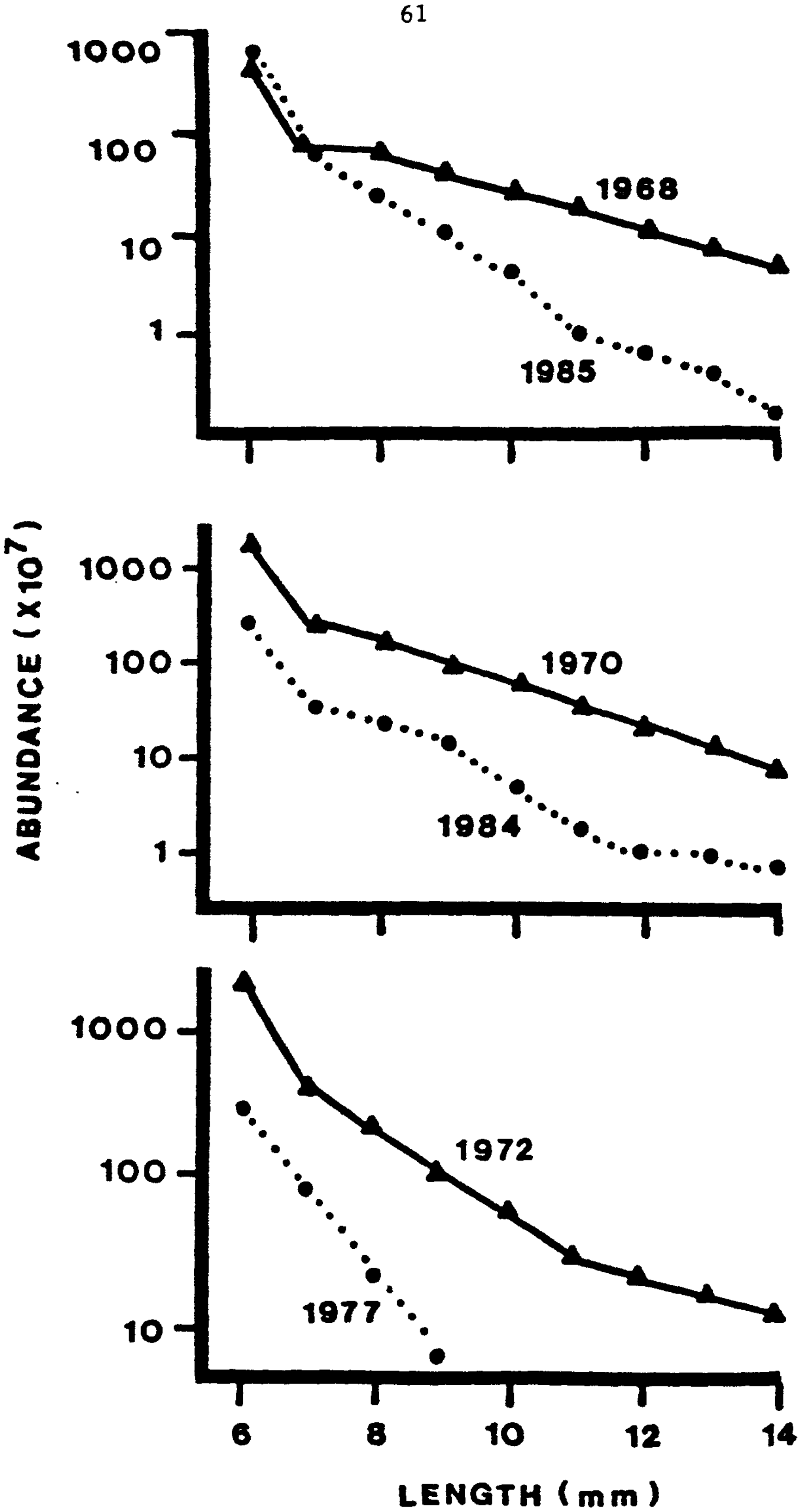


Figure 21. The relative decline in $\log_e$ abundance of 6-14 mm striped bass in the Delta for paired flow years 1968 and 1985, 1970 and 1984, and 1972 and 1977. The greater rates of decline were in the most recent years.

C-045530

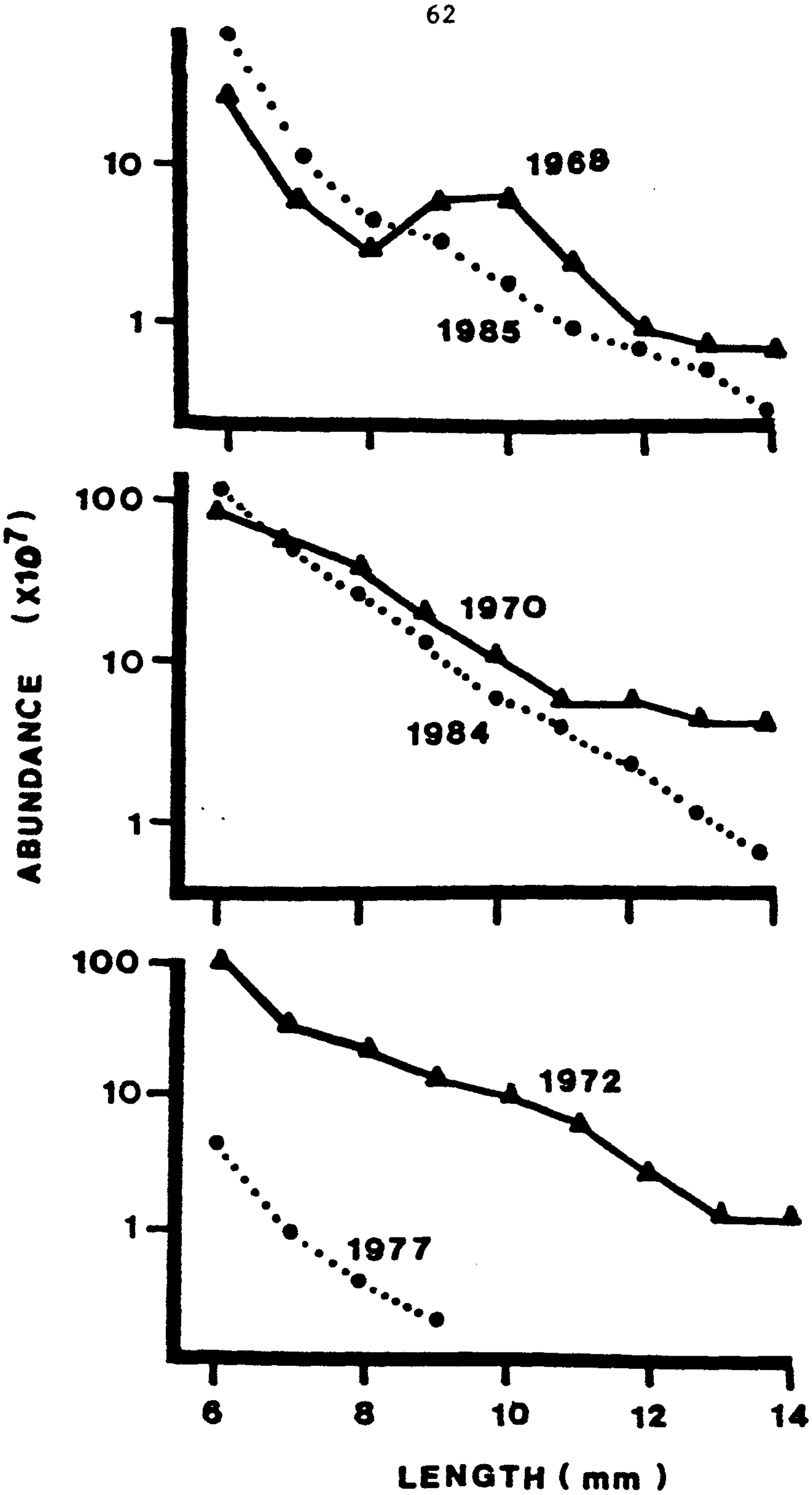


Figure 22. The relative decline in $\log_e$ abundance of 6-14 mm striped bass in Suisun/Grizzly/Honker bays for paired years 1968 and 1985, 1970 and 1984, and 1972 and 1977. On average, decline rates were greater in the most recent years.

C-045531

Table 14. Projected population of 14 mm striped bass using daily decline rates and an initial hypothetical population of one billion 6 mm larvae.

Year	Initial Population	Decline Rate 1/	Daily Decline Rate 2/	Zt 3/	Projected 4/ Population (Millions)	Ratio
1968	1×10^9	-0.530	-0.177	-4.248	14.3	20.4
1985	1×10^9	-0.911	-0.304	-7.296	0.7	
1970	1×10^9	0-.575	-0.192	-4.600	10.1	2.1
1984	1×10^9	-0.667	-0.222	-5.336	4.8	
1972	1×10^9	-0.867	-0.289	-6.936	1.0	16.7
1977	1×10^9	-1.215	-0.405	-9.72	0.06	
Mean 1968, 70, 72					8.5	4.5
Mean 1977, 84, 85					1.9	

1/ Decline rate = decline in abundance from 6 to 14 mm in 1968, 1985, 1970, and 1984; 6 to 9 mm in 1972 and 1977.
2/ Decline rate x estimated growth of 0.333 mm per day. The product is an estimate of the rate of decline per day.
3/ Zt = daily decline rate (Z) times number of days (t) to grow from 6 mm to 14 mm.
4/ Population calculated by $N_t = N_o e^{-Zt}$.

years for the entire estuary. In years represented by 1968, 1970, and 1972, one billion 6 mm larvae would produce an average of 8.1 million 14 mm bass. In the more recent years, 1977, 1984, and 1985, one billion 6 mm larvae would produce 1.9 million 14 mm bass -- only 22% as many (Table 14).

It is the lower populations of larvae, particularly the stages after 8 mm, that have caused the 38 mm index to decline. The low 38 mm abundance indices have been preceded by low abundances of larvae 8 mm or larger and the higher 38 mm indices have been preceded by higher production of larvae (Figure 23). It is apparent that if a year class gets off to a poor start, abundance likely will remain relatively low (i.e., 1977, 1984, 1985). Conversely, if 8-11 mm larvae are abundant, abundance will likely remain higher (pre-1977 years, 1986).

While these correlations clearly demonstrate that the early abundance of larvae establishes the potential year class, it is also important to recognize how later environmental factors are of critical importance in controlling how well that potential is realized. The correlations largely reflect differences between two clusters of years, the lower of which is represented by 1977, 1984, and 1985, and the upper by the years before 1977 plus 1986. Within the upper clusters, fairly wide ranges in larva abundance lead to a much narrower range in the 38 mm index. This contraction reflects different post-larva survival rates among the year classes. Also note that the correlations do not include the truly abundant year classes produced in high flow years such as

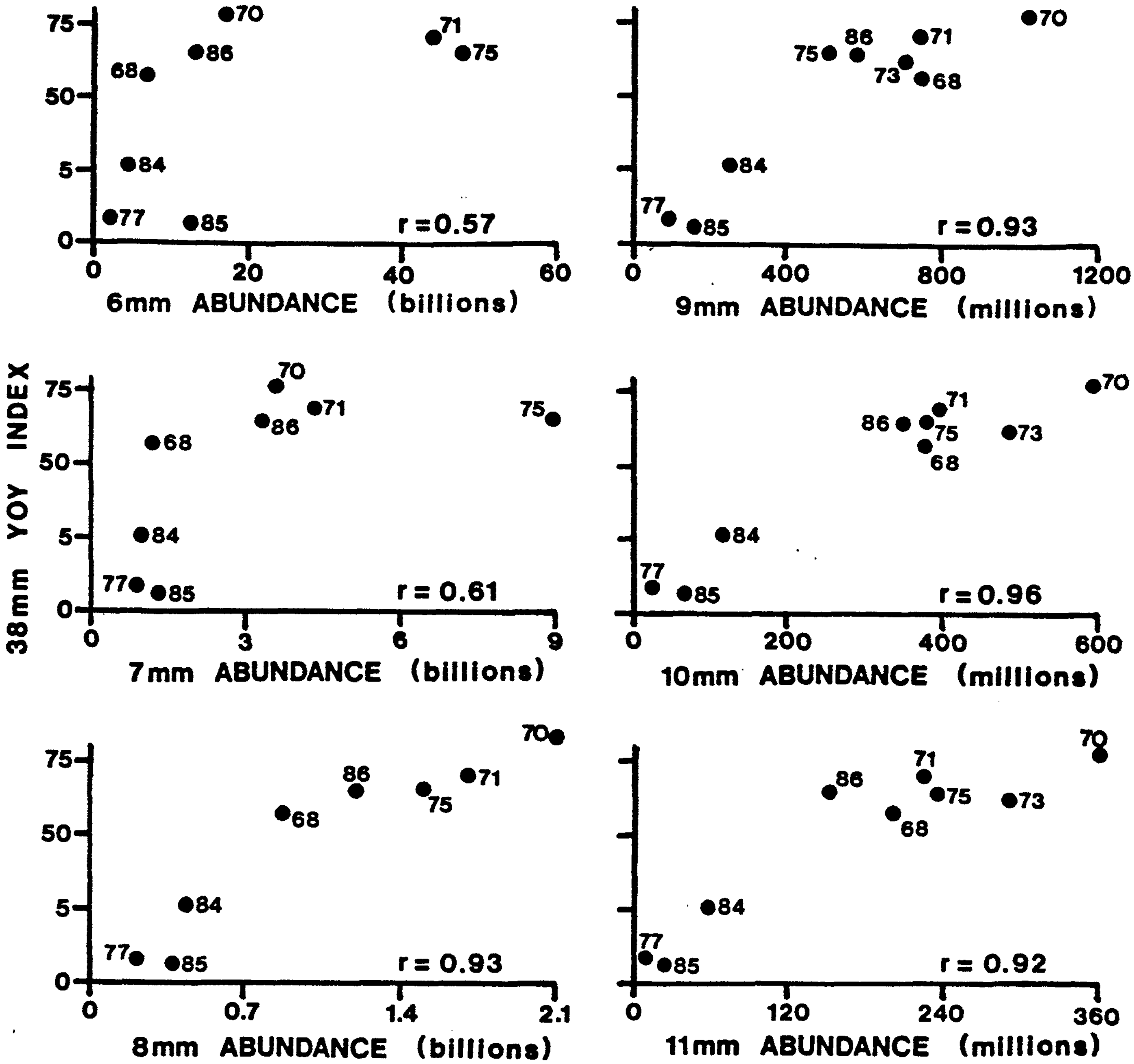


Figure 23. Correlation between abundance of several striped bass larval stages and the 38 mm young bass abundance index. It is the lower populations of larvae, particularly the stages after 8 mm, that have caused the 38 mm index to decline.

1965 and 1967. We do not know if larvae were any more abundant in these years. They may not have been . Logically, effects of outflow and diversions would accrue over a much longer interval than that represented by larva stages alone; thus, it is probable that high 38 mm indices reflect better survival both during and after the larva period.

Direct Mortality of Eggs and Larvae from High Temperatures

Because spring water temperatures in the Sacramento River have been higher in recent years, Mitchell (DWR Exhibit 607) examined the possibility that eggs and larvae might be exposed to harmful water temperatures. Based on laboratory results reported in the scientific literature, he selected temperatures greater than 73^{o}F as adverse. Mitchell found no risk of the most sensitive eggs and yolk sac larvae in the San Joaquin Delta being exposed to such temperatures because Delta spawning is earlier than in the Sacramento River. He found that 18 to 22% of the eggs produced in the Sacramento River were exposed to potentially harmful levels of temperature in 1977, 1985, and 1986, but that none were in 1972, 1973 and 1984.

Entrainment Losses of Eggs and Larvae in Water Diversions

Many striped bass eggs and larvae are lost to entrainment in water diversions of the CVP, SWP, Delta agriculture (DA), and the Pacific Gas and Electric Company (PGE). The reason for losses to local agriculture and PGE power plants is obvious since these are located in major spawning and nursery areas. However, huge entrainment losses also occur at the CVP and SWP despite their intakes being miles from the primary spawning and nursery areas. These losses occur due to the magnitude of the water project diversions, their impact on Delta flow patterns, and the tendency for striped bass eggs and young to be transported and dispersed by river and estuarine currents.

CVP-SWP export pumping has changed the natural flow patterns of the Delta. The pumps are located at the southern edge of the Delta, but pumping rates usually exceed the flow of the San Joaquin River entering the Delta from the south; therefore, most of the water that they export must come from the Sacramento River. Approximately the first 3,500 cfs of flow exported from the Sacramento River crosses the Delta through channels upstream from the mouth of the San Joaquin River. At higher export rates water is drawn up the San Joaquin River from its junction with the Sacramento River (Figure 24). Such net upstream flows in the San Joaquin River are typical in all but wet springs, and in the summer and fall of all years.

The reverse flows to the southern Delta draw young fish and their food organisms out of the spawning and nursery areas and transport them to the diversion sites. The louver screens in front of the SWP and CVP pumps guide many of the young fish to holding tanks and a tank truck in which they are transported back to the western Delta and released. Numerous fish, particularly those too small to swim well, pass through the screens and are

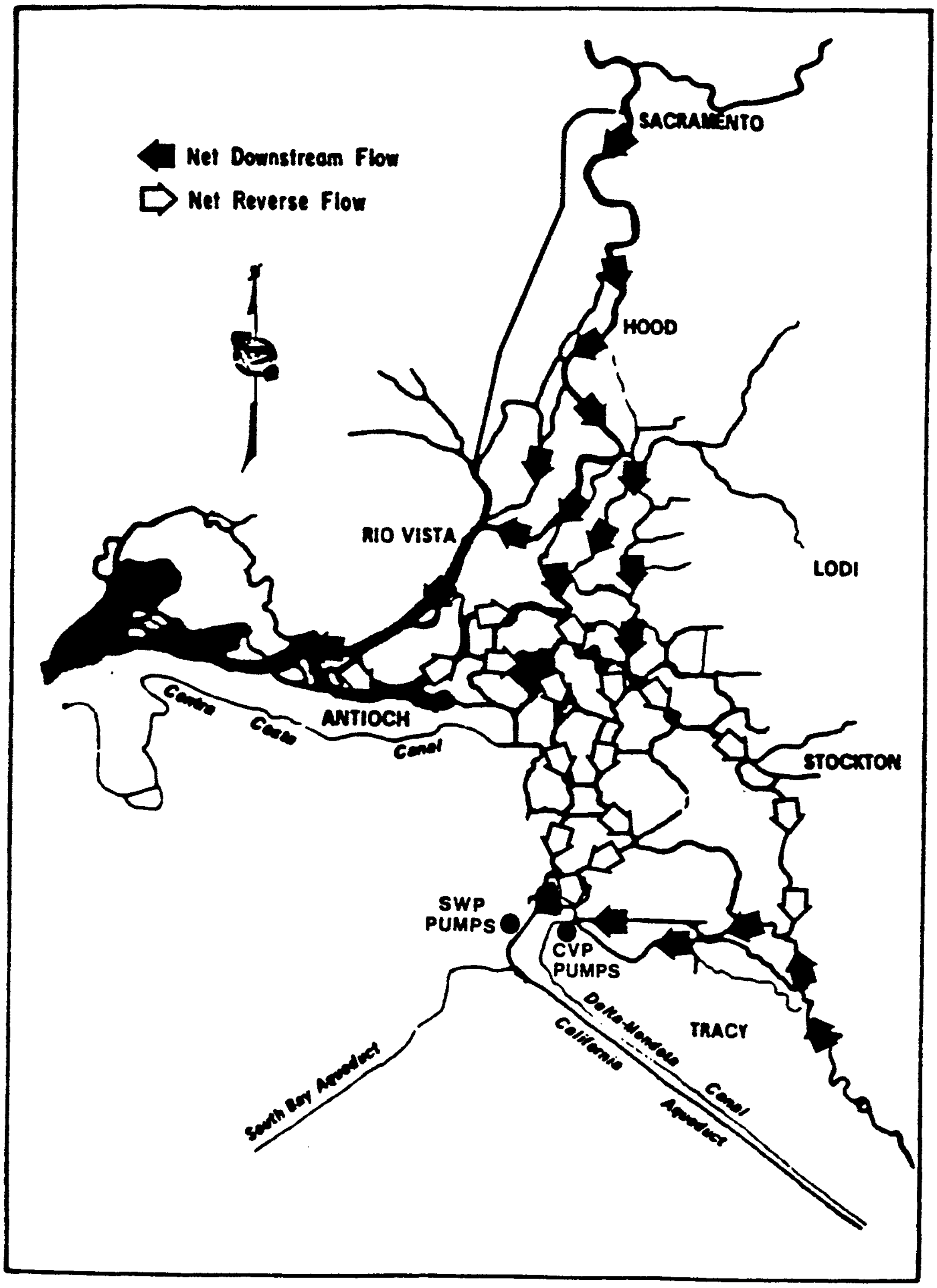


Figure 24. Typical summer flow patterns in the Sacramento-San Joaquin Delta. CVP-SWP export pumping has changed the natural flow patterns. Reverse flows transport many young striped bass from their nursery to the CVP-SWP diversions in the south Delta.

lost into the aqueduct system (DFG Exhibit 17). Substantial numbers of young bass also die due to stresses received during the handling and trucking or are eaten by larger fish in the SWP's Clifton Court Forebay and near the trash racks at both the CVP and SWP screens. The numerous agricultural diversions are not screened at all.

Georgiana Slough and the Cross Channel at Walnut Grove play key roles in the transfer of water across the Delta. The Cross Channel, which was dug by the CVP in the 1950s, connects the Sacramento River with the Mokelumne system, thus providing a more direct route for water to travel to the pumps in the southern Delta. Gates at the entrance to the Cross Channel control whether or not water travels along this route.

The operation of the Cross Channel gates is particularly important to striped bass. If the gates are open when eggs and larvae are drifting downstream, many become entrained in the flow to the pumps where millions are removed from the estuary. If the gates are closed, some fish will still pass through Georgiana Slough, but more will travel downstream and make their way to the nursery in the western Delta and Suisun Bay. However, if the Cross Channel gates remain closed during periods when CVP-SWP pumping rates are high and flows from the San Joaquin River are low, the flow of the Sacramento River passes downstream to the western tip of Sherman Island where much of it is drawn back up the San Joaquin River creating the reverse flows which also transport young bass to the CVP-SWP intakes as we have described previously.

Ideally, the gates would be operated to minimize the direct entrainment of eggs and larvae from the Sacramento River and to minimize flow reversals. Often, however, this is not achieved because eggs and larvae are most abundant during May and June, a period when the need to export water is high and Delta outflows are declining.

Magnitude of Egg and Larva Entrainment Losses

Egg and larva losses depend on the population density at the diversion intakes; the diversion rate; and, in the case of PGE, mortality occurring during passage through the power plants before the cooling water is discharged back into the Delta. No diversions have screens designed to protect eggs and larvae.

The magnitude of such losses in Delta power plants during 1978 and 1979 was estimated for PGE's 316b demonstrations (PGE 1981a; 1981b). These estimates, 154 million in 1978 and 62 million in 1979, are based on sampling within the power plant cooling system. Subsequent to their 316b demonstrations, PGE modified their operations to reduce entrainment losses at the Pittsburg and Contra Costa power plants. The result has been an approximate 75% reduction in entrainment losses (monitoring program reports submitted by PGE to Central Valley and San Francisco Bay Regional Water Quality Control Boards).

We obtained larval bass catch data and effluent flows for the PGE power plants in 1985. These data allowed us to estimate that 70 million larvae were entrained that year, but we could not

C-045539

calculate their mortality, which is substantially less, because simultaneous catch and temperature records were not available.

Estimates of striped bass egg and larva losses to the CVP, SWP, and Delta agricultural diversions were made by multiplying estimates of egg and larva population densities in the Delta channels within the influence of the diversions by the amounts of water being diverted. The sampling of eggs and larvae is based on oblique tows with fine mesh towed nets as described on p 48. Egg and larva losses to the CVP-SWP diversions were estimated by DFG for 1985 and 1986. These estimates were 794 million and 100 million, respectively.

R.L. Brown of DWR estimated that 598 million and 562 million striped bass eggs and larvae were lost to Delta agricultural diversions in 1978 and 1979, respectively.

These entrainment loss estimates for the CVP-SWP and Delta agriculture are minimum estimates as they are based on sampling with nets of unknown, but certainly less than 100%, efficiency. Yet the estimates, which range well into the hundreds of millions, are convincing evidence that large numbers of striped bass eggs and larvae are removed from the estuarine population in many years and that all types of diversions (CVP-SWP, Delta agriculture, PGE) have contributed substantially to these losses.

The 1985 and 1986 egg and larva sampling in the estuary and near the CVP-SWP diversions allowed us to evaluate the extent to which the striped bass population was reduced by egg and larva entrainment at the CVP and SWP in those years.

The percentage reduction in the number of 20 mm larvae was estimated as the cumulative effect of removing eggs and larvae stratified by 1 mm size intervals from the estuary. This analysis is basically a comparison of the survival that actually occurred in the population and the higher survival that would have occurred if there were no CVP-SWP entrainment (Appendix 3).

Estimates of survival with entrainment were made directly from the observed decline in indices of numbers of larvae living in the system. To calculate survival without entrainment, we separated the amount of mortality presently caused by entrainment from total mortality, and then calculated what the rate of total mortality would have been if there were no entrainment. This is equivalent to calculating Ricker's (1975) "conditional natural mortality rate".

Percent Reduction in 1985 During 1985, Delta outflows (mean April-June=6,495 cfs) were not large enough to transport many of the striped bass larvae downstream to Suisun Bay. Hence, a substantial portion of the larvae remained in the Delta where they eventually became vulnerable to the draw of the CVP-SWP pumps. We have calculated that the water projects entrained ("harvested") an average of 4.5% of the initial population of each millimeter size group between the egg and 14 mm larva stage (u in Table 15).

Because our nets are not effective at sampling larvae smaller than 6 mm or larger than 14 mm, direct estimates of how much the population is reduced by entrainment during the larva stage were

Table 15. Estimated impacts of larval striped bass entrainment in 1985.

Size Group (mm)	$\hat{N}_0$ 1/	Entrainment SWP	Entrainment CVP	Entrainment Total	S_E 2/	u 3/	S_{WO} 4/
Eggs	10,266,780,000	85,879,841	84,858,059	170,737,901		.0166	
4	603,710,000	4,733,873	1,945,492	6,679,365		.0111	
5	4,118,750,000	98,263,547	78,225,038	176,488,586		.0428	
6	10,427,200,000	204,234,102	163,958,264	368,192,365	.112	.0353	.122
7	1,170,120,000	23,966,600	15,066,159	39,032,759	.353	.0334	.373
8	413,160,000	12,892,114	4,640,096	17,532,210	.373	.0424	.399
9	153,920,000	6,519,574	1,834,874	8,354,448	.440	.0543	.477
10	67,760,000	1,516,429	1,036,541	2,522,970	.364	.0372	.386
11	24,640,000	0	445,760	445,760	.685	.0181	.700
12	16,880,000	2,583,701	0	2,583,701	.690	.1531	.829
13	11,640,000	337,700	445,760	783,459	.600	.0673	.654
14	6,980,000	211,378	0	211,378		.0303	

1/ Index of number of fish entering each length interval.
2/ Estimated actual survival to next length interval.
3/ Harvest of fish by entrainment (Total entrainment ÷ $\hat{N}_0$).
4/ Estimated survival if there were no entrainment.

C-045542

limited to the time when larvae were growing from 6 to 14 mm. This is a period of about 23 days.

Mortality due to causes other than entrainment averaged about 50% in each millimeter length interval of larvae 6 to 13 mm long although there was a decreasing trend from about 85% for 6 mm larvae to 33% for 13 mm larvae. The cumulative effect was more than a 99% reduction in the abundance of larvae between the 6 and 14 mm stages.

Over the 6-14 mm size interval, estimated survival with entrainment (actual survival) was only 0.000669. In the absence of entrainment, the survival rate would have been 0.001269. While only a tiny fraction of the population survives in both of these cases, the difference between them is important. The net result is a population of 14 mm larvae that is about 47% lower due to entrainment:

Percent reduction =

$$1 - \frac{\text{Survival in the presence of entrainment}}{\text{Survival in the absence of entrainment}} = 1 - \frac{.000669}{.001269} = .473.$$

In other words, entrainment of 6-13 mm larvae at the CVP-SWP pumps reduced the population almost in half. These results obviously imply that the total effect of entrainment was substantially larger, as our calculation did not include effects of the entrainment of eggs, larvae smaller than 6 mm, or fish larger than 13 mm.

A rough approximation of the additional effect of entrainment of eggs and larvae smaller than 6 mm can be made by assuming that actual survival of eggs, 4, and 5 mm larvae equals that of 6 mm larvae; that survival of 5 mm larvae without entrainment equals that of 6 mm larvae; and that the difference between survival with and without entrainment for 4 mm larvae and eggs is half that for 6 mm larvae (% of population entrained, u, for these groups was roughly one half that for 6 mm larvae). Thus, the additional survivals with entrainment would be .112, .112, .112; the without entrainment survivals would be .122 (5 mm), .117 (4 mm), .117 (eggs). Survival from egg to 14 mm with entrainment would be .000000940; without entrainment, survival would be .000002119; and percent reduction from egg to 14 mm would be:

$$1-\frac{.000000940}{.000002119} = .557 \text{ or } 55.7\%.$$

We also know that effects of entrainment continue to accumulate through the size intervals in the other direction (larger fish). We do not have data which allow direct calculations, but to approximate potential entrainment effects over the range from egg to 20 mm we applied the with and without entrainment survivals for 13 mm fish (.600, .654) to the six length groups from 14-19 mm, and the estimated percent reduction from egg to 20 mm was:

$$1-\frac{(.000000940 \times .600^6)}{(.000002119 \times .654^6)} = .735 \text{ or } 73.5\%.$$

Based on these results (a direct estimate of 47.3% reduction in the period between 6 and 14 mm and an extrapolated estimate of 73.5% reduction in the period between egg and 20 mm), the conclusion is inescapable that larva entrainment by the CVP and SWP severely eroded the striped bass population in 1985 and that substantial erosion will occur in any year with similar outflows and water export rates.

We also want to emphasize, however, that these same calculations indicate that larva entrainment is not entirely responsible for the extremely low abundance of the 1985 year class. We have previously indicated that the young-of-the-year striped bass abundance index had an all time low value of 6.3 in summer 1985. Our calculation of a 73.5% reduction in abundance between the egg and 20 mm stages indicates that the index would have been 23.8 if there was no larva entrainment

$$\frac{6.3}{1-0.735} = 23.8.$$

An index of 23.8 is still a low index from the historic perspective, and it is also lower than the index of 34.0 predicted for 1985 from the 1959-1976 relationship between young bass abundance, outflow, anad diversion rates.

Percent reduction in 1986 In 1986, Delta outflows were relatively high (mean April-June=21,190 cfs) and many striped bass larvae were transported to Suisun Bay where they were not subjected to the draw of the CVP-SWP export pumps. As a result, we have calculated that the average entrainment "harvest" of each size group was only 1.4% of the initial population of each group between the egg and 14 mm stages (Table 16).

From 6-14 mm, the estimate of actual survival was .006249; and estimated survival without entrainment was .007309. From these estimates, the cumulative effect of entrainment over the 6-14 mm size range was a 14.5% reduction in the population:

$$1-\frac{.006249}{.007309} = .145.$$

Extending the analysis back to the egg stage and forward to the 20

Table 16. Estimated impacts of larval striped bass entrainment in 1986.

Size Group (mm)	$\hat{N}_0$ 1/	Entrainment SWP	Entrainment CVP	Entrainment Total	S_E 2/	u 3/	S_{WO} 4/
Eggs	5,492,730,000	3,773,199	9,273,122	13,046,321		.0024	
4	570,160,000	365,160	159,006	524,167		.0009	
5	2,830,290,000	15,877,707	6,948,947	22,826,654		.0081	
6	9,414,780,000	10,829,521	6,685,103	17,514,624	.288	.0019	.289
7	2,707,340,000	5,677,200	5,396,107	11,073,307	.456	.0041	.459
8	1,234,600,000	3,058,530	3,869,975	6,928,505	.433	.0056	.436
9	534,540,000	2,340,376	2,141,980	4,482,356	.649	.0084	.656
10	347,030,000	3,140,890	3,863,765	7,004,654	.458	.0202	.471
11	159,070,000	1,786,771	3,136,863	4,923,634	.844	.0310	.873
12	134,240,000	1,671,626	1,802,764	3,424,390	.657	.0255	.678
13	88,250,000	814,674	1,709,896	2,524,570	.667	.0286	.691
14	58,830,000	1,333,116	543,503	1,876,619			

1/ Index of number of fish entering each length interval.
2/ Estimated actual survival to next length interval.
3/ Harvest of fish by entrainment (Total Entrainment ÷ $\hat{N}_0$).
4/ Estimated survival if there were no entrainment.

mm stage as we did for 1985 yields an entrainment caused reduction of 31.3% from the egg to 20 mm stage.

Hence, as expected from the higher outflows causing a more seaward distribution of larvae in 1986, CVP-SWP entrainment impacts were substantially lower than in 1985. Overall, our larval bass percent reduction analysis indicates that CVP-SWP entrainment severely reduces the striped bass larva population with the greatest impact occurring in the drier low flow years.

Sampling indicates that most of this entrainment of larvae probably occurs in May and June although some also are entrained during April and July (Tables 17 and 18).

<u>Entrainment of Larger Striped Bass</u>

In addition to losses of eggs and small larvae which cannot be screened, many larger young bass are lost in diversions from the Delta. As the bass grow from very small larvae to 20 mm, their swimming ability increases and they are less likely to be entrained in the smaller diversions. No tests have been made of this but many estimates of losses at different sizes have been made at the SWP and CVP diversions from the South Delta. Fish entrained at these diversions are collected and returned to the Delta. Major tests over the years have described the efficiency of this salvage operation and the mortality rates associated with collecting and returning fish to the Delta (DFG Exhibit 17).

Assuming a loss of 15% at intakes and trashracks, estimates of entrainment losses range up to 33 million of the bass greater

Table 17. Minimum estimates of entrainment of striped bass eggs and larvae by the State Water Project.

1985	Eggs	3-6 mm	7-10 mm	11-14 mm
Apr 16-30	3,161,003	38,461,069	4,289,227	0
May 1-15	72,754,283	69,328,241	13,288,904	0
May 16-31	9,186,982	133,014,715	2,281,900	337,231
Jun 1-15	776,332	42,792,309	8,809,719	0
Jun 16-30	0	23,174,110	15,141,675	1,919,412
Jul 1-13	0	455,787	1,090,896	879,193
Total	85,878,556	307,226,231	44,902,321	3,135,835
GRAND TOTAL	441,142,942			

1986	Eggs	3-6 mm	7-10 mm	11-14 mm
Apr 16-30	232,944	0	0	0
May 1-15	2,925,636	4,700,959	1,701,729	0
May 16-31	535,473	20,319,317	6,024,493	622,261
Jun 1-15	78,070	1,278,781	6,191,257	3,839,482
Jun 16-30	0	0	0	131,636
Jul 1-11	0	771,049	296,738	1,022,474
Total	3,772,123	27,070,106	14,214,217	5,615,853
GRAND TOTAL	50,672,299			

Table 18. Minimum estimates of entrainment of striped bass eggs and larvae by the Central Valley Project.

	Size Groups			
1985	Eggs	3-6 mm	7-10 mm	11-14 mm
Apr 16-30	1,441,386	36,453,707	5,358,129	0
May 1-15	53,133,878	50,714,312	5,878,537	0
May 16-31	30,287,795	107,676,719	2,467,556	0
Jun 1-15	0	42,307,228	1,475,222	0
Jun 17-30	0	6,977,666	6,392,579	0
Jul 1-13	0	0	1,008,369	887,339
Total	84,863,059	244,129,632	22,580,392	887,339
GRAND TOTAL	352,460,422			

1986				
Apr 16-30	887,433	0	0	0
May 1-15	781,887	307,790	73,543	73,543
May 16-31	7,368,537	11,917,849	8,468,814	3,389,458
Jun 1-15	234,260	937,747	4,031,236	2,458,346
Jun 16-30	0	347,403	1,452,850	0
Jul 1-11	0	283,243	1,245,136	0
Total	9,273,117	13,794,033	15,271,579	7,194,078
GRAND TOTAL	45,531,807			

C-045549

than 20 mm long (Table 19). Assuming a higher loss of 82%, which some studies suggest occurs in the SWP's Clifton Court Forebay, the total annual loss estimates range up to 113 million bass (Table 20). This range of estimates is extremely large because studies to evaluate the losses, probably by predation, in Clifton Court Forebay have not been completed. Loss estimates have tended to be, but are not always, lower since the mid-1970s (Tables 19 and 20) because there now are fewer young bass in the estuary.

As expected, an index of the proportion of the population lost (represented by CVP+SWP screening and salvage losses ÷ young bass abundance index) has tended to decrease as increased Delta outflow transports young fish farther downstream away from the diversions (Figure 25). At any given flow, however, the proportion lost has remained about the same or is higher now than it was previously.

Despite Decision 1485 restrictions on project operations, 1984 and 1985 provided the two highest loss proportions and 1986 also was relatively high compared to most other years. Hence, while total entrainment losses have declined in response to the striped bass population decline, these proportions indicate that the fraction of the population lost has not.

The relationship between entrainment losses and water exports is not a straightforward one. For example, June export rates of about 4,000 cfs led to only about 3% of the annual screening and salvage losses in 1982, when lower San Joaquin River flow averaged 9,813 cfs, but 69% of the losses in 1981, when the Lower San

Table 19. Striped bass (21-150 mm) loss estimates for the SWP and CVP based on tested efficiency of the screens and assuming a 15% loss rate at the intakes and trashracks (Table 10 from DFG Exhibit 17).

Year	SWP Loss Estimate	CVP Loss Estimate	Total Loss Estimate
1957	0	1,620,508	1,620,508
1958	0	595,627	595,627
1959	0	7,588,785	7,588,785
1960	0	9,543,995	9,543,995
1961	0	14,914,267	14,914,267
1962	0	14,557,809	14,557,809
1963	0	22,821,772	22,821,772
1964	0	25,964,402	25,964,402
1965	0	12,595,642	12,595,642
1966	0	33,904,832	33,904,832
1967	0	5,001,933	5,001,933
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
1982	815,078	1,368,322	2,183,400
1983	99,554	162,844	262,398
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

Table 20. Striped Bass (21-150 mm) loss estimates for the SWP-CVP. SWP estimates are based on tested screen efficiencies and assume an 82% loss rate in Clifton Court Forebay. CVP losses assume a 15% loss at the intake and trashrack (Table 12 from DFG Exhibit 17).

Year	SWP Loss Estimate	CVP Loss Estimate	Total Loss Estimate
1957	0	1,620,508	1,620,508
1958	0	595,627	595,627
1959	0	7,588,785	7,588,785
1960	0	9,543,995	9,543,995
1961	0	14,914,267	14,914,267
1962	0	14,557,809	14,557,809
1963	0	22,821,772	22,821,772
1964	0	25,964,402	25,964,402
1965	0	12,595,642	12,595,642
1966	0	33,904,832	33,904,832
1967	0	5,001,933	5,001,933
1968	1,518,640	14,009,334	15,527,974
1969	1,509,202	8,329,794	9,838,996
1970	76,005,080	18,717,177	94,722,258
1971	48,184,312	8,459,477	56,643,788
1972	39,204,045	9,133,657	48,337,702
1973	64,119,553	8,547,806	72,667,359
1974	107,357,172	5,935,344	113,292,516
1975	30,287,227	6,192,385	36,479,612
1976	11,086,632	4,403,134	15,489,766
1977	3,701,321	613,848	4,315,168
1978	24,358,330	3,332,958	27,691,288
1979	18,640,004	2,399,012	21,039,016
1980	17,890,368	1,278,896	19,169,264
1981	6,377,891	5,746,387	12,084,278
1982	6,001,194	1,368,322	7,369,517
1983	781,441	162,844	944,285
1984	51,916,079	5,640,468	57,556,547
1985	26,371,527	1,699,641	28,071,168
1986	92,705,391	4,932,410	97,637,802

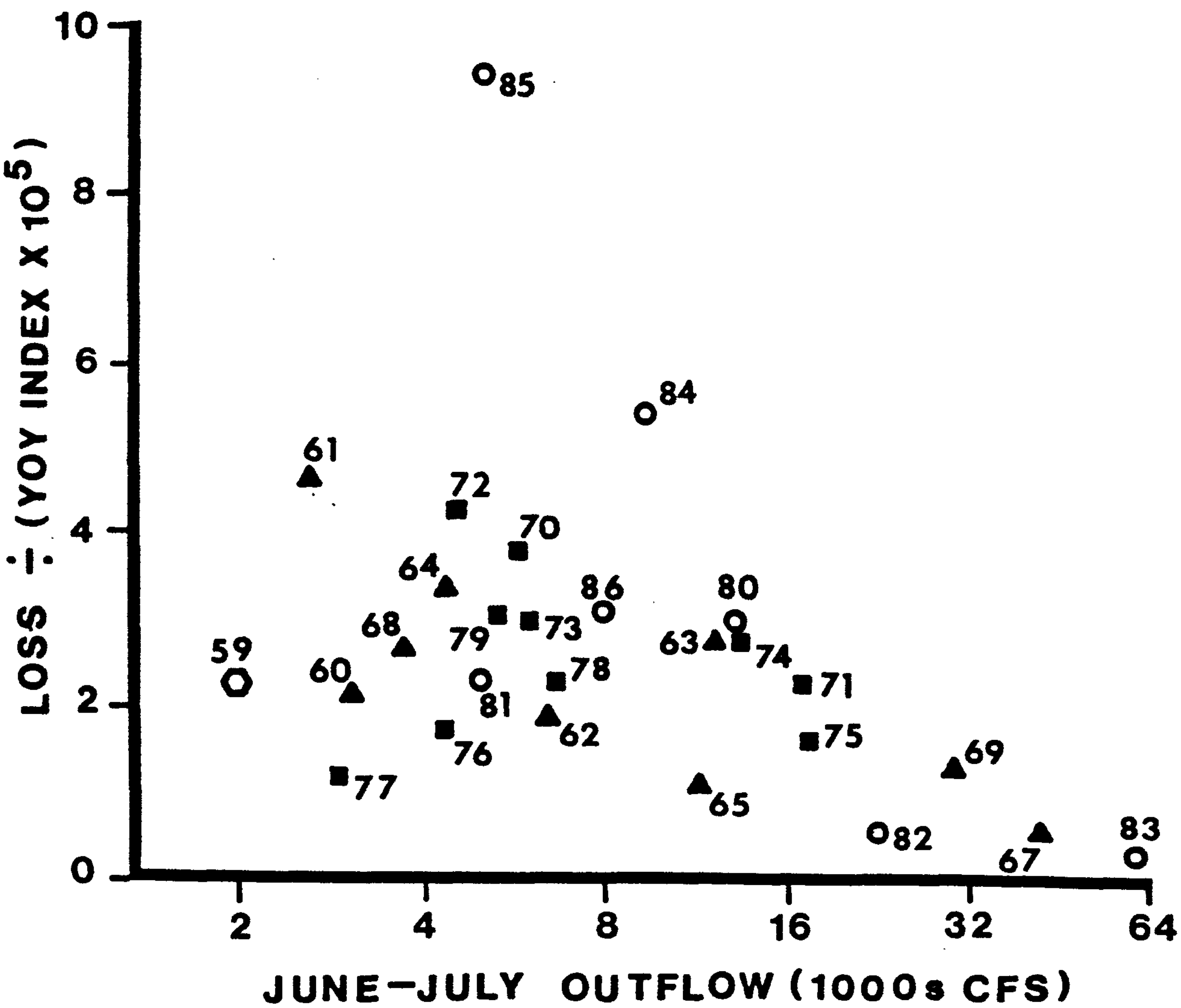


Figure 25. Relationships between an index of the proportion of the young striped bass population lost to entrainment at the CVP and SWP and Delta outflow. At higher flows, the proportion of the population lost to entrainment tends to be lower. At any given flow, recent loss rates have remained about the same or increased. Hence, despite D1485 restrictions on CVP-SWP operations, striped bass entrainment loss rates have not decreased.

Joaquin River flow was only 394 cfs. The largest losses have tended to occur in June and July, although in some years such as 1982 and 1983, August has been important (Table 21). Losses in individual months undoubtedly vary according to the combined effects of export rates, spawning time and location, Delta outflows and reverse flows in the lower San Joaquin River which control the distribution of young bass, and losses during the egg and larva stages.

Philip Wendt of DWR has quantified the effects of Delta flows on losses of young bass larger than 18 mm by developing correlative models (DWR Exhibit 606) which show that from June to August the entrainment loss of bass in the SWP intake system could be described statistically as a function of:

a) quantity and direction of flow in the lower San Joaquin River,

b) total striped bass abundance as measured by DFG's summer tow net index,

c) total CVP and SWP water exports, and

d) striped bass mean size.

In the model based on all data from June to August, the effect of all of these factors was highly significant ($p<0.01$) and overall the model explained 70% of the variation in young striped bass losses.

The model (equation) is:

$$Y_t = -0.0001(Qw) + 0.027(St) + 0.00025\ (Q_p) - 0.044(S_s) + 12.098$$

C-045554

Table 21. Estimated monthly distribution of young striped bass salvage at the CVP-SWP diversions in the Sacramento-San Joaquin Delta. Numbers are percentages of total annual losses presented in Table 19.

Month

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1978	10.6	3.4	0.2	0.0	0.0	29.7	43.4	5.1	0.7	2.2	2.6	2.2
1979	0.8	0.2	0.1	0.3	1.7	30.0	52.2	8.4	0.9	1.5	1.8	1.9
1980	0.6	0.3	0.0	0.1	0.0	17.3	56.0	14.8	3.6	1.3	2.9	3.0
1981	0.8	0.4	0.1	0.1	6.8	69.4	15.4	4.1	0.7	0.5	0.8	0.8
1982	3.1	3.1	1.0	0.5	0.6	2.9	46.2	28.5	3.1	1.6	2.4	6.8
1983	7.8	3.8	0.9	0.5	0.0	6.1	10.0	62.1	4.1	0.3	1.6	2.8
1984	0.0	0.0	0.0	0.0	1.0	51.5	42.0	1.7	0.2	1.5	1.0	1.0
1985	0.5	0.3	0.1	0.1	9.3	53.8	29.7	3.2	0.4	0.2	1.1	1.3
1986	0.2	0.5	0.0	0.0	0.4	54.7	39.8	2.6	0.7	0.3	0.4	0.3

C-045555

C-045555

where:

Y_t = $\log_e$ salvage loss at skinner fish facility,

St = total striped bass index,

Qw = western Delta flow in the lower San Joaquin River in cfs,

Q_p = total Delta exports -- mean monthly values in cfs, and

S_s = mean size (mm) of salvaged fish.

This model closely mimicked the overall trend of the highly variable losses over the 18 year period (1968-1985) of SWP operation (Figure 26).

Wendt's model results stress the interrelationship between reverse flows and export rates in determining entrainment losses. For example, with a reverse flow of 4,000 cfs, a 25% increase in exports (from 8,000 to 10,000 cfs) would increase losses by about 65%. Calculations also show, however, that no increase in losses would occur with such an increase in exports if the lower San Joaquin flow was increased to a positive seaward flow of 1,000 cfs.

If exports were not increased, but the lower San Joaquin flow increased from -4,000 to +1,000 cfs, then the model calculates that losses would be reduced by 39%. Although eliminating reverse flows is advantageous, it is obvious that this action is not the entire solution. With present export rates, substantial entrainment losses would continue to occur if there were moderately low seaward flows from the lower San Joaquin River.

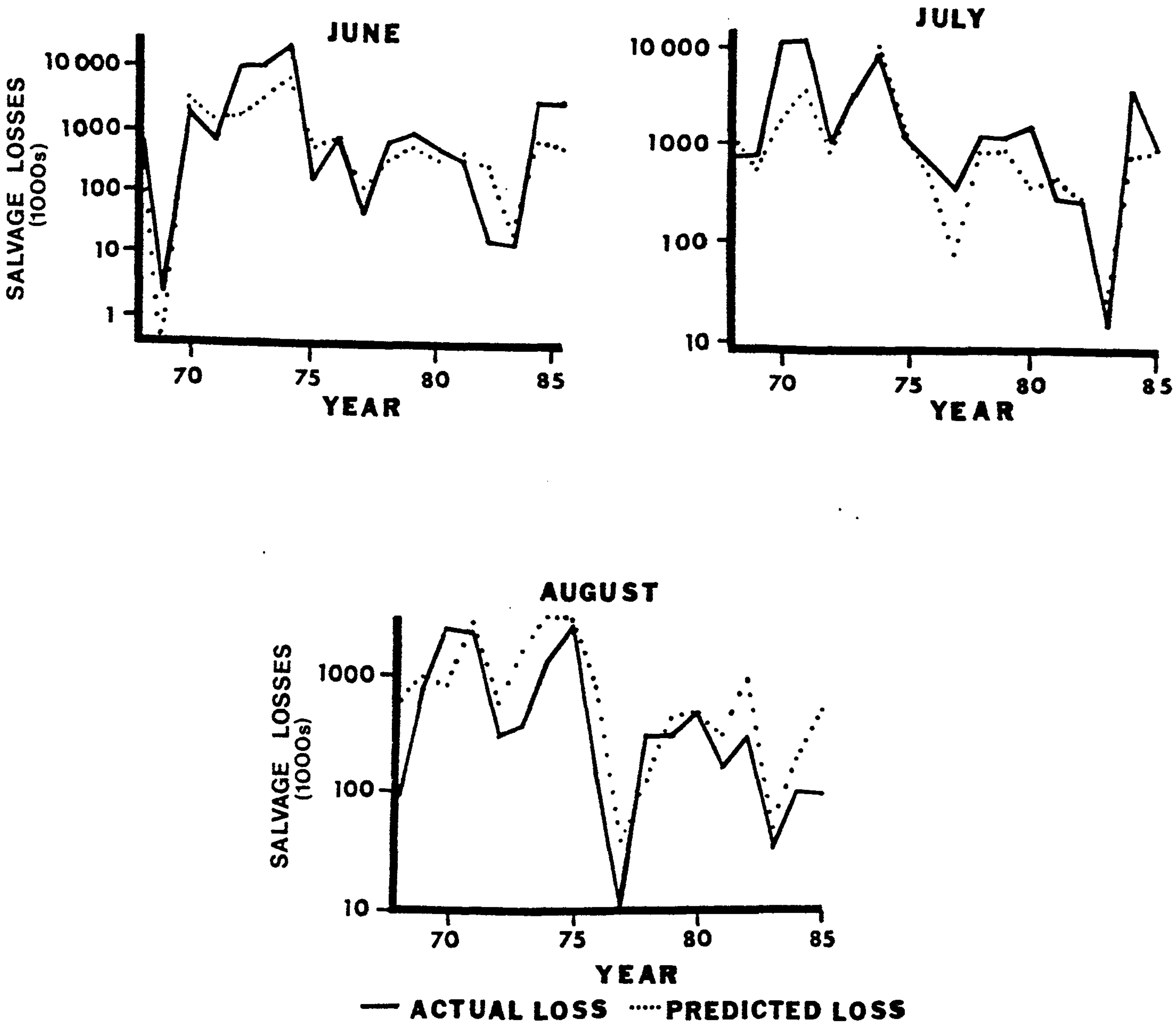


Figure 26. Striped bass losses due to entrainment in the SWP and losses predicted as a function of quantity and direction of flow in the lower San Joaquin River, young striped bass abundance in the estuary, total CVP-SWP water exports, and striped bass mean size. The predictive model closely simulated the overall trends in the highly variable losses.

C — 0 4 5 5 5 7

C-045557

Toxic Substances and Young Striped Bass

The following sections are primarily a summary of a working paper (DWR Exhibit 605) prepared by R.L. Brown to answer the general question, "Have toxicants caused significant reductions in the year class strength (38 mm index) of juvenile striped bass in the Sacramento-San Joaquin Estuary?" Additional detail is found in the Exhibit and the numerous studies cited in its reference section.

The analysis included in this section differs from others in this striped bass report in that the Interagency Program has no specific toxicants component. The approach taken was to assemble much of available literature dealing with this topic and essentially prepare a literature review to synthesize the major findings of various studies. Jeannette Whipple of the National Marine Fisheries Service, who has been involved in much of the striped bass toxicity work conducted in this estuary, provided critical review of the original manuscript and many helpful suggestions for improvements.

The general format of the analysis was to determine if there was significant pollution loading to the estuary, and to determine if there were data regarding the effects of these pollutants on striped bass food organisms, the young bass themselves, and on the adults ability to produce healthy eggs and larvae. Data from other areas, such as the east coast, are included to determine how the bass in this system compare to other populations.

Pollutant Loading

Various reports (as summarized by Citizens for a Better Environment 1983) have published data which document that the estuary receives substantial quantities of such potential toxicants as trace elements, chlorinated hydrocarbons (such as PCBs), and monocyclic aromatic hydrocarbons (MAHS such as benzene). Although loadings have decreased as a result of better waste water treatment over the past several years, the present loadings are still high enough to warrant concern. The Aquatic Habitat Institute (AHI) will be submitting a report which provides their best estimate of pollutant loadings during recent years.

Toxic Substances and Striped Bass Food Supply

Since young striped bass larvae begin feeding on small zooplankton within a few days of hatching, a decreased food supply due to toxic substances or other factors would decrease survival. During the early larval stages the young bass feed on zooplankton, which in turn have fed on algae or detrital material. There has been some limited work on the effects of toxics on algae and zooplankton. Available data indicate that the growth rate of Delta alga populations did not change between the early 1970s and mid-1980s (Interagency Ecological Study Program 1987). The lack of change suggests that toxicity is not a major problem, or, at least, has not become worse.

Most of the studies of the effect of toxic pollutants on zooplankton from the estuary were conducted using subsurface

C-045559

agricultural drainage as the experimental toxicant. Although the studies demonstrated that the ionic composition of the drainage could cause mortality to some zooplankton, the information is not particularly relevant to evaluating effects of drainage constituents in the estuary.

The DFG, the SWRCB, and the Central Valley Regional Water Quality Control Board have conducted studies of rice field herbicides (molinate and thiobencarb) commonly occurring in the Sacramento River above Sacramento. Bioassays indicate that these herbicides are toxic to Neomysis (State Water Resources Control Board 1985) and that concentrations hazardous to Neomysis may exist in the Delta in years with minimal flows in the Sacramento River (Faggella and Finlayson 1987). Rice field herbicides also can be toxic to other food web organisms such as algae (Selenastrum) and a variety of the water flea Ceriodaphnia, but recent data suggest that it is unlikely that concentrations of rice herbicides toxic to these two organisms persist until the water reaches the Delta (Chris Foe, Central Valley Regional Water Quality Control Board, pers. comm).

Direct Toxic Effects on Young Striped Bass

The staff of the National Marine Fisheries Service (NMFS) has conducted laboratory bioassays which demonstrate that several petroleum related compounds (such as benzene) cause mortality and have other adverse impacts on developing striped bass (Benville and Korn 1977; Benville et al. 1985). The necessary field studies have not been conducted to determine if ambient levels of the same pollutants cause problems to naturally developing populations.

There has been considerable interest in the effects on young striped bass of agricultural drain water, particularly that contaminated with selenium, an element common in agricultural drainage from the west side of the San Joaquin Valley, and rice field herbicides, common in drainage from the Sacramento Valley. Based on the ambient concentrations in the Bay-Delta (generally in the 0.1-0.4 ug/L range) and the suggested criterion of 2 ug/L for flowing and enclosed water bodies (Lemly 1985; SWRCB 1987), it appears that selenium in the estuary should not pose any problem to young bass either through the food chain or by direct toxicity.

An assessment of the affects of the rice field herbicides molinate and thiobencarb on young striped bass indicates there is little hazard from existing and expected concentrations of these compounds in the Sacramento River or the estuary downstream (Faggella and Finlayson 1987).

Competition and Predation

Trends in the abundance of several common fish species in the estuary were examined to determine if their trends might explain the young bass decline in terms of either competition or predation.

The abundance indices were calculated from fall midwater trawl surveys conducted by DFG from 1967-1985. No surveys were conducted in 1974 and 1979. Abundance indices for September and December 1976 and November 1969 were estimated because no surveys were conducted in those months. This was done by interpolation using abundance indices from adjacent months.

Monthly abundance was the sum of the products of the mean catch per tow in each of 17 subareas of the estuary and the estimated water volume (acre-feet) of each subarea. The fall abundance index was calculated by summing the September through December indices.

The species examined for trends were northern anchovy, yellowfin goby, American shad, longfin smelt, delta smelt, threadfin shad, inland silverside, and white catfish (Figure 27). These fall indices are comprised of multiple age groups but young-of-the-year fish predominate. Of these species, only the abundance of yellowfin goby and inland silversides has increased since bass abundance declined. Other species either have not increased (American shad) or have declined (white catfish, delta smelt). Delta smelt abundance has been at record lows since 1983.

Inland silversides were first discovered in the estuary in 1975 and have since become established (Meinz and Mecum 1977). Fall silverside abundance is apparently very low, which may be due in part to their distribution along the shore rather than in midchannel depths sampled by the midwater trawl. Although our estimates of silverside abundance are likely biased low, they do demonstrate the presence of this species since 1980.

The mean fall abundance of yellowfin goby (which was introduced accidentally about 1960) has increased from an index of eight for years 1967-1976 to 144 for the years 1977-1985. Although goby abundance has increased and their distribution overlaps that of striped bass, we believe that they are not

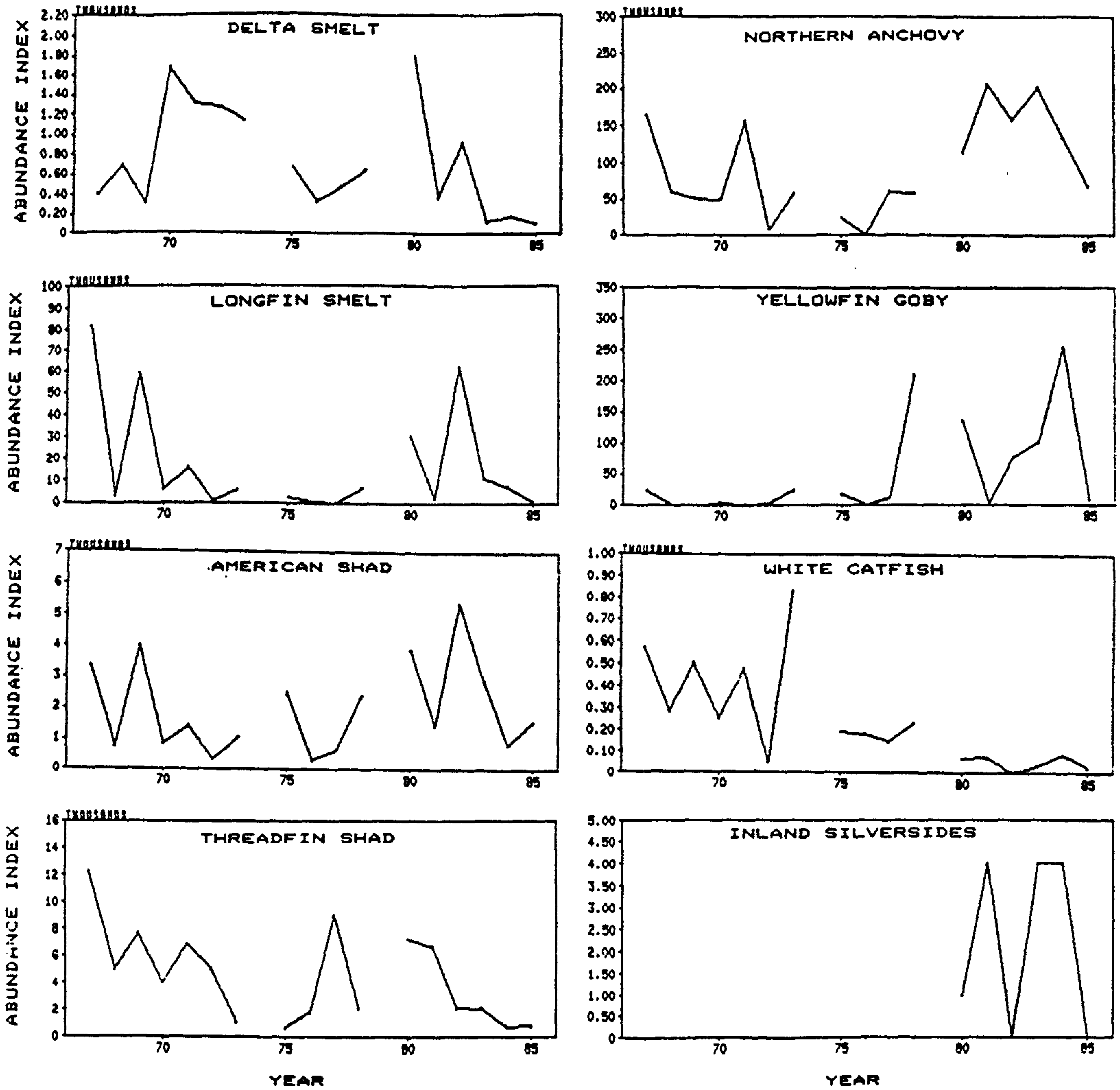


Figure 27. Trends in midwater trawl abundance indices of potential competitors or predators of young striped bass. There has not been a consistent increase in the abundance of any of these species that could account for the decline of striped bass. There were no trawl surveys in 1974 and 1979.

significantly affecting bass abundance. If young bass abundance decreased due to competition with gobies during the 1977-85 period, then we would expect a resurgence in bass abundance in years of low goby abundance such as 1981. The young bass 38 mm index was lower than expected in 1981 as in all other years from 1977 to 1985. Goby abundance also appears to be too low to severely impact bass abundance. The average fall goby abundance index since 1977 (114) is only 2.4% of the average fall bass abundance index since 1977 (4,824).

There has not been a consistent increase in the abundance of any of these species that could account for the decline of young striped bass.

Changes in Food Production for Larval and Juvenile Bass

The development of larval striped bass during the period from the egg to a length of 5-6 mm is dependent upon their endogenous food supply of yolk and oil globule. The yolk is consumed first. In laboratory studies, it is totally absorbed by the time of first feeding which usually occurs at 5 days post hatch (Eldridge et al. 1981). At that time, ideally, food should be plentiful enough to allow for optimal growth because if bass grow slowly they are subject to mortality factors for a longer period at each size interval, and mortality is typically very high on small larvae.

During early life, striped bass feed primarily on crustacean zooplankton, mainly copepods and cladocerans (Table 22). The smallest larvae feed almost entirely on copepods and cladocerans.

C-045564

Table 22. Estimated mean dry weight (ug) of predominant zooplankton food organisms per bass stomach containing food in 1986.

Food Items	Striped Bass Length (mm) 5	6	7	8	9	10	11	12	13	14
Copepoda										
Eurytemora	0.70	.71	4.03	5.56	8.61	12.94	11.86	8.00	8.33	4.00
Adult Calanoida[1/]	0.05	0.20	0.30	0.46	0.87	0.31	0.64	1.60	2.10	2.70
Sinocalanus	--	0.26	0.49	0.73	1.46	1.45	2.83	3.40	3.00	18.45
Adult Cyclopida	0.81	1.60	1.96	1.82	2.25	1.17	0.80	0.89	1.87	0.40
Cyclopoid Copepodids	0.37	0.51	0.53	0.47	0.65	0.28	0.07	0.11	0.42	--
Calanoid Copepodids	0.08	0.23	0.31	0.26	0.27	0.15	0.30	--	0.20	0.15
Harpacticoid	--	--	0.01	0.02	0.02	0.03	0.10	0.04	--	--
Copepod nauplii	0.01	<.01	<.01	<0.01	<0.01	--	--	--	--	--
Diaptomus	--	0.08	0.15	0.49	0.77	0.56	--	0.67	1.00	1.00
Acartia	--	--	--	--	--	--	--	--	--	--
Other Copepods	0.19	0.34	0.38	0.56	0.60	0.76	1.29	1.07	1.80	3.00
Cladocera										
Bosmina	0.95	0.56	0.33	0.35	0.29	0.13	0.11	0.40	0.13	--
Daphnia	0.77	0.56	0.88	1.16	0.93	0.34	0.91	0.71	2.13	0.80
Diaphanosoma	0.09	0.27	0.71	1.62	1.70	1.31	0.55	3.30	2.02	--
Other Cladocerans	0.17	0.18	0.25	0.47	0.56	0.34	0.26	0.36	1.27	0.60
Other Zooplankton	0.26	0.17	0.08	0.06	0.09	0.28	0.34	0.18	0.27	0.40
Malacostraca										
Neomysis	--	--	0.07	0.53	1.36	3.40	6.17	15.00	16.20	17.55
Corophium	--	--	--	--	--	--	--	--	--	--
Amphipoda	--	--	--	--	--	--	--	--	--	--
Rotifera										
All Rotifers	0.04	0.07	0.03	0.05	0.05	--	--	--	--	--
Total	4.49	6.77	10.54	14.60	20.49	23.50	26.18	35.68	40.73	49.05
Number Stomachs	2647	3548	1354	572	333	181	88	57	36	22
Number with Food	187	1062	754	408	259	143	70	45	30	20
Percent with Food	7.0	29.9	55.7	71.8	77.8	79.0	79.5	78.9	83.3	90.9

1/ The category adult calanoid copepods are comprised of Eurytemora, Sinocalanus, Acartia, and Diaptomus which could not be identified to genus.

C-045565

As they grow, young bass selectively feed on larger and larger organisms. Hence, the proportion of larger copepods and cladocerans and larger crustaceans such as Neomysis increases in the stomachs.

Analyses of food selectivity based on Ivlev's (1961) index revealed that initially feeding larvae distinctly preferred the calanoid copepod Eurytemora and cyclopoid copepods (Table 23). The cladoceran Bosmina was highly selected for in Suisun Bay and the lower Sacramento River where they were scarce, but they were not selected for in the San Joaquin River where they were abundant. The recently introduced copepod Sincocalanus, harpacticoid copepods, and copepodid life stages tended to be avoided.

Does food availability account for the lower abundance and survival of young striped bass since 1977? Does it account for the good year class produced in 1986? Currently, the answers to these questions are not clear. The pertinent zooplankton data became available only a few weeks before this report was due and so far only a cursory analysis has been possible.

We examined the density (numbers per m^3) of the major zooplankters during the period April to June in the portions of the estuary used by larval striped bass during early feeding to determine if there had been a decline in their food.

Our examination so far has revealed that the overall plankton abundance declined from 1980 through 1983 but has since recovered (Figure 28). Recent average densities were lower for cladocerans

Table 23. Comparison of Ivlev's (1961) Index of Electivity for 6 mm larval striped bass in various areas of the Sacramento-San Joaquin Estuary in 1984, 1985, and 1986. The index $E = \frac{r - p}{r + p}$ where r = the proportion of the number of a prey organism relative to the total stomach contents of the fish and p = the proportion of the same prey relative to total number of food organisms in the environment. If E = +1, it indicates that a prey is highly preferred, whereas if E = -1, it indicates that the prey item is avoided.

Food Item	Suisun Bay			Grizzly/ Honker			Sacramento River			San Joaquin River			Mean
	84	85	86	84	85	86	84	85	86	84	85	86	
Sinocalanus	-.36	-.39		.23		-.51	-.67	-.83	-.61	-.77	-.85	-.79	-.55
Eurytemora	.19	.23	.27	.51	.57	.37	.83	.62	.08	.77	.79	.84	.51
Cyclopidae							.55	.73	.85	.42	.73	.72	.67
Daphnia							.12		-.20	.03	.09	.10	.03
Harpacticoid	-.28	-.27	-.46	.33	.02	-.56	-.61	-.55			-.07		-.35
Calanoid Copepodids	-.79	-.69	-.57	-.76		-.50	-.83	-.42	-.57			-.41	-.62
Cyclopoid Copepodids	.68	.02	-.24			-.34	-.69	-.32	-.23	-.24	-.03	.07	-.13
Bosmina		.70	.80			.47	.72	.49	.58	.10	-.03	-.10	.41

C-045567

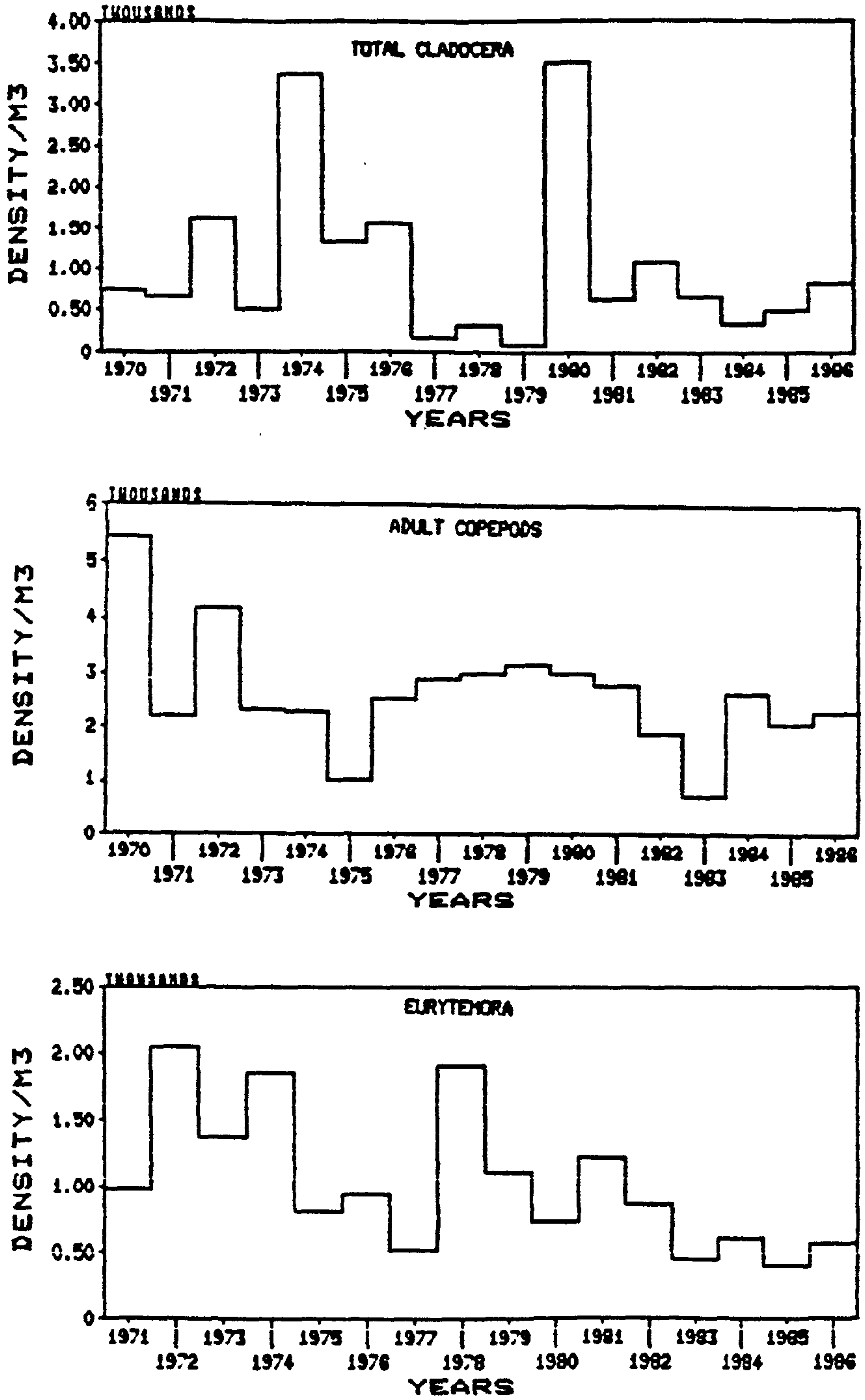


Figure 28. Trends in abundance of the zooplankton utilized by larval striped bass as food. The area-wide decline in the highly preferred copepod Eurytemora does not exactly match the decline of young bass, but its recent abundance generally has been low and may be contributing to the young bass decline.

and Eurytemora, but many recent years were similar to some earlier years. The decline in Eurytemora did not cause an overall decline in copepod adults because the accidentally introduced species Sinocalanus has increased substantially in abundance since it was first discovered in 1979.

Although the areawide decline in the highly preferred Eurytemora does not exactly match that of young bass, its recent abundance generally has been low and may be contributing to the young bass decline. The concurrent increase in Sinocalanus, an organism which is avoided by young bass, may not compensate for the reduced availability of Eurytemora.

Additional evidence of the potential importance of Eurytemora comes from a closer look at the availability of food to larval bass. We calculated average densities of food organisms where larval bass were most concentrated during 1984, 1985, and 1986, years in which zooplankton was sampled concurrently with eggs and larvae. The calculations were for each larva size group from 5 to 10 mm. In general, as larvae increased in size and number downstream, zooplankton availability was higher. For example, in 1984 the average zooplankton population density was about 19,600 $\mu g/m^3$ in those locations where the majority of the 6 mm larvae occurred (Table 24). The average zooplankton population density increased to about 28,900 $\mu g/m^3$ for 10 mm larvae. The average population densities of zooplankton in areas where most larvae bass were found were clearly greatest in 1986 and lowest in 1985. Differences in total zooplankton between 1986 and 1984 were

Table 24. Density of striped bass larvae, total zooplankton, and *Eurytemora* at the minimum number of sampling stations which, when summed, included half of the larval bass populations during 1984, 1985, and 1986.

	Size	Larval Bass/m^3	Total Zooplankton (ug/m^3)	Eurytemora (ug/m^3)
1984	6	1.40	19,640	1,650
	7	.27	21,478	3,510
	8	.14	23,947	4,520
	9	.11	27,392	5,870
	10	.06	28,857	5,980
1985	6	3.87	15,182	870
	7	.38	17,992	1,200
	8	.12	20,054	1,290
	9	.07	21,479	4,340
	10	.04	13,451	6,420
1986	6	2.73	21,369	1,420
	7	.80	30,641	4,440
	8	.39	38,201	8,060
	9	.17	35,729	9,540
	10	.12	30,216	9,140

relatively small, however. The average population densities in 1985 were about half as great as in the other two years. The lower availability of total zooplankton in 1985 may help account for lower larva survival that year, but the differences in total zooplankton between 1984 and 1986 do not seem great enough to account for the much larger year class of bass in 1986.

When Eurytemora alone is considered, the annual differences are more consistent with trends in young bass. Their lowest availability was in 1985, particularly for the larvae from 6 to 8 mm. Larva mortality was exceptionally high within this size range in 1985.

In 1986 Eurytemora availability was similar to that in 1984 for 6 and 7 mm larvae, but it became substantially greater as the larvae grew larger. These larger larvae experienced lower mortality which led to the good 1986 year class.

Are larval bass food needs really so specific that a single food organism, such as Eurytemora, has such a substantial impact on their survival? The answer is not yet clear.

Nonetheless, the close association between Eurytemora abundance and larval bass survival from 1984 to 1986 indicates a need for a closer look at the importance of Eurytemora. Since this copepod is highly selected and a dominant component of the larval bass diet in this and other estuaries, its decline and the reason for its decline will be investigated further.

THE CONSEQUENCES OF REDUCED EGG, LARVA, AND JUVENILE POPULATIONS

The striped bass egg and larva surveys have provided evidence that the distribution of young fish is greatly influenced by Delta flows and that when flows are high more young fish survive.

The entrainment studies also have provided evidence that large numbers of eggs, larvae, and juvenile bass are diverted from the Delta and thereby lost to the Bay-Delta bass population. What are the consequence of such losses? Some have suggested that there is a great surplus of eggs and larvae -- even of 38 mm bass -- and that such losses may not directly reduce future adult bass stocks. There is good evidence that this is not so; major reductions of bass of any size, even of eggs, are likely to influence adult stocks.

The fact that the numbers of fish in consecutive life stages are well correlated is evidence that what happens at each life stage affects the next. Figure 29 illustrates:

(a) the relationship between the CPE striped bass egg abundance index and 9 mm larvae,

(b) The relationship between 9 mm larvae and the mid-summer index of 38 mm bass, and

(c) the relationship between the 38 mm bass index and the population of 4 year old fish, 4 years later.

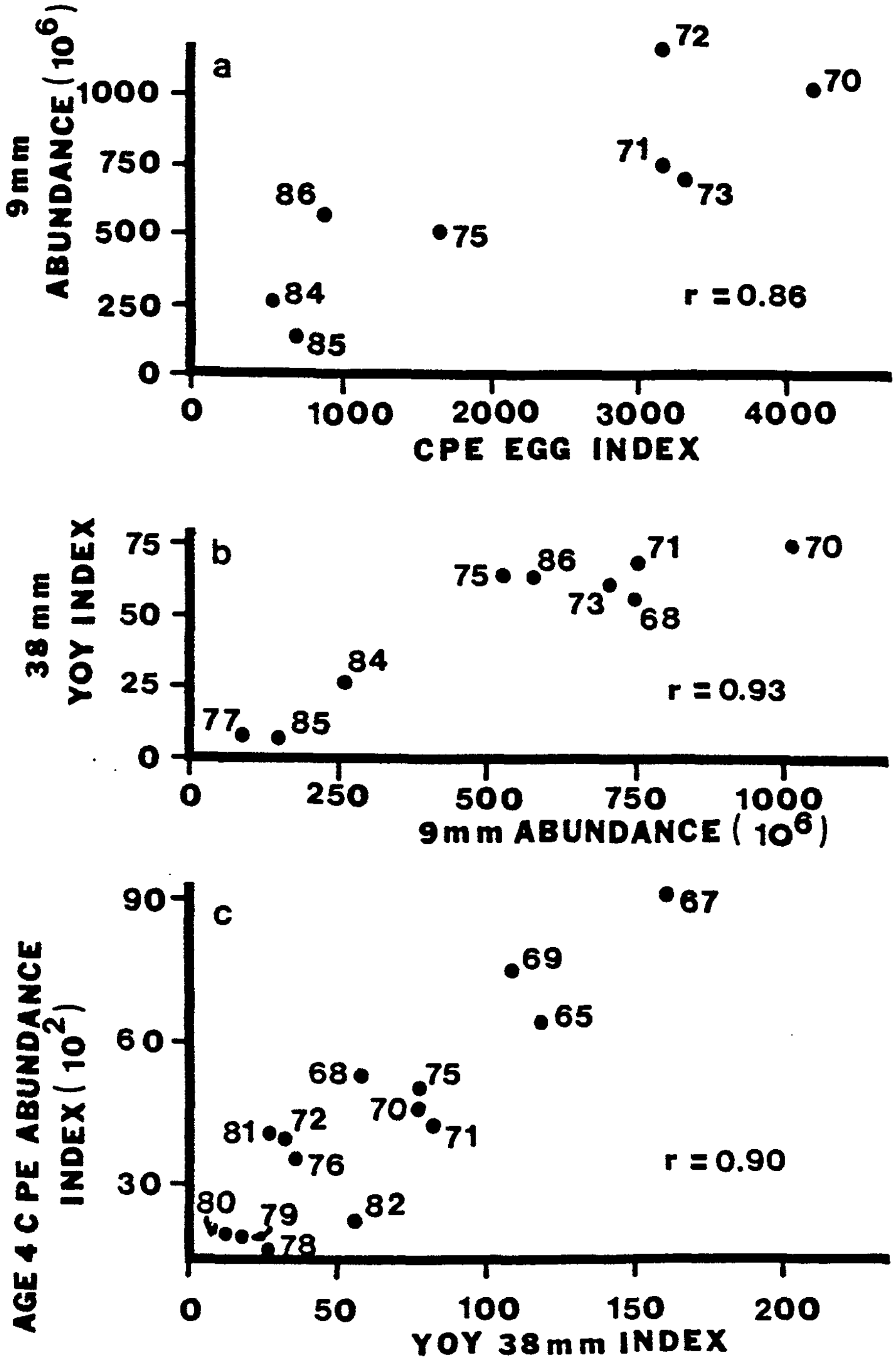


Figure 29. Correlations between: a) a measure of egg production by the striped bass spawning stock and the abundance of 9 mm larvae, b) abundance of 9 mm larvae and the 38 mm abundance index, and c) the 38 mm index and the abundance of that year class as indexed by the catch per unit of effort in gill and trap nets 4 years later. These correlations suggest: 1) major reductions of eggs would reduce abundance of larvae, 2) whatever happens to the larvae is directly reflected in the production of 38 mm bass in mid-summer, and 3) a change in the population of juvenile bass will directly affect the abundance of the adult population. Variability in the upper right hand portion of b) is evidence that abundance of 38 mm bass also is affected by environmental conditions during the 2 month span between the larval and 38 mm stages.

Dr. Louis W. Botsford, a Professor at the University of California, Davis, developed a mathematical life cycle model (Appendix 4) which we used to illustrate how modification of larva and juvenile populations can, and probably have, influenced adult stocks.

The model describes an adult bass population with adult mortality rates calculated from DFG's tag return data (Table 1). Survival rates from 38 mm to adulthood are based on the actual 38 mm indices of young bass and the abundance of the same year classes at age 4.

The Effects of Reduced Egg Production

We first used the model to illustrate how a reduced egg supply caused by a lower number of adults can, over a long period of time, reduce the 38 mm indices. Egg production, calculated by multiplying fecundity at each age (Table 6) by population size at each age, has declined. Depending upon which estimate of adult stock is used, average production from 1982-86 was only 17% or 29% of that from 1969-73, before the bass decline started. Note that this decline in computed egg production is a result of, and not the cause of, the adult bass decline. But once the adult decline started, the lower number of eggs would reduce the chance that large numbers of larvae would be washed into favorable habitat and thus fewer adults would subsequently be produced.

To project the impact of this declining egg supply on production of young bass and future numbers of recruits and total

C-045574

adults, an egg production threshold hypothesis was formulated and used to generate young bass in the model. The hypothesis is that, in years when egg production is above the threshold, young bass production depends solely upon the environment as depicted by the relationship between the 38 mm indices and outflow and diversion rates from 1959-1976 (Figures 10 and 11). In years when egg production is below the threshold, young bass abundance depends both on the environment and egg production.

This threshold function is reasonable because, until 1976, young bass abundance appeared to be completely determined by flows and diversions and not influenced by egg production. This relationship has not held since. With the model we can examine the hypothesis that this change was the result of reduced egg production. The original relationship was developed during years of high egg production. It is possible that during those years of higher adult stocks, there were more than enough eggs to "fill" an environmentally determined carrying capacity, and all excess eggs were surplus. Thus, the 38 mm index would appear to depend solely on the environment during the earlier period when egg production was high, but would exhibit a dependence on egg production when egg production declined.

Including the egg production threshold in the model brings projections of young bass abundance closer to the observed abundance than projections based on the outflow and diversion relationship (Figure 30). It illustrates how reduced egg production could contribute to keeping the young-of-the-year index low, but does not fully explain the decline from 1977 to 1985.

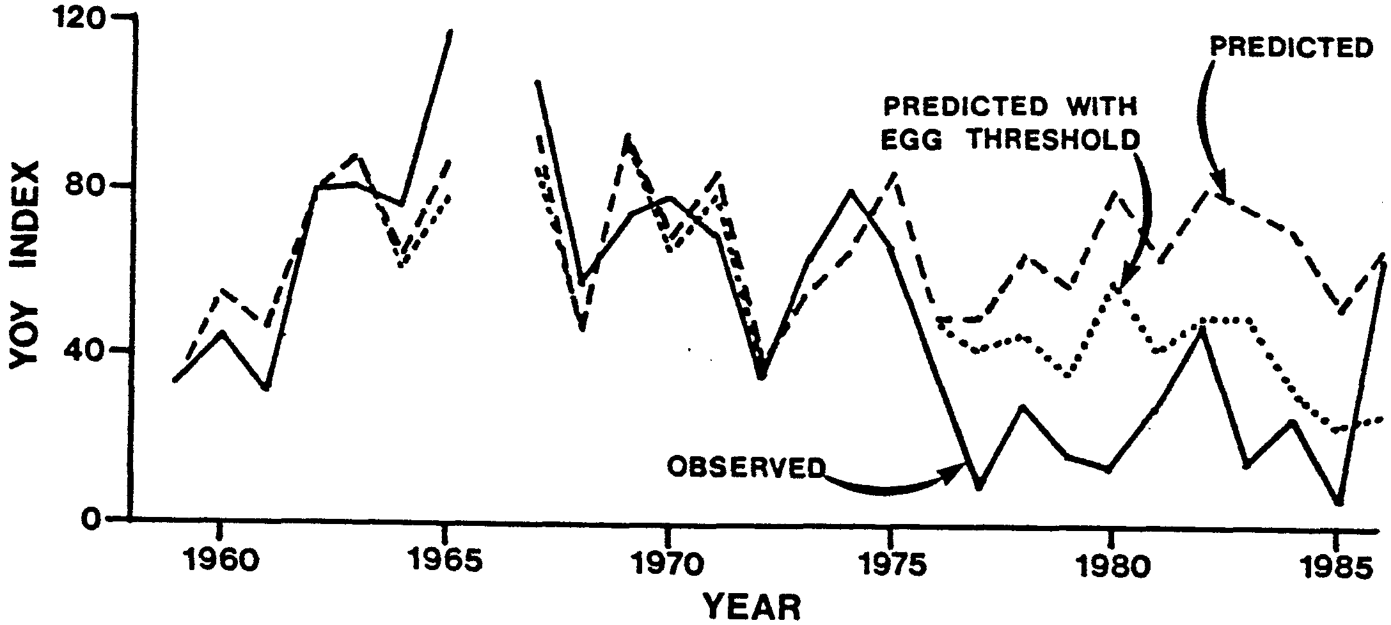


Figure 30. Botsford's mathematical model prediction of the 38 mm young striped bass index based on (1) the 1959-1976 relationship between this index and outflow and diversion rates (top line) and (2) the relationship in (1) and an egg production threshold. Including the egg production threshold substantially improves predictions, but does not fully explain the decline from 1977 to 1985.

Note that the 1986 young bass abundance index appears to be inconsistent with the egg limitation hypothesis. We are not sure of the significance of this abberation. Considering that reduced egg production only partly explains the decline of young bass and that larval mortality has increased, environmental factors also are implicated in the decline. In 1986, by chance, there simply may have been an unusual link between undefined, but exceptionally good, environmental conditions and the occurrence of spawning.

Professor Botsford also used this striped bass population model to illustrate the likely effect of entrainment losses at the CVP and SWP diversions on the adult striped bass population and fishery in ensuing years. We had good estimates of larval bass entrainment for only two years, 1985 and 1986 (Table 18). Based on these estimates we made rough estimates of the annual impact of larva entrainment by assuming that the annual percentage reduction of the young bass population varied linearly with the percentage of inflow diverted.

These annual estimates of percentage reduction were then used in conjunction with the young bass index to calculate what young bass abundance would have been in the absence of larva entrainment. These calculations illustrate that young bass abundance could have been substantially reduced by larva entrainment from the late 1950s to the present (Figure 31). In this illustration, the simulated 38 mm population declined along with the actual index of abundance in the late 1970s and 1980s, reinforcing that current entrainment losses do not account for the

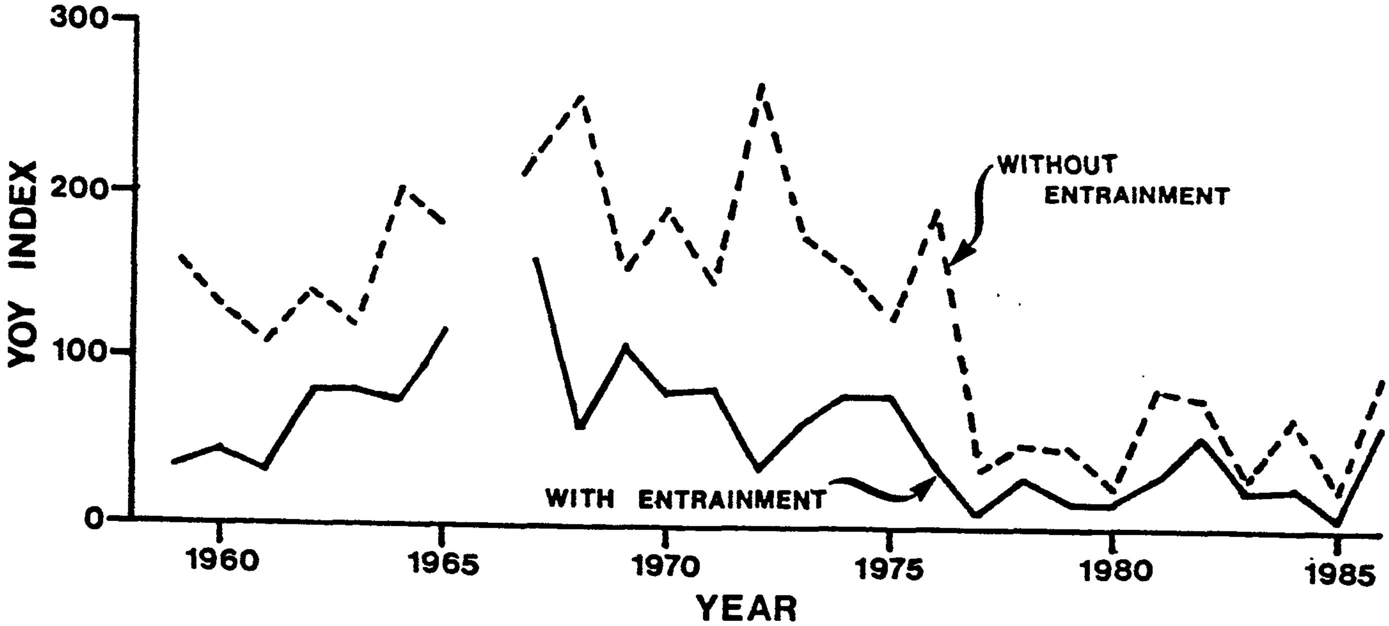


Figure 31. Estimate of the young striped bass index in the absence of larval bass entrainment compared with actual young striped bass index (with entrainment). This comparison suggests that young bass abundance could have been substantially reduced by larva entrainment from the late 1950s to the present.

decline in the index. Note, however, that the simulated indices do not include effects of reduced spawning stocks caused by past larva entrainment.

Professor Botsford then calculated the direct impacts of larva entrainment on total catch by anglers using angler harvest rates based on tag return data in his model. The model depicted a major reduction in the striped bass fishery due to the estimated reductions in larval bass abundance (Figure 32). Because of entrainment by the CVP, the striped bass catch in the late 1960s was estimated to have been reduced to about half of what it would have been. In the mid-1970s, the striped bass catch was projected to be about one-third of what it would have been had larva entrainment not occurred. This was due to higher diversion rates by the CVP and the start of the SWP in the late 1960s and early 1970s.

Professor Botsford also used this striped bass population model to evaluate the effect of entrainment losses of larger young bass that are incurred during the screening and salvage operations at the CVP and SWP diversions (Tables 19 and 20).

He assumed that these entrained fish would have survived and grown as did fish that were not entrained. This assumption is supported by the excellent correlations between the abundance of bass eggs, larvae, and juveniles in the same year and with 4-year-olds, four years later.

To compute the "without entrainment" case, Dr. Botsford added our estimates of losses of bass occurring in the CVP and SWP

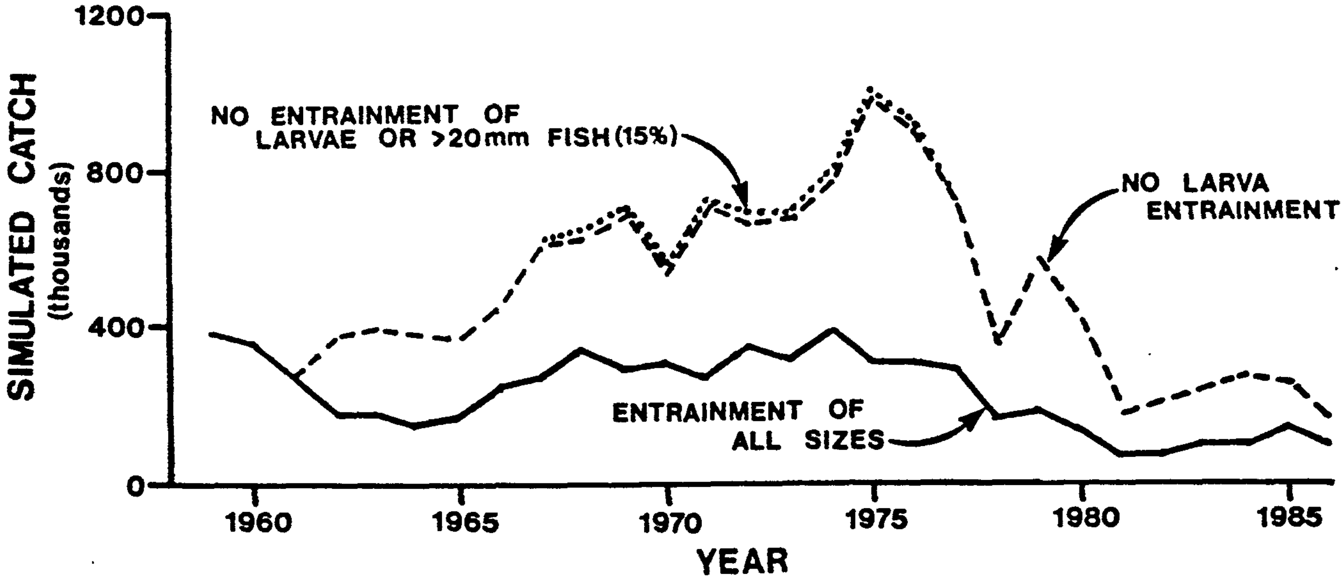


Figure 32. Botsford's model projection of striped bass catch by anglers with and without entrainment losses of young bass (which subsequently reduce the adult stock) at the CVP and SWP diversions. Top line assumes a 15% predation loss of fish larger than 20 mm.

screening and water transport system back into the population at age 1 after reducing them to account for mortality that would have occurred in the interim (between entrainment and age 1).

In the model, survival rates from the young-of-the-year to the 4-year-old stage were based on comparisons of bass abundance at three stages: 1) mid-summer during the first year of life as measured by DFG's 38 mm index, 2) the following March 1 as estimated from DFG's trawl survey, and 3) on May 1 at age 4 from DFG's Petersen population estimates. Dr. Botsford converted the ratios of abundance at the first two stages to an annual rate and used the average over 7 years as the survival rate through the first year (townet survey index was arbitrarily defined as millions). The ratio of abundance at the second and third stages was also converted to an annual rate, and the average was used as the survival rate from age 1 through age 4.

The effect of the entrainment of these larger young bass depends on the predation rate assumed to occur at the SWP. Assuming a 15% predation loss results in only a very slight additional decrease in catch (Figure 32). If the 82% predation loss is assumed, the catch is reduced by an extra 14% by 1976 and by 26% by 1983 (Figure 33).

A second impact of interest is the impact of entrainment on future generations through reduced reproduction because of the fish lost from entrainment. The impact on projected annual egg production is similar to that on catch. Were it not for entrainment, egg production would have been about twice as high in

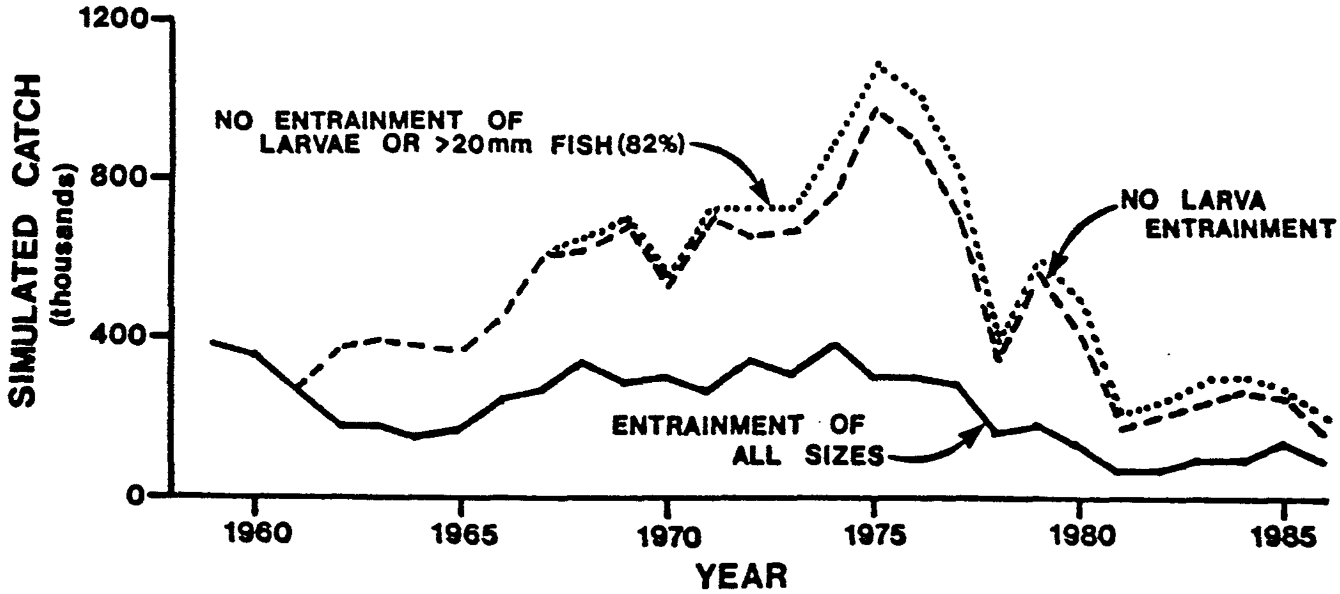


Figure 33. Botsford's model projection of striped bass catch by anglers with and without entrainment losses of young bass (which subsequently reduce the adult stock) at the CVP and SWP diversions. Top line assumes an 82% predation loss of fish larger than 20 mm at the SWP, and a 15% predation loss of such fish at the CVP.

the late 1960s and 1970s, and about three times as high in the 1980s, depending on the predation rate assumption (Figures 34 and 35).

Hence, the modeling illustrates that entrainment of young bass by the water projects could have had a substantial detrimental effect on the striped bass population. This, combined with the evidence that numbers of young fish are directly related to subsequent adult stocks, leads us to believe that entrainment is a very serious problem.

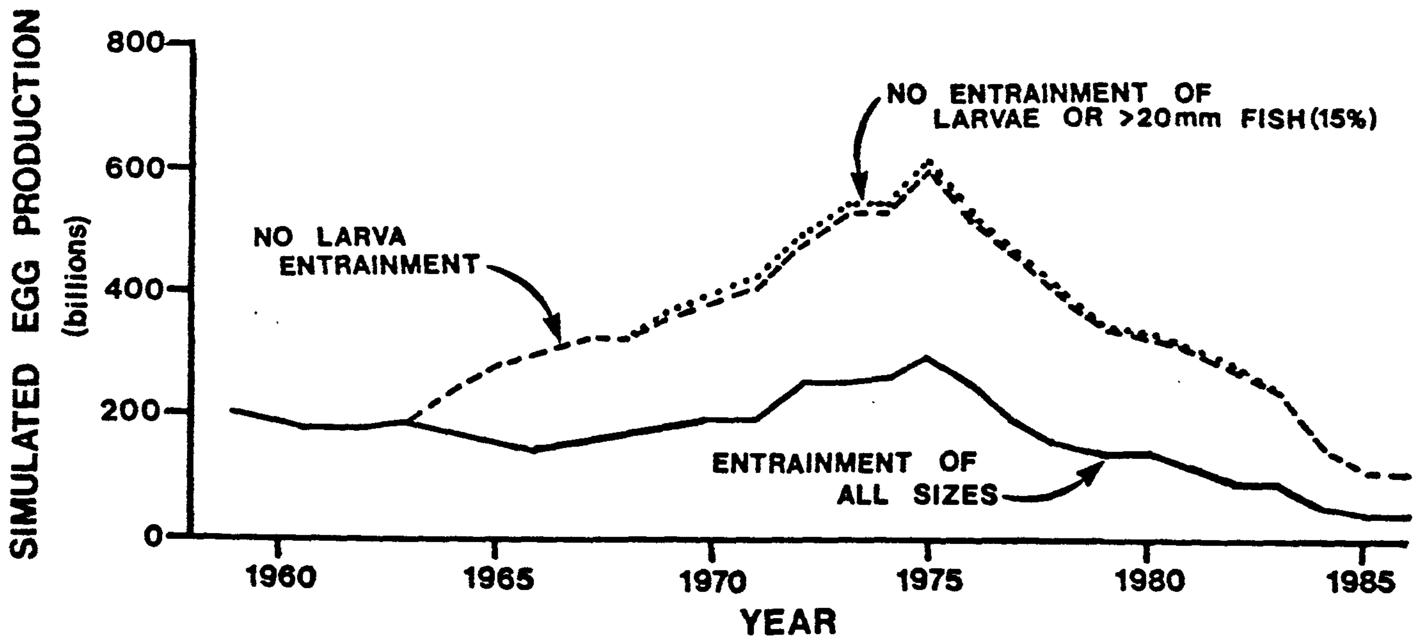


Figure 34. Botsford's model projection of egg production by the striped bass stock with and without entrainment losses of young bass (which subsequently reduce the adult stock) at the CVP and SWP diversions. Top line assumes a 15% predation loss of fish larger than 20 mm.

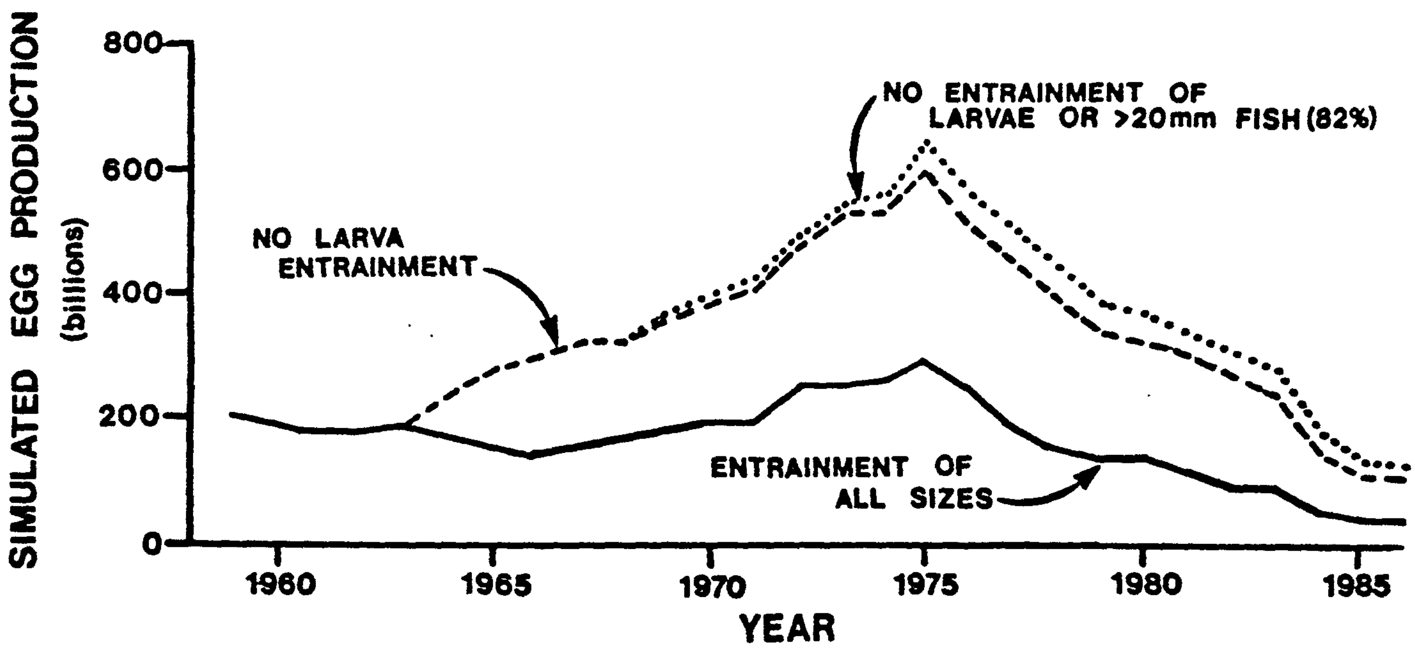


Figure 35. Botsford's model projection of egg production by the striped bass stock with and without entrainment losses of young bass (which subsequently reduce the adult stock) at the CVP and SWP diversions. Top line assumes an 82% predation loss of fish larger than 20 mm at the SWP, and a 15% predation loss of such fish at the CVP.

SUMMARY OF FACTORS INFLUENCING THE STRIPED BASS POPULATION

The size and age structure of the adult striped bass population is a function of the number of eggs previously produced, the rate at which those eggs survive through the larval and juvenile stages to become adults 4 years later, and survival rate of adults as they grow larger and older. The number of eggs produced is, in turn, a function of the size, age structure, and likely the health of the adult population. We have watched adult stocks and survival rates of the young , which have such a large effect, decline severely in the last several decades.

Adult Stock Size and Age Composition

The present small adult stock of about 800,000 bass with fewer large and more productive females cannot, under present environmental conditions that cause high mortality rates of larvae and young bass, produce striped bass year classes as large as those which existed before 1976 (Table 25).

As adult stocks fell, restoration of the population required reductions in young bass mortality rates which did not occur.

These mortality rates appear to be independent of the size of the adult, egg, larva, or juvenile bass populations. They are controlled by environmental conditions in the Delta.

Thus, the population remains low, with egg production at 17-29% of 1969-73 levels and with little ability to grow because

Table 25. Measures of striped bass production.

Year	CPE Egg Production Index	Percent of 8 mm Larvae in Delta	6-14 mm Larvae Decline Rate Delta	6-14 mm Larvae Decline Rate Suisun Bay	38 mm Index	CPE Year Class Recruitment Index at Age 4
1959					33.7	
1960					45.6	
1961					31.6	
1962					78.9	
1963					81.7	
1964					75.4	
1965					117.2	6448
1966						5277
1967					108.7	9155
1968		95.8	-.540	-.386	57.3	5434
1969	6212				73.8	7583
1970	4195	80.6	-.611	-.405	78.5	4763
1971	3166	29.5	-.773	-.748	69.6	4333
1972	3157	90.6	-.601	-.531	34.5	3989
1973	3324		-.443 1/	-.393 1/	62.7	
1974	2383				80.8	
1975	1671	25.5	-.847	-.759	65.5	4913
1976	1632				35.9	3671
1977		97.7	-1.220 2/	-1.007 2/	9.0	
1978					29.6	1722
1979	1276				16.9	2392
1980	534				14.0	2041
1981					29.1	4398
1982	599				48.7	2307
1983	636				15.4	
1984	525	42.4	-.716	-.607	26.3	
1985	699	87.4	-1.048	-.577	6.3	
1986	879	44.5	-.771	-.575	64.9	

1/ Decline rates based on 9-14 mm bass abundance in 1973.

2/ Decline rates based on 6-9 mm bass abundance in 1977.

C-045587

of high mortality rates on eggs, larvae, and juvenile bass controlled by environmental conditions.

The evidence is that increasing the adult stock and egg production would increase the subsequent populations but that the increase would probably not be sustained without changes in environmental conditions to increase survival rates of egg, larvae, and/or juvenile bass.

Reducing adult mortality rates by further restricting harvest or by other means would help, but would be most effective in combination with improvement of the environment to reduce losses of the eggs, larvae, and juveniles.

Effect of Toxic Substances

Tissues of some adult striped bass collected from this estuary have contained measurable levels of toxic substances including heavy metals, volatile petrochemicals, and pesticides. Levels are highly variable and no increasing or decreasing trends are apparent. A relatively high percent of the adults have higher rates of tapeworm infestation and egg resorption than have been found in other estuaries and these may be related to toxic substances. We cannot quantify this effect on mortality rates of adults or on their reproduction.

We have not included in this report a discussion of the deaths of thousands of adult striped bass which have occurred in Suisun and San Pablo bays every spring for well over 30 years (Kohlhorst 1973, 1975). The cause of the deaths has never been identified, although recent information indicates deaths may be caused by liver disfunction. Considering its long history and lack of information on cause, we decided that it is not an important item for these hearings.

Limited studies have indicated that zooplankton, which is the food supply for juvenile bass, has not been seriously damaged by pollution. We also are not aware of evidence that spawned eggs, larvae, or juvenile bass have been damaged by toxic substances. Nevertheless, discharges of trace elements and hydrocarbons are high enough to warrant concern.

Mortality of Bass Eggs

Except for losses to diversions, there is no evidence or reason to believe that egg mortality is abnormally high except that, in some years, spring water temperatures in the Sacramento River are higher than desirable when eggs are drifting downstream. In the 2 of the 9 recent years when egg data is available, from 4 to 9% of the eggs or very young larvae were exposed to water temperatures known to reduce survival. The effect of the exposure is unknown.

Mortality of Larvae

Mortality rates of larvae have increased in recent years. Comparison of three pairs of years with similar spring Delta flow patterns that should have distributed the larvae in similar ways resulted in our estimating that survival of larvae from 6 to 14 mm in the post-1976 years was only 22% of that in comparable pre-1976 years. Present data analysis does not allow good comparisons of survival rates in different portions of the estuary, but we suspect that mortality of larvae not flushed into the Suisun/Grizzly/Honker bay area is higher. Certainly, when most larvae remain in the Delta, overall survival is substantially less than when most larvae are in Suisun Bay.

Reasons for the recent lower survival are still unknown. Speculation centers on three possibilities:

1) The reduced spawning stock and consequent lower egg production may be important. This is contrary to the general expectation that reduced production of eggs and larvae should either not affect, or should increase, survival. A mechanism for lower larva abundance causing a decrease in their survival exists if high average survival requires at least a small fraction of the population to find areas of exceptionally high food abundance or other beneficial conditions. A small population of larvae might decrease the probability of this link with their food and thus decrease average survival.

Average entrainment mortality may be reduced when there is more spawning to spread out larvae over space and time. The additional eggs and larvae may differ in vulnerability to entrainment because this is controlled by the geographical distribution of the fish and variable water diversion schedules, river flows, and tides.

C-045590

In 1986, perhaps by chance, spawning and environment meshed well despite a low probability of success similar to other recent years.

2) As summarized below, lower food availability may have caused lower larval bass survival.

3) Toxic substances may have increased mortality rates. See the summary on page 118.

Food Supply

Current data analysis provides little evidence of a general decline in total zooplankton. There may, however, be a mismatch of abundant zooplankton at the right time and place for the larval bass, and there has been a general decline in the most important zooplankter, Eurytemora. The high 1986 production of 38 mm bass, in spite of low egg production may have been the result of a major portion of the larvae being washed into Suisun, Grizzly, and Honker bays when the population of Eurytemora was high there.

Entrainment Losses to Diversions

Very large numbers of unscreenable eggs and larvae are lost in water diversions which in many years take more than 50% of the Delta inflow (Tables 26, 27 and 28).

Before modification of their operations, Pacific Gas & Electric Company power plants at Antioch and Pittsburg caused the estimated loss of 154 million larvae in 1978 and 62 million in

Table 26. Average May hydrologic conditions in the Sacramento-San Joaquin Estuary.

Year	Sacramento River flow at I Street	Cross Channel and Georgiana Slough	San Joaquin River at Jersey Point	CVP-SWP Exports	Effective Percent Diverted[1]	Delta Outflow
1959	11,412	5,434	2,154	2,661	37	7,303
1960	16,077	6,801	3,777	2,688	25	12,407
1961	13,110	5,931	2,140	2,837	35	8,580
1962	19,748	7,876	6,952	2,963	13	18,173
1963	42,784	6,519	16,331	2,774	2	53,124
1964	13,945	6,176	2,726	3,261	32	9,784
1965	30,097	5,399	8,358	3,193	5	32,370
1966	14,205	6,252	2,597	3,381	32	9,835
1967	51,932	7,736	29,767	1,921	2	74,550
1968	13,316	5,992	164	5,611	51	6,737
1969	40,606	6,320	30,320	2,990	2	64,564
1970	14,265	6,270	3,561	4,012	27	10,761
1971	29,190	7,856	5,032	4,549	14	26,406
1972	12,848	5,855	-1,042	6,495	61	5,140
1973	16,416	6,378	2,413	6,501	34	11,699
1974	29,177	9,937	6,981	7,130	18	25,544
1975	30,265	10,958	10,055	5,583	12	28,796
1976	10,910	5,287	-745	5,488	63	4,066
1977	7,597	4,316	1,082	2,987	48	3,999
1978	25,194	7,570	24,040	3,058	3	40,874
1979	17,984	7,359	3,605	6,245	31	13,435
1980	15,894	3,583	9,281	4,630	6	20,912
1981	13,781	5,405	1,595	4,478	35	9,143
1982	42,358	6,463	22,517	5,994	3	57,876
1983	62,303	9,115	42,361	3,293	1	97,996
1984	15,406	5,483	2,068	5,929	32	11,204
1985	13,432	5,553	351	6,215	47	7,378
1986[2]	12,761	3,626	6,418	6,327		14,901

1/ 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 calculation.

2/ Preliminary Estimates.

C-045592

Table 27. Average June hydrologic conditions in the Sacramento-San Joaquin Estuary.

Year	Sacramento River flow at I Street	Cross Channel and Georgiana Slough	San Joaquin River at Jersey Point	CVP-SWP Exports	Effective Percent Diverted 1/	Delta Outflow
1959	8,016	4,439	-957	3,564	84	1,322
1960	10,866	5,274	-467	3,825	65	3,847
1961	10,935	5,294	-847	3,992	68	3,541
1962	13,011	5,902	4,465	3,799	29	10,317
1963	17,603	6,222	8,915	3,543	13	19,180
1964	11,104	5,344	509	3,795	53	5,302
1965	16,017	6,783	8,200	3,694	15	16,190
1966	9,583	4,898	-946	4,075	75	2,460
1967	43,023	6,871	24,846	2,162	3	61,265
1968	11,353	5,416	-986	4,708	68	3,666
1969	23,123	6,740	31,383	2,214	4	46,596
1970	11,787	5,543	1,202	4,997	49	6,214
1971	27,550	10,162	4,944	5,768	25	21,218
1972	13,837	6,144	-3,569	8,111 2/	79	2,891
1973	14,937	5,336	-1,115	7,355	54	7,211
1974	24,413	9,243	2,946	9,130	34	16,943
1975	23,710	9,037	9,111	4,520	14	22,508
1976	10,935	5,294	-426	4,152	64	3,915
1977	6,865	4,026	992	739	63	2,521
1978	12,660	5,799	3,519	7,621	36	9,086
1979	12,207	5,667	79	6,341	60	5,326
1980	17,813	6,305	4,643	5,961	25	14,870
1981	10,729	5,233	394	4,032	58	4,596
1982	26,076	6,167	9,813	3,935	8	28,515
1983	48,380	7,264	30,127	5,010	3	72,154
1984	14,990	6,482	804	6,165	49	8,038
1985	13,310	5,371	-1,483	6,530	61	5,215
1986 3/	11,850	5,562	3,967	6,363		9,043

1/ 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 calculation.

2/ Includes diversion of water into Andrus Island.

3/ Preliminary estimates.

C-045593

Table 28. Average July hydrologic conditions in the Sacramento-San Joaquin Estuary.

Year	Sacramento River flow at I Street	Cross Channel and Georgiana Slough	San Joaquin River at Jersey Point	CVP-SWP Exports	Effective Percent Diverted[1/]	Delta Outflow
1959	10,554	5,182	-1,296	4,005	76	2,561
1960	10,396	5,136	-1,525	4,095	79	2,244
1961	10,545	5,180	-2,183	4,656	84	1,672
1962	10,246	5,092	-851	4,229	73	2,795
1963	12,142	5,648	626	4,198	54	5,639
1964	11,622	5,495	-1,456	4,619	73	3,185
1965	12,139	5,647	880	4,361	53	5,865
1966	11,584	5,484	-1,426	4,597	73	3,155
1967	19,490	7,801	13,667	2,697	12	23,864
1968	12,594	5,780	-1,610	5,168	71	3,684
1969	14,216	6,355	6,673	3,252	22	13,143
1970	13,174	5,950	-461	5,227	61	5,256
1971	20,981	8,237	419	6,509	46	11,654
1972	15,000	6,485	-783	5,001	59	6,211
1973	15,168	5,087	-3,973	7,693	70	4,599
1974	21,752	7,946	-3,099	10,691	58	9,365
1975	18,284	7,447	1,768	5,184	41	11,129
1976	12,077	5,629	-583	4,109	64	4,343
1977	8,248	4,433	919	845	61	3,212
1978	14,300	6,280	-2,540	8,088	73	3,974
1979	16,413	6,899	-2,919	9,339	68	5,384
1980	17,726	7,284	2,049	6,869	39	11,191
1981	15,294	6,571	-1,920	7,046	66	5,296
1982	17,632	7,256	7,888	4,032	20	16,849
1983	30,990	6,594	20,937	5,207	6	43,881
1984	21,632	8,428	1,450	9,457	54	10,252
1985	16,035	6,788	-2,791	9,465	70	4,934
1986[2/]	16,881	7,036	-1,081	8,619		7,337

1/ 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 calculation.

2/ Preliminary estimates.

C-045594

1979. Pursuant to provisions in the National Pollutant Discharge Elimination System permits, PGE started measures to reduce losses in 1983 and when those meaures were fully implemented in 1986, losses were reduced about 75% from average 1976, 1978-79 levels. Loss reductions will vary from year to year depending on conditions in the estuary.

Agricultural diversions were estimated to have taken 598 million larvae in 1978 and 562 million in 1979.

The SWP/CVP diversions were estimated to have removed 441 million larvae in 1985, a dry year when most larvae were left in the Delta, and 51 million in 1986, a year when higher flows in the lower San Joaquin washed many of the eggs and larvae out of the interior Delta. While entrainment is only one cause of larva mortality, its accumulative effect can be great. We calculated that without entrainment losses at the CVP/SWP diversions in 1985, the population of 20 mm larvae would have been about four times as large as it was.

Estimates of losses of young bass, after they have grown larger than 20 mm, to the CVP/SWP diversions range from less than one million to 113 million, depending on the year and the assumptions made about the predation losses in Clifton Court Forebay. A 1986 agreement between DWR and DFG provides annual compensation for these losses at the SWP diversion.

We believe that this evidence indicates that entrainment is substantially more important in limiting bass production than was inferred from the correlations for the years 1959-1976.

C-045595

Conclusion

Our analysis leads us to the opinion that the bass stocks are being kept low by the combined effects of low egg production and high mortality rates, probably from the egg to midsummer 38 mm size. Entrainment losses and, perhaps, a mismatch of food and larvae in time and space are the most likely reasons for the high mortality rates. Both are greatly influenced, and in many years controlled, by the distribution of eggs, larvae, and juvenile bass in the Delta. While evidence exists that low egg production has limited bass production during the last 10 or so years, that is not consistent with the high juvenile bass production in 1986. Hence, it is possible that food supply is more important than our analysis has shown so far. Restoration of the bass population will require at least several years of higher than average, and much higher than current, survival rates.

HISTORY OF EFFORTS TO PROTECT THE DELTA BASS STOCKS

Potential fisheries impacts of the Central Valley Project (CVP) and State Water Project (SWP) have been studied by both the fisheries and water development agencies for nearly 50 years. The DFG began measuring the seaward migration and spawning habitat of juvenile salmon, bass, and shad in 1939 (Hatton 1940) in connection with the proposed CVP. Investigations of striped bass reproduction (Calhoun and Woodhull 1948; Calhoun, et al. 1950) and the distribution of striped bass, salmon, and shad eggs, larvae, and juveniles (Erkkila et al. 1950) all led to very early warnings that the use of Delta channels as canals to carry water to diversions was a major risk to these resources. These warnings resulted only in building louver screens in front of the USBR Tracy Pumping Plant.

In the 1960s, new studies conducted jointly by the DFG and DWR provided evidence that irrigation season diversions into the Delta Cross Channel and out of the Tracy Pumping Plant were causing reverse flows and entrainment losses and reducing food production (California Departments of Fish and Game and Water Resources 1962; Turner 1966; Turner and Heubach 1966; Hazel and Kelley 1966). The prospect of major increases in the rate and duration of water export expected to occur with completion of the SWP export pumps near the CVP facilities started a new generation of studies.

In 1964 DFG biologists defined the characteristics of the Delta environment desirable for fish and wildlife (California

C-045597

Departments of Fish and Game and Water Resources 1964). Their major recommendation, that the use of interior Delta channels as canals should be greatly reduced, resulted in the design of the Peripheral Canal to carry Sacramento River water around the eastern rim of the Delta to the SWP and CVP export pumps. Outlet facilities along the way would have released water into eastern and southern Delta channels. Thus, by isolating the water destined for export from the estuary and redistributing Delta inflow via canal releases, reverse (upstream) flows in western and southern Delta channels would have been eliminated and downstream flows would have been restored. The entrance to the Peripheral Canal from the Sacramento River was to have been screened to reduce losses of fish large enough to be protected and the diversion was to have been curtailed when large numbers of striped bass eggs and larvae were passing by. The canal would have significantly reduced diversions from the Delta nursery area for striped bass and many other fishes. Water exports would have drawn fewer fish out of their natural migration routes and would not have reduced populations of invertebrate food organisms in the Delta.

The Peripheral Canal was soundly rejected by California voters in 1982 and solutions to Delta bass problems have since been sought by improvement of existing fish screens on the CVP and SWP pumping plants, by modification of Delta flows with existing facilities, and by stocking striped bass.

Interagency Ecological Study Program

In July 1970, a Memorandum of Agreement was signed by the California Departments of Fish and Game and Water Resources, the U.S. Bureau of Reclamation, and the U.S. Bureau of Sports Fisheries and Wildlife (now the Fish and Wildlife Service). This agreement was an outgrowth of testimony at the water rights hearing that led to Decision 1379, which suggested that construction and operation of the State Water Project (SWP) and Federal Central Valley Project (CVP) contributed to fish and wildlife problems in the estuary. Testimony also indicated a need for more information regarding environmental needs of fish and wildlife and ways to design and operate the water projects to minimize detrimental effects on those resources.

The Memorandum of Agreement contained an appendix that described studies needed to define the environmental requirements and agency responsibilities for conducting and funding the studies. Findings are documented in annual progress reports submitted to the State Water Resources Control Board (SWRCB) and other agencies, organizations, and individuals.

The Memorandum of Agreement provides that the program be reviewed annually with the goal of modifying the studies to reflect changes in engineering and biological needs.

After Decision 1485, the SWRCB and U.S. Geological Survey joined the program as informal participants. Within the Interagency Program, six technical committees develop specific study proposals and budgets and exercise day-to-day technical supervision over individual studies. Agency coordinators resolve issues regarding funding and organization. Agency directors generally meet at least once a year to review progress and to resolve any major issues regarding differences in agency policy. An annual workshop is held to bring program participants and others up to date on the various program elements.

Funding made available by the water development agencies through the Interagency Program has allowed development of much of the information on striped bass that is in this report. Additional funds for this work were provided by the Department of Fish and Game and its special funds, including Federal Aid to Fish Restoration (Dingell-Johnson) Project California F-9-R, "A Study of Sturgeon, Striped Bass, and Resident Fishes" and the Striped Bass Stamp Fund.

Decision 1379

The SWRCB and its predecessor agency, the State Water Rights Board, have been considering water rights for the CVP and SWP since the late 1950s. In early decisions they established interim conditions for protection of fish and wildlife and for salinity control, but reserved jurisdiction to revise or formulate additional terms pending development of further information. The hearing which led to Decision 1379 was convened in July 1969 and continued until October 1970.

Decision 1379 was issued in July 1971. It set three standards for striped bass:

1) "For five weeks after the water temperature at Antioch reaches 60°F, the mean daily salinities in the San Joaquin River at the Antioch Water Works Intake and at Prisoners Point shall not exceed 1,500 micromhos and 550 micromhos (approximately 1,000 and 350 mg/l TDS), respectively."

This standard was set to protect water quality for striped bass spawning. It is consistent with present knowledge of striped bass spawning requirements (pages 42-46).

2) "Export pumping shall be minimized for a five (5) week period from April 25 through May 31 of each year during the peak of striped bass spawning. Permittees shall file with the State Water Resources Control Board by April 15 of each year the proposed schedule of pumping during the immediately following said 5-week period."

This standard was to minimize entrainment of striped bass eggs and larvae by the CVP and SWP. However, it set no specific limits on water exports and they increased substantially above those in previous years (Tables 26, 27, and 28). Based on our evaluation of entrainment impacts and substantial decreases in the Delta portions of the young striped bass index that began in the 1970s (Figure 9), we conclude that this standard did not provide adequate protection for young striped bass.

3) "A mean daily chloride concentration of 4,000 mg/l or less at Chipps Island shall be maintained for *Neomysis*."

This standard was set to maintain habitat for the opossum shrimp, a major food of young striped bass. As salinities increase, the shrimp are forced upstream and their abundance declines (DFG Exhibit 28). Actually, when this standard of 4,000 mg/l chlorides is reached at Chipps Island, the bulk of the Neomysis population will be in the Delta -- from Collinsville upstream in the Sacramento River and from Antioch upstream in the San Joaquin River. A more stringent standard (lower salinity) would have maintained more Neomysis habitat in Suisun Bay and resulted in more forage for young striped bass. This standard was exceeded according to DFG salinity measurements in most of 1976 and 1977. The high 1976-77 salinity intrusion reduced habitat and contributed to low Neomysis populations in those years (Knutson and Orsi 1983).

Decision 1485

The next SWRCB proceeding regarding Delta standards was initiated in April 1976. Decision 1485 replaced Decision 1379 in August 1978. The Decision 1485 goal was to restore "without project" levels of protection for striped bass, and an average 38 mm striped bass index of about 79. The standards were taken essentially from a draft Four-Agency Agreement developed through 5 years of negotiations between DWR, USBR, DFG, and USFWS. This agreement was never executed.

These striped bass standards (Table 29) were more extensive and detailed than those in Decision 1379.

The salinity (EC) standards were essentially the same as those in Decision 1379 except for the relaxation provisions that apply when the projects imposed deficiencies in their firm water deliveries. The relaxation provisions have never been implemented as deficiencies in firm supplies have not been imposed on CVP and SWP customers since 1978.

Additionally, Decision 1485 provided an outflow standard from April 1 to 14 which also included a relaxation provision. This relaxation was never implemented.

The basic (without relaxation) standards (EC and outflow) are consistent with present knowledge of striped bass spawning requirements.

The outflow standards for June and July were based on the historic 1959-1976 relationships between the young striped bass index and June and July Delta outflows. The standards for May are lower than the May flows which accompanied the 1959-76 historic relationship and are lower than desirable for striped bass survival. In part, these standards were intended to replace the Neomysis standard in Decision 1379.

The SWRCB expected that these flow standards, in conjunction with other Decision 1485 standards, would provide 38 mm striped bass indices that would vary annually depending on year type, but, over an extended period of years, would average 79. Using the 1959-76 historic relationship between June-July outflow and the 38

Table 29. SWRCB Decision 1485 striped bass standards.

Striped Bass Spawning	Parameter	Description	Year Type	Values	
Prisoners Point on the San Joaquin R.	Electrical Conductivity	Average of mean daily EC for the period not to exceed	All	April 1 to May 5 0.550 mmhos	
Chipps Island	Delta Outflow Index in cfs	Average of the daily Delta outflow index for the period, not less than	All	April 1 to April 14 6700 cfs	
Antioch Waterworks Intake on the San Joaquin River	Electrical Conductivity	Average of mean daily EC for the period, not more than	All	April 15 to May 5 1.5 mmhos	
Antioch Waterworks Intake	Electrical Conductivity (Relaxation Provision - replaces the above Antioch and Chipps Island Standard whenever the projects impose deficiencies in firm supplies	Average of mean daily EC for the period, not more than the values corresponding to the deficiencies taken (linear interpolation to be used to determine values between those shown)	All-whenever the projects impose deficiencies in firm supplies	Total Annual Imposed Deficiency MAF	April 1 to May 5 EC in mmhos
				.0	1.5
				0.5	1.9
				1.0	2.5
				1.5	3.4
				2.0	4.4
				3.0	10.3
				4.0 or more	25.2

Striped Bass Survival	Parameter	Description	Year Type	Values: May 6-31	June	July
Chipps Island	Delta Outflow Index in cfs	Average of the daily Delta outflow index for each period shown not less than	Wet	14,000	14,000	10,000
			Ab. Normal	14,000	10,700	7,700
			Bl. Normal	11,400	9,500	6,500
			Subnormal Snowmelt	6,500	5,400	3,600
			Dry	4,300	3,600	3,200
			Dry or Critical	3,300	3,100	2,900

Operational Constraint	Parameter	Description	Year Type	Values: May	June	July
Minimize diversion of young striped bass from the Delta	Diversions in cfs	The mean monthly diversions from the Delta by the State Water Project (Department) not to exceed the values shown.	All	3,000	3,000	4,600
		The mean monthly diversions from the Delta by the Central Valley Project (Bureau), not to exceed the values shown.	All	3,000	3,000	

Operational Constraint	Description	Year Type	Period
Minimize diversion of young striped bass into Central Delta	Closure of Delta cross channel gates for up to 20 days but no more than two out of four consecutive days at the discretion of the Department of Fish and Game upon 12 hours notice.	All-whenever the daily Delta outflow index is greater than 12,000 cfs	April 16-May 31

C-045604

C-045604

mm index to establish standards required an assumption that the relationship was not likely to change in the future. Almost immediately it did. Except in 1986, the outflow standards have failed to provide the expected levels of young bass abundance. Excluding 1986 (index=64.9), the index ranged from 6.3 (1985) to 48.7 (1982) between 1979 and 1987. Again excluding 1986, the average index was 27.0 over this period. If the relationship had held, the index should have averaged about 65.

Decision 1485 also imposed operational constraints on the CVP and SWP to limit entrainment of young bass.

The main constraint is that mean monthly diversions by the SWP were not to exceed 3,000 cfs in May and June and 4,600 cfs in July. Mean monthly diversions by the CVP were not to exceed 3,000 cfs in May and June. According to official operations records, these standards were met. From Tables 26, 27, and 28, it can be seen that these restrictions resulted in average diversions in May and June remaining at approximately the same level they were from 1970-76, while average July diversions have increased about 1,000 cfs. Our analysis of entrainment impacts indicates that the standards allow rates of entrainment which cause substantial reductions in young bass abundance.

A second operational constraint required temporary closures of the Delta cross channel when Delta outflow exceeds 12,000 cfs to minimize diversions of young bass from the Sacramento River.

At the request of DFG, USBR has generally kept the cross channel gates closed continuously whenever outflow has exceeded

12,000 cfs from April 16 to May 31. While this practice has reduced the diversion of bass from the Sacramento River when flows are high, the greatest need is in drier years when diversions remove a higher percentage of the river flow. This operational constraint provides no protection under those lower flow conditions.

The final set of Decision 1485 standards for protection of striped bass pertains to operation of the fish protective facilities at the CVP and SWP diversions (Table 30).

These standards reflected the best available information at the time and have generally been met by the project operators, although problems have occurred with record keeping, fish identification, and fish hauling. Activities at the two facilities are conducted by the operators of the projects, with overview by a biologist employed by the DFG under contract to the two projects. Some of the entrainment loss information presented earlier in this report is based on records collected at the two facilities as required by the standards.

One problem is that the standards have prevented application of new test results and revised operational criteria except under the provisions of the biological testing exemption. We had, for example, changed from a fixed date to a dynamic response system for choosing between operational criteria for striped bass and chinook salmon at the time Decision 1485 was published. The incorporation of these criteria as standards forced us to revert to the earlier fixed date response as these were the criteria

Table 30. SWRCB Decision 1485 standards for operating fish protective facilities to protect striped bass.

FISH PROTECTIVE FACILITIES

Maintain appropriate records of the numbers, sizes, kinds of fish salvaged and of water export rates and fish facility operations.

State Fish Protection Facility

The facility is to be operated to meet the following standards to the extent that they are compatible with water export rates:

Striped Bass and White Catfish - from May 15 through October, standards shall be as follows:

(1) Approach Velocity - in both the primary and secondary channels, maintain a velocity as close to 1.0 feet per second as is possible.

(2) Bypass Ratio
  a. When only Bay A (with center wall) is in operation maintain a 1.2:1.0 ratio
  b. When both primary bays are in operation and the approach velocity is less than 2.5 feet per second, the bypass ratio should be 1.5:1.0.
  c. When only Bay B is operating the Bypass ratio should be 1.2:1.0
  d. Secondary channel bypass ratio should be 1.2:1.0 for all approach velocities.

(3) Primary Channel - Use Bay A (with center wall) in preference to Bay B

(4) Screened Water Ratio - if the use of screened water is necessary, the velocity of water exiting the screened water system is not to exceed the secondary channel approach velocity

(5) Clifton Court Forebay Water Level - maintain at the highest practical level.

Tracy Fish Protective Facility

The secondary system is to be operated to meet the following standards, to the extent that they are compatible with water export rates:

(1) To the extent possible, the secondary velocity should not exceed 2.5 feet per second and preferably 1.5 feet per second between June 1 and August 31, to increase the efficiency for striped bass, catfish, shad and other fish. Secondary velocities should be reduced even at the expense of bypass ratios in the primary, but the ratio should not be reduced below 1:1.0.
(2) The screened water discharge should be kept at the lowest possible level consistent with its purpose of minimizing debris in the holding tanks.

(3) The bypass ratio in the secondary should be operated to prevent excessive velocities in the holding tanks, but in no case should the bypass velocity be less than the secondary approach velocity.

incorporated in the Decision and could not be changed without reopening the hearing process. We should avoid duplicating this error in future decisions, especially in cases where additional information is being collected on the nature of the facility operations and the effects of fish salvage.

Striped Bass Stocking Program

Hatchery production may help to rebuild the striped bass population. Moderately large numbers of fish are now being planted and the stocking is being evaluated.

From 1981 through 1986, more than 2 million hatchery reared striped bass have been released into the estuary. Stocking increased steadily from about 62,000 fish in 1981 to 1.3 million fish in 1986. Additional releases of the 1986 magnitude are planned through 1991. To evaluate this stocking program, over 1.5 million of these fish have been marked with fin clips, freeze brands, or coded wire tags implanted in the cheek muscle. Mark recoveries are obtained through a combination of striped bass angler creel censuses and DFG netting and trapping. This sampling has recovered more than 700 of these marked fish. Preliminary analyses suggest that on the order of 15-20% of the fish are surviving to be recruited into the fishery at age 3. This rate of survival seems high enough that the stocking stands a reasonable chance of success.

1986 DWR/DFG Agreement to Offset Direct Losses Related to H.O. Banks Pumping Plant

In December 1986, DWR and DFG signed an agreement specifying that DWR will offset "direct" losses caused by SWP diversions at the H.O. Banks pumping plant. Losses are to be estimated annually from estimates of entrainment and methods by which the losses will be "offset" chosen by the DFG and DWR with advice from representatives of fishing groups and water users. Guidelines for objective analysis of suggested methods are included in the agreement. The agreement is designed to compensate for SWP entrainment losses but also requires that the parties begin discussions on developing ways to offset other adverse effects of the SWP and to involve the USBR in developing ways to offset their impacts.

A Delta Transfer Facility

Continued and increasing use of Delta channels as canals to deliver water stored in Shasta, Oroville, and Folsom reservoirs to various regions of use has, as predicted, greatly reduced the Delta's value as striped bass habitat. Restoration of the Delta bass habitat was the goal of a properly designed and operated Peripheral Canal, but that now seems politically unlikely, if not impossible.

We have seen no alternatives that would restore these channels as useful habitat; however, those which reduce flow reversals in the lower San Joaquin should lessen some of the current problems. They are worthy of careful study.

So long as spring water exports are high and are made by drawing them through the Delta channels, young striped bass will probably survive better if they can be flushed quickly into Suisun, Grizzly, and Honker bays where there is more food and less exposure to entrainment (Table 31).

Table 31. Mean April-June zooplankton densities (dry weight µg/m³) for four areas of the Sacramento-San Joaquin Estuary, 1984-1986.

Year	Suisun Bay	Grizzly/ Honker Bays	Lower Sacramento River	Lower San Joaquin River
1984	35,079	41,617	13,261	25,039
1985	27,945	23,688	15,395	24,999
1986	47,414	53,811	21,883	23,767

RECOMMENDATIONS

The following should be considered as measures to improve protection of striped bass.

1. Seek ways to move eggs and larvae past the Delta into Suisun, Grizzly, and Honker bays and to keep them there.
2. Test the results of Recommendation (1) with modification of Delta flows and appropriate monitoring.
3. Reduce entrainment of bass. Several valuable suggestions have been made:
    a. Screen agricultural diversions.
    b. Improve design and operations at both the CVP/SWP screens.
    c. Curtail water exports in critical periods.

    The evidence that entrainment losses are significant warrants placing some major efforts here.
4. Continue investigation of toxicity. Experiments to determine cause and effect relationships with toxicants should be undertaken. After the pollution phase of the hearing, evidence should be carefully evaluated to detemine whether additional specific controls on toxicants are warranted.
5. Continue analysis of existing data. There is much to be learned from it. Emphasis should be placed on developing and testing causes for the increased mortality rate for larval bass. That may require some additional studies.

REFERENCES

Bailey, N.T.J. 1951. On estimating the size of mobile populations from recapture data. Biometrika 38:293-306.

Benville, P.E., Jr. and S. Korn. 1977. The acute toxicity of six monocyclic aromatic crude oil components to striped bass (Morone saxatilis) and bay shrimp (Crangon franciscorum). California Fish and Game 63:204-209.

Benville, P.E., Jr., J.A. Whipple, and M.B. Eldridge. 1985. Acute toxicity of seven alicyclic hexanes to striped bass, Morone saxatilis, and bay shrimp, Crangon franciscorum, in seawater. California Fish and Game 71:132-140.

Bonnell, M.L., B.J. LeBeuf, M.O. Pierson, D.H. Dettman, G.D. Farrens, C.B. Heath, R.F. Gautt, and D.J. Larsen. 1978. Summary of marine mammal and seabird surveys off the Southern California Bight area. Regents of the University of California, Santa Cruz. 534 p.

Bonnell, M.L., M.O. Pierson, and G.D. Farrens. 1983. Pinnipeds and sea otters of central and northern California: status, abundance, and distribution. Center for Coastal Marine Studies, University of California, Santa Cruz. 221 p.

Calhoun, A.J. 1949. California striped bass catch records from the party boat fishery: 1938-1948. California Fish and Game 35:211-253.

Calhoun, A.J. 1952. Annual migrations of California striped bass. California Fish and Game 38:391-403.

Calhoun, A.J. and C.A. Woodhull. 1948. Progress report on studies of striped bass reproduction in relation to the Central Valley Project. California Fish and Game 34:171-188.

Calhoun, A.J., C.A. Woodhull, and W.C. Johnson. 1950. Striped bass reproduction in the Sacramento River system in 1948. California Fish and Game 36:135-145.

California Departments of Fish and Game and Water Resources. 1962. Annual Report (1961-62) Delta Fish and Wildlife Protection Study. The Resources Agency of California. 219 p.

California Departments of Fish and Game and Water Resources. 1964. The effect of water development on the Delta environment. Annual Report (1963-64) Delta Fish and Wildlife Protection Study. The Resources Agency of California. 33 p.

Chadwick, H.K. 1963. An evaluation of five tag types used in a striped bass mortality rate and migration study. California Fish and Game 49:64-83.

Chadwick, H.K. 1967. Recent migrations of the Sacramento-San Joaquin River striped bass population. Transactions of the American Fisheries Society 96:327-342.

Chadwick. H.K. 1968. Mortality rates in the California striped bass population. California Fish and Game 54:228-246.

Citizens for a Better Environment. 1983. Toxics in the Bay: An assessment of the discharge of toxic pollutants to San Francisco Bay by municipal and industrial point sources. San Francisco.

Collins, B.W. 1982. Growth of adult striped bass in the Sacramento-San Joaquin Estuary. California Fish and Game 68:146-159.

Columbia National Fisheries Research Laboratory. 1984. Impacts of contaminants on the early life stages of striped bass, Progress Report 1980-1983. U.S. Fish and Wildlife Service, Columbia, Missouri.

Coutant, C.C. 1985. Striped bass, temperature, and dissolved oxygen: a speculative hypothesis for environmental risk. Transactions of the American Fisheries Society 114:31-61.

Crosby, D.G., K. Hogan, G.W. Bowes, and G.L. Foster. 1986. The potential impact of chlorinated hydrocarbon residues on California striped bass (Standard Agreements No. 9-102-400 and 2-089-420). State Water Resources Control Board, Cooperative Striped Bass Study, Technical Supplement I.

Eldridge, M.B., J.A. Whipple, D. Eng, M.J. Bowers, B.M. Jarvis. 1981. Effects of food and feeding factors on laboratory-reared striped bass larvae. Transactions of the American Fisheries Society 110:111-120.

Erkkila, L.F., J.W. Moffett, O.B. Cope, B.R. Smith, and R.S. Nielson. 1950. Sacramento-San Joaquin Delta fishery resources: Effects of Tracy pumping plant and Delta Cross Channel. U.S. Fish and Wildlife Service, Special Scientific Report, Fisheries No. 56. 109 p.

Faggella, G.A. and B.J. Finlayson. 1987. Hazard assessment of rice herbicides, molinate and thiobencarb, to larval and juvenile striped bass. California Department of Fish and Game, Environmental Services Division Administrative Report No. 87-2. 83 p.

Hallock. R.J., D.H. Fry, Jr., and D.A. LaFaunce. 1957. The use of wire fyke traps to estimate runs of adult salmon and steelhead in the Sacramento River. California Fish and Game 43:271-298.

Hatton, S.R. 1940. Progress report on the Central Valley Fisheries Investigations, 1939. California Fish and Game 26:334-373.

Hazel, C.R. and D.W. Kelley. 1966. Zoobenthos of the Sacramento-San Joaquin Delta. California Department of Fish and Game, Fish Bulletin 133:1-13.

Interagency Ecological Study Program. 1987. 1985-1986 Annual Report, R.L. Brown (compiler). Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary, Report AR-15/87.

Ivlev. V.S. 1961. Experimental ecology of the feeding of fishes. Yale University Press. New Haven. 302 p.

Jung, M., J.A. Whipple, and M. Moser. 1984. Summary report of the Cooperative Striped Bass Study. Institute for Aquatic Resources, Santa Cruz, California. 117 p.

Knudsen, D.L. and D.W. Kohlhorst. 1987. Striped bass health monitoring 1985 final report. Prepared for the California State Water Resources Control Board under Interagency Agreement 4-090-120-0. 31 p + appendices.

Knutson, A.C., Jr. and J.J. Orsi. 1983. Factors regulating abundance and distribution of the shrimp, Neomysis mercedis, in the Sacramento-San Joaquin Estuary. Transactions of the American Fisheries Society 112:476-485.

Kohlhorst, D.W. 1973. An analysis of the annual striped bass die-off in the Sacramento-San Joaquin Estuary, 1971-72. California Department of Fish and Game, Anadromous Fisheries Branch Administrative Report No. 73-7. 22 p.

Kohlhorst, D.W. 1975. The striped bass (Morone saxatilis) die-off in the Sacramento-San Joaquin Estuary in 1973 and a comparison of its characteristics with those of the 1971 and 1972 die-offs. California Department of Fish and Game, Anadromous Fisheries Branch Administrative Report No. 74-13. 14 p.

Lemly, A.D. 1985. Toxicology of selenium in a freshwater reservoir: implications for environmental hazard evaluation and safety. Ecotoxicology and Environmental Safety 10:314-338.

Meinz, M. and W.L. Mecum. 1977. A range extension for Mississippi silversides in California. California Fish and Game 63:277-278.

Meyer Resources. 1985. The economic value of striped bass, Morone saxatilis, chinook salmon, Oncorhynchus tshawytscha, and steelhead trout, Salmo gairdneri, of the Sacramento and San Joaquin River systems. California Department of Fish and Game, Anadromous Fisheries Branch Administrative Report 85-03. 44 p.

Miller, L.W. 1974. Mortality rates for California striped bass (Morone saxatilis) from 1965-1971. California Fish and Game 60:157-171.

PGE (Pacific Gas and Electric Company). 1981a. Contra Costa Power Plant cooling water intake structures 316(b) demonstration. PGE, San Francisco, California.

PGE (Pacific Gas and Electric Company). 1981b. Pittsburg Power Plant cooling water intake structures 316(b) demonstration. PGE, San Francisco, California.

Radovich, J. 1963. Effect of ocean temperature on the seaward movements of striped bass, Roccus saxatilis, on the Pacific coast. California Fish and Game 49:191-206.

Radtke, L.D. and J.L. Turner. 1967. High concentrations of total dissolved solids block spawning migration of striped bass (Roccus saxatilis) in the San Joaquin River, California. Transactions of the American Fisheries Society 96:405-407.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191. 382 p.

Scofield, E.C. 1931. The striped bass of California (Roccus lineatus). California Division of Fish and Game, Fish Bulletin 29.

State Water Resources Control Board. 1985. Acute toxicity of rice herbicides to Neomysis mercedis; chronic toxicity of rice herbicides to Neomysis mercedis. Stanford Research Institute International Project LSU-7578, Menlo Park, California.

State Water Resources Control Board. 1987. Regulation of agricultural drainage to the San Joaquin River. State Water Resources Control Board Order No. WQ85-1, Draft Technical Committee Report.

Stevens, D.E. 1977a. Striped bass (Morone saxatilis) year class strength in relation to river flow in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society 106:34-42.

Stevens, D.E. 1977b. Striped bass (Morone saxatilis) monitoring techniques in the Sacramento-San Joaquin Estuary. Pages 91-109 in W. Van Winkle, editor. Proceedings of the conference on assessing the effects of power-plant-induced mortality on fish populations. Pergamon Press, New York, New York.

Stevens, D.E., D. W. Kohlhorst, L.W. Miller, and D.W. Kelley. 1985. The decline of striped bass in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society 114:12-30.

Striped Bass Working Group. 1982. The striped bass decline in the San Francisco Bay-Delta Estuary. Report to California State Water Resources Control Board, Sacramento, California.

Turner, J.L. 1966. Seasonal distribution of crustacean plankters in the Sacramento-San Joaquin Delta. California Department of Fish and Game, Fish Bulletin 133:95-104.

Turner, J.L. and H.K. Chadwick. 1972. Distribution and abundance of young-of-the-year striped bass, Morone saxatilis, in relation to river flow in the Sacramento-San Joaquin Estuary. Transactions of the American Fisheries Society 101:442-452.

Turner, J.L. and T.C. Farley. 1971. Effects of temperature, salinity, and dissolved oxygen on the survival of striped bass eggs and larvae. California Fish and Game 57:268-273.

Turner, J.L. and W. Heubach. 1966. Distribution and concentration of Neomysis awatschensis in the Sacramento-San Joaquin Delta. California Department of Fish and Game, Fish Bulletin 133:105-112.

Turner, J.L. 1976. Striped bass spawning in the Sacramento and San Joaquin rivers in Central California from 1963 to 1972. California Fish and Game 62:106-118.

Whipple, J.A., M.B. Eldridge, and P.E. Benville, Jr. 1981. An ecological perspective of the effects of monocyclic aromatic hydrocarbons on fishes. Pages 483-551 in S.J. Vernberg, A. Calabrese, F.P. Thurberg, and W.B. Vernberg, editors. Biological monitoring of marine pollutants. Academic Press, New York, New York.

Whipple J.A., R.B. MacFarlane, P.E. Benville, Jr., and M.B. Eldridge. 19__. A multivariate approach to studying the interactive effects of inherent and environmental factors, including pollutants, on striped bass (Morone saxatilis) in the San Francisco Bay-Delta, California. Draft MS.

C-045618

C-045618

APPENDIX 1

COMPARISON OF TWO MEASURES OF ADULT STRIPED BASS ABUNDANCE

DFG has measured adult striped bass abundance with Petersen mark-recapture population estimates and the catch-per-effort (CPE) of adult (total length at least 16 inches) striped bass captured during tagging studies.

Modified Petersen population estimates (Bailey 1951) were calculated annually from 1969 through 1985. Striped bass were tagged with disc-dangler tags (Chadwick 1963) during their spring spawning migration to the Delta and Sacramento River. The ratio of tagged to untagged fish in the population was estimated during annual summer-fall creel censuses in the San Francisco Bay area and subsequent spring tagging operations.

The abundance estimation procedures are complicated by sex and age sampling biases (Chadwick 1967; Stevens 1977b). Hence, all of the abundance estimates are based on samples stratified by sex and age (Stevens 1977b).

Our second assessment of adult striped bass stocks is from catches of striped bass in gill nets and fyke traps (Hallock et al. 1957) during tagging operations in the Delta and Sacramento River. This CPE index is the sum of catches in the fishing gears after annual effort was standardized to four gill-netting boat-months and 36 fyke-trap-months. A boat-month is 20 8-hour days of fishing a 600 ft. long drift gill net (4 - 5-1/2 inch stretched mesh). A trap-month is 30 24-hour days of fyke trap fishing. In years when fishing occurred, effort ranged from 2 to 4.5 boat-months and from 11 to 42 trap-months.

Tagging began in 1958 (Chadwick 1968), but the most relible CPE records start in 1969. No CPE index is available for 1977, 1978, or 1981 because fyke traps were not fished in those years.

To attempt to determine which measure was more reliable, we looked for clues to the precision of each. Direct measures of precision were available for the Petersen estimates in the form of 95% confidence intervals for each annual estimate of adult striped bass abundance. The confidence intervals indicated that the Petersen estimates were quite precise from 1969 to 1974. During this period the confidence intervals averaged only ± 13% of the estimated value (Figure 1). Thereafter, as the numbers of tagged fish released and recaptured decreased, the estimates became less precise; confidence intervals averaged ± 34% of the estimated value from 1975 to 1985.

No direct measure of the precision of the CPE indices is available.

Precision of the measures of adult bass abundance was also evaluated indirectly by examining the strength of the association between two adjacent ages of the same year class (cohort). The abundance of a cohort should decline consistently rather than

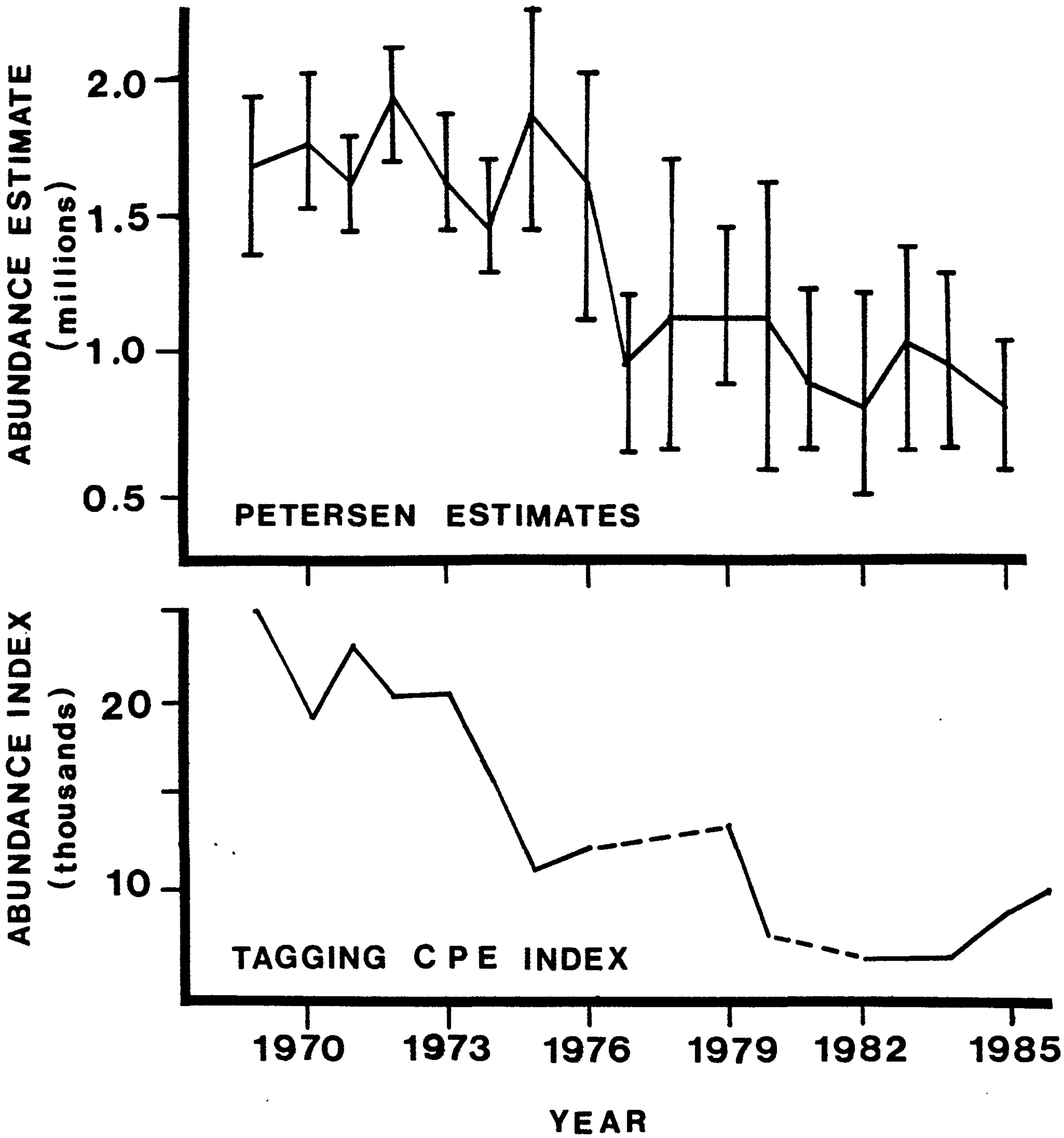


Figure 1. Trends in abundance of adult striped bass (at least 16 inches total length) in the Sacramento-San Joaquin Estuary. Direct measures of precision for the Petersen estimates in the form of 95% confidence intervals are depicted by vertical bars.

erratically; therefore, a strong association implies low sampling variability in the abundance measure. The statistic examined was the correlation coefficient (r) between the natural logarithm ($\log_e$) of the abundance of age i in year t and $\log_e$ of the abundance of age i+1 in year t+1. Three of the four r values were statistically significant ($p<0.05$) for the Petersen estimates (r ranged from 0.456-0.840) (Table 1). However, comparisons of CPE indices yielded higher correlations (r ranged from 0.685-0.967) that were all statistically significant at the 0.05 level.

To test whether the lower correlations between adjacent Petersen estimates were the result of the unusual decrease in abundance that they depicted between 1976 and 1977, estimates when t = 1976 and t+1 = 1977 were omitted and the correlations were recalculated. Even with that adjustment, correlations between adjacent ages were considerably lower than those for the CPE index (Table 1).

These results suggest that the CPE index is more reliable and that conclusions based on it should be given more weight where only an index rather than an absolute measure of abundance is needed.

Table 1. Correlation coefficients for the association between $\log_e$ (abundance at age i in year t) and $\log_e$ (abundance at age i+1 in year t+1) for Petersen estimates and CPE indices of adult striped bass in the Sacramento-San Joaquin Estuary from 1969 to 1986. * = statistically significant with $p < 0.05$.

Ages Compared		Correlation Coefficients		
		$\log_e$ Petersen Estimates		
Age i	Age i+1	All Years (n = 16)	Without Estimates When t = 1976[1/] (n = 15)	$\log_e$ CPE Indices (n = 12)
3	4	0.499*	0.731*	0.685*
4	5	0.456	0.451	0.806*
5	6	0.619*	0.629*	0.927*
6	7	0.840*	0.893*	0.942*
7	8			0.967*
8	9			0.966*
9	10			0.958*
10	11			0.921*
11	12			0.902*

1/ See text.

C-045624

TABLE 1

VARIABLES USED IN THE PRINCIPAL COMPONENT ANALYSES OF POLLUTANT & HEALTH VARIABLES FROM MATURE, FEMALE STRIPED BASS COLLECTED IN THE SACRAMENTO - SAN JOAQUIN DELTA.

Name	Scale	Transformation in PCA on: All 8 Yrs	1984-85	Relative Degree of Normality[1/]
Location	0=San Joaquin River 1=Sacramento River	None	None	Binary Variable
Age	In Years From Scales	Square root	None	2
STRPtot	Total sum of six sections on one side of the fish for 1=Solid & 2=Broken Striping Pattern. The sum of these scores ranged from 6 to 12.	None	None	2
RANK2EC	Egg color ranged from yellow to green scored 8 to 16.	LN	LN	2
TAPELARV	Tapeworm larvae abundance ranked from 1 to 5 at each location of occurrance - The variable is the sum of all occurances. 2=Few 3=Average 4=Many 5=Very Many/Heavily Parasitized.	Not Used[2/]	LN	3
TAPERAFT	Tapeworm rafts scored as was TAPELARV	Not Used[2/]	LN	3
TAPELESN	Tapeworm induced lesions scored as was TAPELARV	Not Used[2/]	LN	3
RNDWLARV	Roundworm larvae scored as was TAPELARV.	Not Used[2/]	LN	3
TOT_PAR	All parasites combined scored as was TAPELARV	LN	Not Used[3/]	3
MES-FAT	Mesenteric fat abundance rank 1 to 4 1=None 2=Sparse 3=Average 4=Abundant	None	None	3
EGGSTAGE	Dominant eggstage in the ovary, 1-11	None	None	2
PERC_RES	% of eggs resorbing, 0-100%	Arcsine-square root	Arcsine-square root	3
Cd Cr Cu Hg Zn Se	Trace metals in ppm dry weight of liver	Not Available[4/]	Raw, square root, or LN as needed	1 or 2
MAH	Monocyclic aromatic hydrocarbons in ppm wet weight of liver	LN	LN	3
AH	Alicyclic hexanes in ppm wet weight of liver	LN	Not used because all values = 0	3

APPENDIX 2

C—045624

C-045625

TABLE 1 (Continued)

Name	Scale	Transformation in PCA on: All 8 Yrs	Transformation in PCA on: 1984-85	Relative Degree of Normality[1/]
LIPID	% Lipid in the liver	Not Available[4/]	Arcsine-square root	2
TOT_PCB	Total concentration of all forms of PCB measured in ppm wet weight of liver	Not Available[4/]	Square root	1
DDT_MET[5/]	The summed concentration of DDT and its metabolic products in ppb wet weight of liver	Not Available[4/]	LN	3
PESTICID[6/]	The summed concentrations of all pesticides found in ppb wet weight of liver	Not Available[4/]	LN	3
TOT_ABN	Sum of all skeletal abnormalities ranked in severity from 1 to 5 at each location of occurrence	LN	LN	3
KFL	Wet Wet/(Fork Length)^3 a standard condition factor for fish tested as applicable to striped bass	None	None	1 and 2
BODY PROP	Body depth behind the operculum divided by fork length	Square root	None	2
IFECUND	Index of fecundity = # of eggs per fish/wet weight of the fish	Square root	None	2
GSI	Gonadal somatic index wet weight = gonad/wet weight fish	None	None	1 and 2
LSI	Liver somatic index wet weight = liver/wet weight fish	Arcsine-square root	Arcsine-square root	2
TIME	Days since 6/1/1960 representing linear time over years	None	Not Used	2
DAY_IN_Y	Julian day of the year representing seasonal time trends	None	None	2

1/ Relative degree of normality 1=Tested as Normal 2=Approximates Normal 3=Non-Normal
2/ Inconsistently scored over the course of the study.
3/ Redundant with the individual parasite severities used in the 1984/85 analysis.
4/ Not measured in the majority of fish collected between 1978 and 1983.
5/ Includes p,p' -DDT; o.p-, p,p'-DDD; and o,p-, p,p' -DDE.
6/ Includes toxaphene, chlordane, nonachlor, oxychlordane, hexachlorobenzene.

C-045625

C-045626

TABLE 2

EIGENVALUES AND PROPORTION OF VARIANCE ASSOCIATED WITH THE UNROTATED COMPONENTS FROM THE PRINCIPAL COMPONENTS ANALYSIS ON POLLUTANT & HEALTH VARIABLES FROM MATURE, FEMALE STRIPED BASS COLLECTED IN THE SACRAMENTO - SAN JOAQUIN DELTA FROM 1978 TO 1985. (N=199)

COMPONENT #	EIGENVALUE	CUMULATIVE PROPORTION OF VARIANCE IN DATA SPACE	CUMULATIVE PROPORTION OF VARIANCE IN COMPONENT SPACE	ABSOLUTE PROPORTION OF VARIANCE IN DATA SPACE	ABSOLUTE PROPORTION OF VARIANCE IN COMPONENT SPACE
1	2.9432	0.1731	0.2615	0.1731	0.2615
2	1.9305	0.2867	0.4330	0.1136	0.1715
3	1.5701	0.3790	0.5724	0.0923	0.1394
4	1.3411	0.4579	0.6916	0.0789	0.1192
5	1.2170	0.5295	0.7997	0.0716	0.1081
6	1.1576	0.5976	0.9025	0.0681	0.1028
7	1.0975	0.6622	1.0000	0.0646	0.0975
8	0.8981	0.7150		0.0528	
9	0.8466	0.7648		0.0498	
10	0.7681	0.8100		0.0452	
11	0.6997	0.8511		0.0411	
12	0.6585	0.8899		0.0388	
13	0.5846	0.9243		0.0344	
14	0.4720	0.9520		0.0277	
15	0.3776	0.9742		0.0222	
16	0.2777	0.9906		0.0164	
17	0.1603	1.0000		0.0094	

THE EIGENVALUES ARE FOR EACH COMPONENT BEFORE ROTATION. THE CUMULATIVE OR ABSOLUTE PROPORTION OF VARIANCE IN DATA SPACE IS THE AMOUNT OF VARIABILITY IN THE ORIGINAL DATA ACCOUNTED FOR BY THAT MANY COMPONENETS OR THAT COMPONENT, RESPECTIVELY, AND THE PROPORTION IN COMPONENT SPACE IS THE AMOUNT OF VARIABILITY IN THE PRINCIPAL COMPONENT ANALYSIS SOLUTION ACCOUNTED FOR BY THAT MANY COMPONENTS (CUMULATIVE), OR THAT COMPONENT INDIVIDUALLY (ABSOLUTE).

C-045626

TABLE 3

SORTED ROTATED COMPONENT LOADINGS (PATTERN MATRIX) FOR THE PRINCIPAL COMPONENTS ANALYSIS ON POLLUTANT & HEALTH VARIABLES FROM MATURE, FEMALE STRIPED BASS COLLECTED IN THE SACRAMENTO - SAN JOAQUIN DELTA FROM 1978 TO 1985. (N=199)

COMPONENT #	1	2	3	4	5	6	7
COMPONENT NAME	SEXUAL MATURITY	MORPHOLOGY & SEASONAL LIVER CONDITION	SACRAMENTO RIVER FISH	LESS ALYCYCLIC HEXANES THROUGH TIME	OLDER FISH WITH MORE PARASITES	ABNORMALITIES & BROKEN STRIPING PATTERN	MONOCYCLIC AROMATIC HYDROCARBONS
GSI	0.860	0.000	0.000	0.000	0.000	0.000	0.000
IFECUND	0.849	0.000	0.000	0.000	0.000	0.000	0.000
BODYPROP	0.000	0.635	0.000	0.000	0.000	0.000	0.000
KFL	0.000	0.625	0.000	-0.418	0.000	0.318	0.000
DAY_IN_Y	0.000	-0.539	0.000	0.000	0.000	0.000	0.000
LSI	-0.404	0.520	0.416	0.000	0.000	0.000	0.000
LOCATION	0.000	0.000	0.753	0.000	0.000	0.000	0.000
EGGSTAGE	0.433	0.000	-0.664	0.000	0.000	0.000	0.000
TIME	0.000	0.000	0.000	0.769	0.000	0.000	0.000
AH	0.000	0.000	0.000	-0.696	0.000	0.000	0.000
TOT_PAR	0.000	0.000	0.000	0.000	0.764	0.000	0.000
AGE	0.000	0.000	0.000	0.000	0.682	0.000	0.000
TOT_ABN	0.000	0.000	0.000	0.000	0.000	0.792	0.000
STRPtot	0.000	0.000	0.000	0.000	0.000	0.581	-0.447
MAH	0.000	0.000	0.000	0.000	0.000	0.000	0.781
RANK2EC	0.000	-0.487	0.000	0.000	0.000	0.000	0.000
PERC_RES	-0.475	0.000	0.000	-0.334	0.000	0.000	0.444
% OF VARIANCE	13.52	9.87	9.45	9.41	8.14	7.94	7.88

THE ABOVE COMPONENT LOADING MATRIX HAS BEEN REARRANGED SO THAT THE COLUMNS APPEAR IN DECREASING ORDER OF VARIANCE EXPLAINED BY COMPONENTS. THE ROWS HAVE BEEN REARRANGED SO THAT FOR EACH SUCCESSIVE COMPONENT, LOADINGS GREATER THAN 0.5000 APPEAR FIRST. LOADINGS LESS THAN 0.3160 HAVE BEEN REPLACED BY ZERO AS THEY WERE NOT INTERPRETED. THE "% OF VARIANCE" EQUALS THE AMOUNT OF VARIABILTY (VARIANCE) IN THE ORIGINAL DATA ACCOUNTED FOR BY THAT SPECIFIC COMPONENT. A "NAME" WAS ASSIGNED TO EACH COMPONENT BASED ON THE VARIABLES THAT WERE MOST HIGHLY CORRELATED WITH IT, TO HELP THE READER INTERPRET AND IDENTIFY INDIVIDUAL COMPONENTS.

C-045627

C-045627

C-045628

TABLE 4

CORRELATION MATRIX FOR THE PRINCIPAL COMPONENTS ANALYSIS ON POLLUTANT & HEALTH VARIABLES FROM MATURE, FEMALE STRIPED BASS COLLECTED IN THE SACRAMENTO - SAN JOAQUIN DELTA FROM 1978 TO 1985. (N=199)

	LOCATION	AGE	STRPtot	RANK2EC	EGGSTAGE	PERC_RES	MAH	AH	TOT_PAR	TOT_ABN	KFL	BODYPROP	IFECUND
LOCATION	1.000												
AGE	0.137	1.000											
STRPtot	-0.049	-0.131	1.000										
RANK2EC	0.040	0.051	0.075	1.000									
EGGSTAGE	-0.221	0.029	0.122	0.034	1.000								
PERC_RES	-0.090	-0.062	-0.110	-0.142	-0.302	1.000							
MAH	-0.129	0.128	-0.070	-0.067	-0.023	0.192	1.000						
AH	0.046	-0.042	-0.079	0.010	-0.002	0.153	0.025	1.000					
TOT_PAR	0.050	0.207	-0.010	-0.037	0.016	-0.250	-0.049	-0.136	1.000				
TOT_ABN	-0.016	0.183	0.144	0.059	0.116	0.108	0.152	0.015	-0.088	1.000			
KFL	-0.146	0.026	0.016	-0.115	0.163	0.131	-0.010	0.117	-0.044	0.169	1.000		
BODYPROP	0.005	0.150	-0.079	0.123	-0.043	-0.013	0.086	0.029	0.053	0.067	0.301	1.000	
IFECUND	0.148	0.109	-0.037	0.049	0.110	-0.366	-0.087	-0.070	0.031	0.009	-0.004	0.026	1.000
GSI	-0.122	0.250	-0.047	0.135	0.546	-0.350	0.020	-0.053	0.030	0.105	0.127	0.015	0.643
LSI	0.104	-0.145	-0.114	-0.195	-0.554	0.357	-0.006	0.082	-0.122	-0.074	0.225	0.046	-0.207
TIME	0.152	-0.032	0.055	0.062	-0.119	-0.335	-0.022	-0.296	0.114	0.022	-0.339	0.035	0.356
DAY_IN_Y	0.032	0.049	0.077	0.118	0.206	-0.087	0.079	-0.056	-0.023	0.156	-0.079	-0.137	0.157

	GSI	LSI	TIME	DAY_IN_Y
GSI	1.000			
LSI	-0.447	1.000		
TIME	0.062	-0.115	1.000	
DAY_IN_Y	0.196	-0.405	0.018	1.000

C-045628

TABLE 5

EIGENVALUES AND PROPORTION OF VARIANCE ASSOCIATED WITH THE UNROTATED COMPONENTS FROM THE PRINCIPAL COMPONENTS ANALYSIS ON POLLUTANT & HEALTH VARIABLES FROM MATURE, FEMALE STRIPED BASS COLLECTED IN THE SACRAMENTO - SAN JOAQUIN DELTA IN 1984 & 1985. (N=74)

COMPONENT #	EIGENVALUE	CUMULATIVE PROPORTION OF VARIANCE IN DATA SPACE	CUMULATIVE PROPORTION OF VARIANCE IN COMPONENT SPACE	ABSOLUTE PROPORTION OF VARIANCE IN DATA SPACE	ABSOLUTE PROPORTION OF VARIANCE IN COMPONENT SPACE
1	6.8108	0.2349	0.3309	0.2349	0.3309
2	2.8981	0.3348	0.4716	0.0999	0.1407
3	2.7935	0.4311	0.6073	0.0963	0.1357
4	2.3164	0.5110	0.7199	0.0799	0.1126
5	1.6768	0.5688	0.8013	0.0578	0.0814
6	1.5009	0.6206	0.8742	0.0518	0.0729
7	1.3681	0.6677	0.9407	0.0471	0.0665
8	1.2208	0.7098	1.0000	0.0421	0.0593
9	1.0591	0.7464		0.0366	
10	0.9937	0.7806		0.0342	
11	0.8161	0.8088		0.0282	
12	0.7763	0.8355		0.0267	
13	0.5948	0.8561		0.0206	
14	0.5741	0.8759		0.0198	
15	0.5262	0.8940		0.0181	
16	0.4341	0.9090		0.0150	
17	0.3802	0.9221		0.0131	
18	0.3702	0.9348		0.0127	
19	0.3174	0.9458		0.0110	
20	0.2994	0.9561		0.0103	
21	0.2808	0.9658		0.0097	
22	0.2146	0.9732		0.0074	
23	0.1948	0.9799		0.0067	
24	0.1540	0.9852		0.0053	
25	0.1479	0.9903		0.0051	
26	0.1196	0.9944		0.0041	
27	0.0861	0.9974		0.0030	
28	0.0475	0.9990		0.0016	
29	0.0276	1.0000		0.0010	

THE EIGENVALUES ARE FOR EACH COMPONENT BEFORE ROTATION. THE CUMULATIVE OR ABSOLUTE PROPORTION OF VARIANCE IN DATA SPACE IS THE AMOUNT OF VARIABILITY IN THE ORIGINAL DATA ACCOUNTED FOR BY THAT MANY COMPONENETS OR THAT COMPONENT, RESPECTIVELY, AND THE PROPORTION IN COMPONENT SPACE IS THE AMOUNT OF VARIABILITY IN THE PRINCIPAL COMPONENT ANALYSIS SOLUTION ACCOUNTED FOR BY THAT MANY COMPONENTS (CUMULATIVE), OR THAT COMPONENT INDIVIDUALLY (ABSOLUTE).

C-045629

C-045629

TABLE 6

SORTED ROTATED COMPONENT LOADINGS (PATTERN MATRIX) FOR THE PRINCIPAL COMPONENTS ANALYSIS ON POLLUTANT & HEALTH VARIABLES FROM MATURE, FEMALE STRIPED BASS COLLECTED IN THE SACRAMENTO - SAN JOAQUIN DELTA IN 1984 & 1985. (N=74)

COMPONENT #	1	2	3	4	5	6	7	8
COMPONENT NAME	SEXUAL MATURITY	FAT SOLUBLE POLLUTANTS	PARASITES & TRACE METALS	MORPHOLOGY, SEASON & Cr	LEAN OLDER FISH & Hg	FECUNDITY & FISH CONDITION	TAPEWORM LESIONS & RAFTS	YELLOW EGG COLOR & MAH's
EGGSTAGE	0.857	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LSI	-0.806	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Zn	0.742	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cu	0.685	0.000	0.000	0.000	0.000	0.000	0.000	0.418
GSI	0.638	0.000	0.000	0.000	0.000	0.540	0.000	0.000
PESTICID	0.000	0.854	0.000	0.000	0.000	0.000	0.000	0.000
DDT_MET	0.000	0.842	0.000	0.000	0.000	0.000	0.000	0.000
LIPID	-0.399	0.707	0.000	0.358	0.000	0.000	0.000	0.000
TOT_PCB	0.000	0.688	0.000	-0.351	0.000	0.000	0.000	0.000
TAPELARV	0.000	0.000	0.765	0.000	0.000	0.000	0.000	0.000
Cd	0.455	0.000	0.623	0.000	0.000	0.000	0.000	0.000
RNDWLARV	0.000	0.000	0.592	0.000	0.000	0.000	0.000	0.000
Se	0.383	0.000	0.544	0.000	0.347	0.000	0.000	0.371
BODYPROP	0.000	0.000	0.000	0.872	0.000	0.000	0.000	0.000
Cr	0.000	0.000	0.000	-0.678	0.000	0.000	0.000	0.000
DAY_IN_Y	0.354	0.000	0.000	-0.613	0.000	0.000	0.000	0.000
MES_FAT	0.000	0.322	0.000	0.000	-0.740	0.000	0.000	0.000
Hg	0.000	0.000	0.000	0.000	0.723	0.000	0.000	0.000
AGE	0.000	0.000	0.497	0.000	0.574	0.000	0.000	0.000
IFECUND	0.000	0.000	0.000	0.000	0.000	0.810	0.000	0.000
KFL	0.000	0.000	-0.430	0.000	-0.356	0.573	0.000	0.000
TAPELESN	0.000	0.000	0.000	0.000	0.000	0.000	0.788	0.000
TAPERAFT	0.000	0.000	0.000	0.000	0.000	0.000	0.744	0.000
RANK2EC	0.000	0.000	0.000	-0.370	0.000	0.000	0.000	-0.704
MAH	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.689
STRPtot	0.000	0.000	0.000	0.000	0.413	0.000	0.359	0.000
PERC_RES	0.429	0.319	0.000	0.000	0.000	-0.462	0.000	0.000
LOCATION	0.000	0.429	0.449	0.000	0.000	0.000	-0.349	0.000
TOT_ABN	0.354	0.000	0.000	0.000	0.000	0.000	0.000	0.000
% OF VARIANCE	14.14	11.86	9.73	8.18	7.99	6.62	6.40	6.06

THE ABOVE COMPONENT LOADING MATRIX HAS BEEN REARRANGED SO THAT THE COLUMNS APPEAR IN DECREASING ORDER OF VARIANCE EXPLAINED BY COMPONENTS. THE ROWS HAVE BEEN REARRANGED SO THAT FOR EACH SUCCESSIVE COMPONENT, LOADINGS GREATER THAN 0.5000 APPEAR FIRST. LOADINGS LESS THAN 0.3160 HAVE BEEN REPLACED BY ZERO AS THEY WERE NOT INTERPRETED. THE "% OF VARIANCE" EQUALS THE AMOUNT OF VARIABILTY (VARIANCE) IN THE ORIGINAL DATA ACCOUNTED FOR BY THAT SPECIFIC COMPONENT. A "NAME" WAS ASSIGNED TO EACH COMPONENT BASED ON THE VARIABLES THAT WERE MOST HIGHLY CORRELATED WITH IT, TO HELP THE READER INTERPRET AND IDENTIFY INDIVIDUAL COMPONENTS.

C-045630

C-045630

C-045631

TABLE 7

CORRELATION MATRIX FOR THE PRINCIPAL COMPONENTS ANALYSIS ON POLLUTANT & HEALTH VARIABLES FROM MATURE. FEMALE STRIPED BASS COLLECTED IN THE SACRAMENTO - SAN JOAQUIN DELTA IN 1984 & 1985. (N=74)

	LOCATION	AGE	STRPtot	RANK2EC	TAPELARV	TAPERAFT	RNDWLARV	MES_FAT	EGGSTAGE	PERC_RES	Cd	Cr	Cu
LOCATION	1.000												
AGE	0.275	1.000											
STRPtot	0.063	-0.030	1.000										
RANK2EC	0.205	0.091	0.118	1.000									
TAPELARV	0.138	0.191	-0.067	0.074	1.000								
TAPERAFT	-0.079	0.049	0.172	-0.029	0.341	1.000							
RNDWLARV	0.147	0.452	0.006	0.121	0.308	0.135	1.000						
MES_FAT	-0.026	-0.302	-0.156	-0.078	-0.078	-0.103	-0.040	1.000					
EGGSTAGE	-0.289	-0.099	0.050	-0.059	0.040	0.063	-0.158	-0.265	1.000				
PERC_RES	0.005	-0.128	0.130	-0.146	-0.005	0.190	-0.253	0.207	0.241	1.000			
Cd	-0.066	0.317	-0.020	-0.070	0.594	0.383	0.267	-0.193	0.309	0.063	1.000		
Cr	0.082	-0.141	0.008	0.345	-0.048	-0.013	-0.066	-0.018	0.199	-0.014	-0.035	1.000	
Cu	-0.139	-0.069	0.003	-0.232	0.310	0.123	0.048	-0.036	0.518	0.145	0.544	0.044	1.000
Hg	0.041	0.562	0.207	0.076	0.152	0.194	0.448	-0.551	0.209	-0.213	0.338	0.075	0.125
Zn	-0.140	-0.026	0.042	-0.199	0.246	0.179	0.053	-0.230	0.637	0.112	0.401	0.142	0.688
Se	-0.007	0.269	0.095	-0.140	0.476	0.161	0.323	-0.333	0.277	-0.116	0.691	-0.003	0.638
MAH	-0.130	-0.069	-0.044	-0.367	0.090	-0.014	-0.016	0.230	0.004	0.156	0.068	-0.092	0.169
LIPID	0.104	-0.071	-0.062	-0.157	-0.249	-0.219	-0.118	0.493	-0.426	0.161	-0.361	-0.448	-0.323
TOT_PCB	0.268	0.081	0.193	-0.011	0.093	0.035	0.120	0.142	-0.173	-0.023	-0.001	-0.028	-0.018
DDT_MET	0.256	-0.166	0.046	-0.081	-0.395	-0.261	-0.205	0.397	-0.249	0.187	-0.487	-0.177	-0.330
PESTICID	0.245	-0.202	0.105	-0.104	-0.340	-0.209	-0.255	0.429	-0.330	0.212	-0.465	-0.143	-0.330
TOT_ABN	0.008	0.129	0.012	0.048	0.087	0.045	-0.127	-0.169	0.199	-0.034	0.236	0.146	0.140
TAPELESN	-0.210	0.096	0.063	-0.135	0.181	0.449	0.098	-0.116	0.098	0.062	0.319	-0.078	0.178
KFL	-0.390	-0.239	-0.037	-0.023	-0.211	-0.006	-0.079	0.142	0.158	-0.052	-0.139	-0.053	0.052
BODYPROP	-0.223	0.074	-0.292	-0.290	0.082	0.010	0.063	0.132	0.011	0.201	0.158	-0.512	0.027
IFECUND	0.042	0.250	-0.031	-0.034	0.048	0.082	0.131	-0.120	-0.062	-0.318	0.139	0.003	0.045
GSI	-0.196	0.174	-0.081	0.023	0.165	0.113	0.128	-0.309	0.629	-0.050	0.386	0.189	0.452
LSI	0.083	-0.055	-0.027	-0.142	-0.196	-0.179	0.057	0.322	-0.736	-0.116	-0.491	-0.301	-0.525
DAY_IN_Y	0.100	-0.229	0.196	0.303	0.034	0.090	-0.037	0.023	0.308	0.041	0.005	0.365	0.118

	Hg	Zn	Se	MAH	LIPID	TOT_PCB	DDT_MET	PESTICID	TOT_ABN	TAPELESN	KFL	BODYPROP	IFECUND
Hg	1.000												
Zn	0.324	1.000											
Se	0.544	0.483	1.000										
MAH	-0.059	0.049	0.116	1.000									
LIPID	-0.537	-0.513	-0.516	0.160	1.000								
TOT_PCB	-0.060	-0.129	-0.050	0.095	0.357	1.000							
DDT_MET	-0.394	-0.347	-0.510	0.058	0.785	0.432	1.000						
PESTICID	-0.489	-0.377	-0.510	0.098	0.802	0.542	0.920	1.000					
TOT_ABN	0.192	0.190	0.225	0.026	-0.176	0.049	-0.112	-0.101	1.000				
TAPELESN	0.118	0.079	0.236	-0.116	-0.053	0.210	-0.164	-0.125	0.037	1.000			
KFL	-0.162	0.097	-0.278	0.027	0.095	-0.091	0.060	-0.021	0.038	0.012	1.000		
BODYPROP	-0.133	-0.054	0.021	0.151	0.250	-0.366	-0.021	-0.070	-0.122	0.019	0.272	1.000	
IFECUND	0.327	0.010	0.116	-0.036	-0.180	-0.047	-0.167	-0.215	0.241	-0.084	0.216	0.073	1.000
GSI	0.488	0.489	0.367	-0.058	-0.513	-0.213	-0.451	-0.490	0.234	0.063	0.209	0.120	0.526
LSI	-0.342	-0.636	-0.386	0.195	0.637	0.247	0.410	0.502	-0.255	-0.129	0.001	0.084	-0.052
DAY_IN_Y	0.125	0.172	0.015	-0.124	-0.284	0.159	0.032	-0.046	0.172	0.026	0.121	-0.418	0.119

	GSI	LSI	DAY_IN_Y
GSI	1.000		
LSI	-0.572	1.000	
DAY_IN_Y	0.271	-0.339	1.000

C — 0 4 5 6 3 1

APPENDIX 3

STRIPED BASS EGG AND LARVA LOSSES AT THE CVP AND SWP

Estimates of striped bass egg and larva losses to the CVP and SWP have been made by multiplying estimates of egg and larva population densities in the Delta channels within the influence of the diversions by the amounts of water being diverted. The sampling of eggs and larvae is based on oblique tows with large plankton nets. We evaluated the extent to which the egg and larva population was reduced by entrainment by the CVP and SWP during the egg and larva stages in 1985 and 1986.

This analysis was only possible for the CVP-SWP in 1985 and 1986 because it required good measures of the numbers and sizes of larvae entrained and similar measures of the population in the estuary. Complete information was not available for the other diversions, other years, or fish beyond the larval stage.

The percentage reduction in the number of 20 mm larvae was estimated as the cumulative effect of removing eggs and larvae stratified by 1 mm size intervals from the estuary. This analysis is basically a comparison of the survival that actually occurred in the population and the higher survival that would have occurred if there were no CVP-SWP entrainment. The extent to which the population is reduced by entrainment during the egg and larva stages (percent reduction, PR) is

obtained from

$$PR = 1 - \frac{S_E}{S_{WO}} \times 100$$

where S_E is present survival (with entrainment) and S_{WO} is an estimate of what survival would have been if there were no entrainment.

Estimates of survival with entrainment were made directly from the observed decline in indices of numbers of larvae living in the river system. For this purpose we estimated indices of numbers of fish growing through successive 1 mm length classes (Appendix Tables 1-4). Indices of the numbers of larvae entering each length class (N_0) were based on DFG's striped bass egg and larva survey.

To calculate N_0 for each length group we used the following equation:

$$N_0 = \frac{\bar{N} \cdot Z \cdot 90}{A}$$

The numerator ($\bar{N} \cdot Z \cdot 90$) is an estimate of the number of deaths that occur in a season. $\bar{N}$ is the total weighted catch over the season divided by the number of sampling days. The symbol, Z, is an estimate of the instantaneous mortality rate[1/] based on the daily decline in weighted catch of larvae as they grow from 6-14 mm (Appendix Figure 1).

$\bar{N} \cdot Z$ then is the average number of deaths per day. Multiplying $\bar{N} \cdot Z$ by 90 estimates the number of deaths over the 3 month sampling season.

1/ The natural logarithm (with sign changed) of the survival rate. The ratio of number of deaths per unit time to population abundance during that time if all deceased fish were to be immediately replaced so that population does not change.

Table 1. Indices of Larval Striped Bass Abundance in 1985.

Length group (mm)	Total Wtd 1/ Catch x 10^4	# Sampling days	N x 10^4 2/	x	Z 3/	x	Season 4/ Length	÷	$1-e^{-zt}$ 5/	(t) 6/	$\hat{N}_0$ x 10^4 7/
Eggs	636,328	38	16,745		.327		90		.4800	2.00	1,026,678
4	36,395	23	1,582		.327		90		.7712	4.51	60,371
5	248,243	23	10,793		.327		90		.7712	4.51	411,875
6	628,451	23	27,324		.327		90		.7712	4.51	1,042,720
7	62,336	23	2,710		.327		90		.6816	3.50	117,012
8	18,317	23	796		.327		90		.5670	2.56	41,316
9	7,418	23	323		.327		90		.6176	2.94	15,392
10	3,110	23	135		.327		90		.5863	2.69	6,776
11	1,090	23	47		.327		90		.5613	2.52	2,462
12	674	23	29		.327		90		.5057	2.15	1,688
13	466	23	20		.327		90		.5057	2.15	1,164
14	281	23	12		.327		90		.5057	2.15	698

1/ Totals of egg and larva population densities x volume of each portion of the estuary represented by sampling station
2/ Average daily weighted catch (Total weighted catch ÷ sampling days).
3/ Instantaneous mortality rate based on estimated daily decline in abundance (See Appendix 3, Figure 1).
4/ Season length in days.
5/ Mortality (Ricker's A).
6/ Estimated time to grow through length interval (days).
7/ Index of numbers of fish entering each length interval.

C-045634

Table 2. Estimated impacts of larval striped bass entrainment in 1985.

Size Group (mm)	$\hat{N}_0$ 1/	Entrainment SWP	Entrainment CVP	Entrainment Total	S_E 2/	Z 3/	u 4/	A 5/	F 6/	M 7/	n 8/	S_{WO} 9/
Eggs	10,266,780,000	85,879,841	84,858,059	170,737,901			.0166					
4	603,710,000	4,733,873	1,945,492	6,679,365			.0111					
5	4,118,750,000	98,263,547	78,225,038	176,488,586			.0428					
6	10,427,200,000	204,234,102	163,958,264	368,192,365	.112	2.189	.0353	.888	.0870	2.102	.878	.122
7	1,170,120,000	23,966,600	15,066,159	39,032,759	.353	1.041	.0334	.647	.0537	.987	.627	.37[illegible]
8	413,160,000	12,892,114	4,640,096	17,532,210	.373	.986	.0424	.627	.0667	.919	.601	.39[illegible]
9	153,920,000	6,519,574	1,834,874	8,354,448	.440	.821	.0543	.560	.0796	.741	.523	.47[illegible]
10	67,760,000	1,516,429	1,036,541	2,522,970	.364	1.011	.0372	.636	.0591	.952	.614	.386
11	24,640,000	0	445,760	445,760	.685	.378	.0181	.315	.0217	.356	.300	.700
12	16,880,000	2,583,701	0	2,583,701	.690	.371	.1531	.310	.1832	.188	.171	.829
13	11,640,000	337,700	445,760	783,459	.600	.511	.0673	.400	.0860	.425	.346	.65[illegible]
14	6,980,000	211,378	0	211,378			.0303					

1/ Index of number of fish entering each length interval.
2/ Estimated actual survival to next length interval.
3/ Instantaneous mortality rate to next length interval $Z=-\log_e S_E$.
4/ Harvest of fish by entrainment (Total entrainment ÷ $\hat{N}_0$).
5/ % mortality in length interval $A=1-S_E$.
6/ Instantaneous rate of entrainment mortality $F=\frac{Zu}{A}$.
7/ Instantaneous rate of natural mortality $M=Z-F$.
8/ Conditional natural mortality rate (rate of mortality if there were no entrainment) $n=1-e^{-M}$.
9/ Estimated survival if there were no entrainment $S_{WO}=1-n$.

Table 3. Estimation of larval striped bass abundance in 1986.

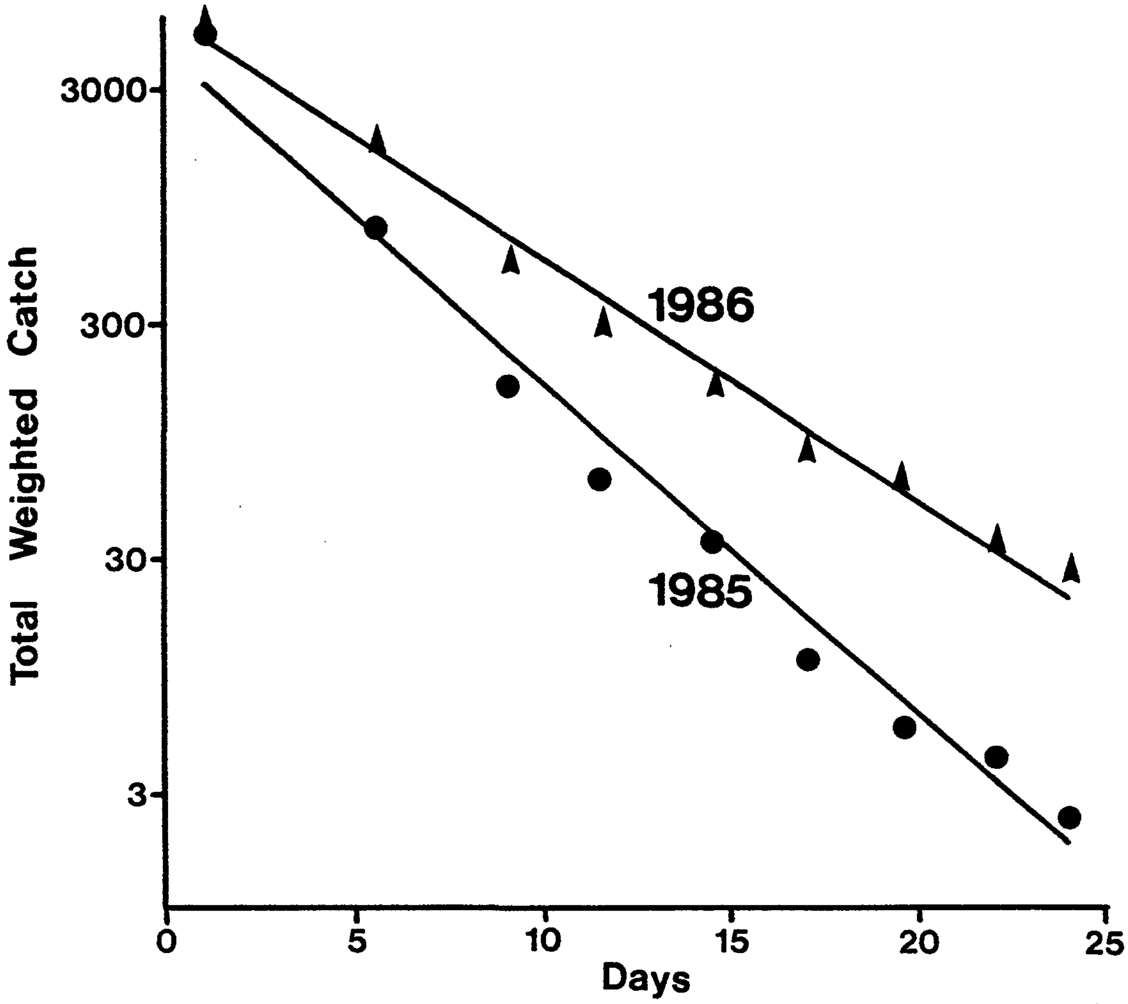
Length Group (mm)	Total Wtd[1/] Catch x 10^4	# Sampling Days	$N \times 10^4$ [2/]	x	Z[3/]	x	Season[4/] Length	÷	$1-e^{-zt}$ [5/]	(t)[6/]	$\hat{N}_0 \times 10^4$ [7/]
Eggs	369,030	38	9,711		.238		90		.3787	2.00	549,273
4	40,297	23	1,752		.238		90		.6582	4.51	57,016
5	200,035	23	8,697		.238		90		.6582	4.51	283,029
6	665,393	23	28,930		.238		90		.6582	4.51	941,478
7	164,353	23	7,145		.238		90		.5653	3.50	270,734
8	60,479	23	2,630		.238		90		.4563	2.56	123,460
9	28,882	23	1,256		.238		90		.5033	2.94	53,454
10	17,621	23	766		.238		90		.4728	2.69	34,703
11	7,703	23	335		.238		90		.4511	2.52	15,907
12	5,767	23	251		.238		90		.4005	2.15	13,424
13	3,793	23	165		.238		90		.4005	2.15	8,825
14	2,532	23	110		.238		90		.4005	2.15	5,883

1/ Totals of egg and larva population densities x volume of each portion of the estuary represented by sampling stations.
2/ Average daily weighted catch (Total weighted catch ÷ # sampling days).
3/ Instantaneous mortality rate based on estimated daily decline in abundance (See Appendix 3, Figure 1).
4/ Season length in days.
5/ Mortality (Ricker's A).
6/ Estimated time to grow through length interval (days).
7/ Index of numbers of fish entering each length interval.

Table 4. Estimated impacts of larval striped bass entrainment in 1986.

Size Group (mm)	$\hat{N}_0$ 1/	Entrainment SWP	Entrainment CVP	Entrainment Total	S_E 2/	Z 3/	u 4/	A 5/	F 6/	M 7/	n 8/	S_{WO} 9/
Eggs	5,492,730,000	3,773,199	9,273,122	13,046,321			.0024					
4	570,160,000	365,160	159,006	524,167			.0009					
5	2,830,290,000	15,877,707	6,948,947	22,826,654			.0081					
6	9,414,780,000	10,829,521	6,685,103	17,514,624	.288	1.245	.0019	.712	.0033	1.242	.711	.289
7	2,707,340,000	5,677,200	5,396,107	11,073,307	.456	.785	.0041	.544	.0059	.779	.541	.459
8	1,234,600,000	3,058,530	3,869,975	6,928,505	.433	.837	.0056	.567	.0083	.829	.564	.436
9	534,540,000	2,340,376	2,141,980	4,482,356	.649	.432	.0084	.351	.0103	.422	.344	.656
10	347,030,000	3,140,890	3,863,765	7,004,654	.458	.781	.0202	.542	.0291	.752	.529	.471
11	159,070,000	1,786,771	3,136,863	4,923,634	.844	.170	.0310	.156	.0338	.136	.127	.873
12	134,240,000	1,671,626	1,802,764	3,424,390	.657	.420	.0255	.343	.0312	.389	.322	.678
13	88,250,000	814,674	1,709,896	2,524,570	.667	.405	.0286	.333	.0348	.370	.309	.691
14	58,830,000	1,333,116	543,503	1,876,619								

1/ Index of number of fish entering each length interval.
2/ Estimated actual survival to next length interval.
3/ Instantaneous mortality rate to next length interval $Z=-\log_e S_E$.
4/ Harvest of fish by entrainment (Total Entrainment ÷ $\hat{N}_o$).
5/ % mortality in length interval $A=1-S_E$.
6/ Instantaneous rate of entrainment mortality $F=\frac{Zu}{A}$.
7/ Instantaneous rate of natural mortality $M=Z-F$.
8/ Conditional natural mortality rate (rate of mortality if there were no entrainment) $n=1-e^{-M}$.
9/ Estimated survival if there were no entrainment $S_{WO}=1-n$.



Appendix 3, Figure 1. Rate of decline of striped bass larvae in 1985 and 1986.

The denominator, A, is an estimate of the percentage of the population that died. $A=1-e^{-Zt}$ (Ricker 1975) where e is the base of the set of natural logarithms and t is an estimate of the number of days that it takes for larvae to grow through the length interval (from Low 1986). The term, e^{-Zt} represents survival during the period required for larvae to grow through the length class.

Because our nets are not effective at sampling larvae smaller than 6 mm or larger than 14 mm, direct estimates of how much the population is reduced by entrainment during the larva stage are limited to the period when larvae were growing from 6 to 14 mm. We have estimated that this is a period of about 23 days.

The estimate of survival with entrainment over this period, $S_{E,\ 6\text{-}14}$, is simply:

$$S_{E,\ 6\text{-}14} = \frac{N_{0,14}}{N_{0,6}}$$

Calculating survival without entrainment is more complex. Our approach, for each length interval, was to separate the amount of mortality presently caused by entrainment from total mortality, and then calculate what the rate of total mortality would have been if there were no entrainment. This is equivalent to calculating Ricker's (1975) "Conditional Natural Mortality Rate" which he defines as "The fraction of an initial stock that would die from causes other than fishing (entrainment in our case) during a year (or season), if there were no fishing (entrainment) mortality. The letter n is used to denote the conditional natural mortality rate. For each 1 mm length group, survival without entrainment (S_{WO}) is calculated from:

$S_{WO} = 1-n$

Survival without entrainment over the entire interval from 6-14 mm is the product obtained when all of the individual survivals are multiplied together.

$S_{WO,\ 6-14} = S_{WO,6} \times S_{WO,7} \times \ldots \times S_{WO,13}$

Several steps are necessary to calculate n for each length interval.

$n = 1-e^{-M}$ (Ricker 1975)

where e is the base of the set of natural logarithms and M is the instantaneous rate of mortality from "natural causes" (causes other than entrainment).

M=Z-F (Ricker 1975) where Z is the instantaneous rate of mortality from all causes and F is the instantaneous rate of mortality from entrainment (from fishing in the classical use of this equation).

$Z = -\log_e S_E$ where S_E represents survival during the period that larvae are within a length interval.

S_E is calculated from indices of numbers of larvae entering a length interval (length i) and subsequently surviving to the next length interval (length i+1).

$$S_E = \frac{N_{0\ i+1}}{N_{0\ i}}$$

$F = \frac{Zu}{A}$ (Ricker 1975), where u is the expectation of loss from entrainment (expectation of death from fishing or "exploitation rate" in the classical use).

Expectation of entrainment loss $u=\frac{E}{N_O}$, where E is an index of the number of larvae of the appropriate length that were entrained.

Indices of numbers of larvae entrained catagorized by 1 mm size intervals were based on the sampling near the CVP and SWP intakes. This sampling consisted of 10-minute tows with the same net that is used for the egg and larva surveys. A total of 62 samples were taken in 1985 and 82 samples were collected in 1986. The sampled densities of larvae in each length category were multiplied by the amounts of water diverted during the days represented by each sample. These products were summed to obtain totals for each length category in each season (Appendix 3, Tables 2 and 4).

A has previously been defined as the percentage of the population that dies (Ricker uses the terms "actual total mortality rate" or "expectation of death").

$A=1-S_E$.

Percent Reduction in 1985

During 1985, outflows (mean April-June=6495 cfs) were not large enough to transport many of the striped bass larvae downstream to Suisun Bay. Hence, a substantial portion of the larvae remained in the Delta where they eventually became vulnerable to the draw of the CVP-SWP pumps. We have calculated that the water project pumps "harvested" an average of 4.5% of the initial population of each group of fish between the egg and 14 mm larva stage (u in Appendix 3, Table 2).

During this period, mortality was very high from all causes, as indicated by the decline in estimated abundance of more than 10 billion 6 mm larvae to about 7 million 14 mm larvae. Factors other than entrainment in exported water obviously caused a vast majority of the deaths (compare u with A, or F with Z and M in Appendix 3, Table 2). However, while the project pumps entrained an average of only 4.5% of the larvae in each size interval, the cumulative effect of this entrainment rate quickly becomes large (assuming that the entrained fish would have survived and grown in the same way that the fish that were not entrained did).

We have estimated that over the 6-14 mm size interval, survival with entrainment (actual survival) was 0.000669. If entrainment had not occurred, we estimate that the survival rate would have been .001269. The ratio of these survival estimates yields a percent reduction estimate of 47.3%

$$1-\frac{.000669}{.001269} = .473$$

In other words, entrainment of 6-13 mm larvae at the CVP-SWP pumps reduced the population almost in half. These results obviously imply that the total effect of entrainment was substantially larger as our calculation did not include effects of the entrainment of eggs, larvae smaller than 6 mm, or fish larger than 13 mm.

A rough approximation of the additional effect of entrainment of eggs and larvae smaller than 6 mm can be made by assuming that actual survival of eggs, 4, and 5 mm larvae equals that of 6 mm larvae; that survival of 5 mm larvae without entrainment equals that of 6 mm larvae; and that the difference between survival with and without entrainment for 4 mm larvae and eggs is half that for

6 mm larvae (% of population entrained, u, for these groups was roughly one half that for 6 mm larvae). Thus, the additional survivals with entrainment would be .112, .112, .112; the without entrainment survivals would be .122 (5 mm), .117 (4 mm), .117 (eggs). Survival from egg to 14 mm with entrainment would be .000000940; without entrainment, survival would be .000002119; and percent reduction from egg to 14 mm would be

$$1-\frac{.000000940}{.000002119} = .557 \text{ or } 55.7\%$$

We also know that effects of entrainment continue to accumulate through the size intervals in the other direction (larger fish). We do not have data which allow direct calculations, but to approximate potential entrainment effects over the range from egg to 20 mm we applied the with and without entrainment survivals for 13 mm fish (.600, .653) to the six length groups from 14-19 mm, and the estimated percent reduction from egg to 20 mm was

$$1-\frac{(.000000940 \times .600^6)}{(.000002119 \times .654^6)} = .735 \text{ or } 73.5\%$$

Based on these results (a direct estimate of 47.3% reduction in the period between 6 and 14 mm and an extrapolated estimate of 73.5% reduction in the period between egg and 20 mm), the conclusion is inescapable that larva entrainment by the CVP and SWP severely eroded the striped bass population in 1985 and that substantial erosion will occur in any year with similar outflows and water export rates.

We also want to emphasize, however, that these same calculations indicate that larva entrainment is not entirely responsible for the extremely low abundance of the 1985 year class. We have previously indicated that the young-of-the-year striped bass abundance index had an all time low value of 6.3 in summer 1985. Our calculation of a 73.5% reduction in abundance between the egg and 20 mm stages indicates that the index would have been 23.8 if there was no larva entrainment

$$\frac{6.3}{1-0.735} = 23.8.$$

An index of 23.8 is a relatively low index from the historic perspective.

Percent reduction in 1986

In 1986, Delta outflows were relatively high (mean April-June=21,190 cfs) and many striped bass larvae were transported to Suisun Bay where they were not subjected to the draw of the CVP-SWP export pumps. As a result, we have calculated that the average entrainment "harvest" of each size group was only 1.4% of the initial population of each group between the egg and 14 mm stages (Appendix 3, Table 4).

From 6-14 mm, the estimate of actual survival was .006249; and estimated survival without entrainment was .007309. From these estimates, the cumulative effect of entrainment over the 6-14 mm size range was a 14.5% reduction in the population.

$$1-\frac{.006249}{.007309} = .145$$

Extending the analysis back to the egg stage and forward to the 20 mm stage as we did for 1985 yields an entrainment caused reduction of 31.3% from the egg to 20 mm stage.

Hence, as expected from the higher outflows causing a more seaward distribution of larvae in 1986, CVP-SWP entrainment impacts were substantially lower than in 1985. Overall, our larval bass percent reduction analysis indicates that CVP-SWP entrainment severely reduces the striped bass larva population with the greatest impact occurring in drier, low flow years.

C-045645

Striped Bass Simulation Model
··· STRIPER ···

The Striped Bass Simulation Model, STRIPER, simulates the Striped Bass population in the Sacramento/San Joaquin Delta and San Francisco Bay region. It was initially designed to answer specific questions posed by the various committees studying the reasons for the decline of the fishery in recent years. It can be configured to evaluate hypotheses regarding issues such as the factors controlling recruitment, the effects of entrainment, the effects of stocking, and changes in size limit and fishing effort. A valuable feature of the simulation is that it contains what is known about the population and is driven by actual environmental data. Consequently it is well suited to answering the kinds of questions that have been asked by the various agencies concerned with fishery and water management.

STRIPER is an age-structured model. It keeps track of the number of fish at each age in the population. There are 15 year classes in the model. They are initialized to the population structure in 1958 then the model runs forward in time. For each year of the simulation, the program starts by computing recruitment for that year by one of several methods. It then computes the survival for each year class. Survivors are then promoted to the next year class and the young-of-the-year put in year class 1.

Recruitment

There are four relationships that can be used to drive recruitment in STRIPER. The first relationship simply uses the number of fish determined by the CDF&G Young-of-the-Year Index to drive the population. The second uses the regression of recruitment on historical water flows and diversions in the Delta to project recruitment. The third uses the projected egg production to adjust the second relationship under certain conditions. The fourth relationship uses the projected egg production and an index of larval survival from Delta flows to determine the yearly recruitment.

- Young-of-the-Year Index

Recruitment each year is simply the CDF&G Young-of-the-Year Index multiplied by one million.

$$YOY = YOY\_Index * 10^6$$

• Fish and Game Flow and Diversion relation

The Fish and Game Flow and Diversion recruitment relation uses a function of the Sacramento/San Joaquin Delta water outflow and delta agriculture diversions to specify the young-of-the-year each year of the simulation.

$$YOY = Abundance\_Index * 10^6$$

Where the young-of-the year Abundance_Index is from Stevens et al. (1985, p18):

$$\begin{aligned} Abundance\_Index = (& -170 \\ & - 0.196 * mean\_May\text{-}June\_diversions \\ & + 178.0 * log\_mean\_May\_outflow \\ & - 34.2 * (log\_mean\_May\_outflow)^2) \\ & + (-162.8 + 208.4 * log\_mean\_June\text{-}July\_outflow \\ & - 33.7 * (log\_mean\_June\text{-}July\_outflow)^2) \end{aligned}$$

The Abundance Index is calculated each time the model is run and stored in a model variable so that it can be plotted and displayed.

• Fish and Game Flow and Diversion with Threshold relation

A threshold value of egg production, below which recruitment depends on egg production in addition to flows and diversion, is added to the model. This type of recruitment relationship provides a better fit to the observed young-of-the-year index. The value of the egg threshold must be specified in the model If fecundity is less than the egg threshold

$$YOY = Abundance\_Index * (Fecundity / Egg\_Threshold) * 10^6$$

and above the threshold

$$YOY = Abundance\_Index * 10^6$$

• Fish and Game Survival relation

This recruitment relation uses a Survival Index and predicted egg production to determine the recruitment for each year.

$$YOY = Survival\_Index * Fecundity / Survival\_Multiplier$$

Where the Survival Multiplier is a model variable which must be specified and the Survival Index is from Stevens et al. (1985, p20):

Survival_Index = -3.7 + 2.39 * mean_May-July_outflow

The Survival Index is calculated each time the model is run and is stored so that it can be plotted or displayed at any time.

Harvest

The harvest of striped bass in STRIPER is based on harvest rates specified separately for males and females for each year. The default values used are from estimates supplied by CDF&G. To accommodate a minimum size limit for fishing and other factors limiting vulnerability, age 3 and 4 fish are harvested according to the harvest vulnerability specified for each of the ages and sexes. Age 5 and older fish are fully vulnerable to fishing. The total harvest each year can be plotted or printed at any time.

The abundance each year is calculated as if the harvest rates were equal to 1 (vulnerability is taken into account). The abundance each year can be plotted or printed at any time.

Natural Survival

Striper has 13 variables specifying natural survival. Three variables specify survival of young-of-the-year, age 1 through 3, and age 9 through 15, are constant throughout the simulation, and effect males and females equally. Ten variables control the survival due to natural causes separately for males and females at each of ages four through 8. Having this many variables is rather cumbersome but allows the model to simulate any of the various current views of the age dependence of mortality. For the baseline model we have used the natural mortality estimate based on tag returns.

Stocking

The model allows for stocking different numbers of fish each year but all stocking must be of fish at a given age over all years. The model is initialized with the historic stocking levels. Stocked fish are simply added to the population in the age class specified.

Entrainment

The data used to drive the Striped Bass Simulation Model were collected during periods of historic entrainment of larval fish. As a result, the recruitment relations in the model effectively assume entrainment. To determine how things would have been different under various entrainment levels, the historic entrainment must be compensated. This is handled by adding the appropriate number of fish to recruitment to decrease the effects of entrainment. Fish may also be removed from the population to effectively increase entrainment.