

FCG-1990

1990 Working Papers of the Food Chain Group

Interagency Ecological Studies Program
for the
Sacramento-San Joaquin Estuary

Working Papers 1-6

June 1991

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Foreword

The Food Chain Group was formed in January 1988 to increase communication, integrate studies, facilitate work, and increase efficiency within the Interagency Fisheries and Water Quality Committee of the Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary. We were asked to examine two questions:

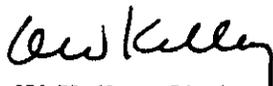
- » What has caused the changes in production at all levels of the food chain in the estuary?
- » Has the increased mortality of young striped bass been caused by a change in food supply?

Both are complicated questions, requiring descriptions of the changes, as defined by rigorous analysis of the large databases, and then a search for causes. To that end, we have met almost monthly for a full day's examination of data analyses on new and old hypotheses. Meetings are open to any scientist with information on this subject.

More than two dozen draft "working papers" have been presented by members and others for review and criticism. For the first 2 years, we were using these only as tools in a very dynamic and serious peer review process. Often the discussions have caused authors to modify their ideas or methods, or even to discard them.

Last year we were asked to share with others the information developed in this peer review. We decided to release those papers that had evolved to a level that might interest other workers in the form of a working paper series. This 1990 compilation is our first six.

All of these papers are relevant to the food chain or web of this estuary, but their relationship to other work is not always apparent. We thought it useful to write a short "Comments of the Food Chain Group" at the end of each paper to help us all understand how this work is related to other investigations and to our charge, to express divergent views, and to remind us about next steps.



D. W. Kelley, Chairman
Food Chain Group

These working papers reflect the authors' current ideas and understanding, but not necessarily the consensus of the Food Chain Group or the Interagency Ecological Studies Program. The ideas, data analyses, and drafts were critiqued in one or more of our regular meetings and in discussions and correspondence after those meetings, but they are still subject to change as more information is analyzed and our understanding improves.

Information presented here should not be quoted or used without discussing it with the author and obtaining his or her consent.

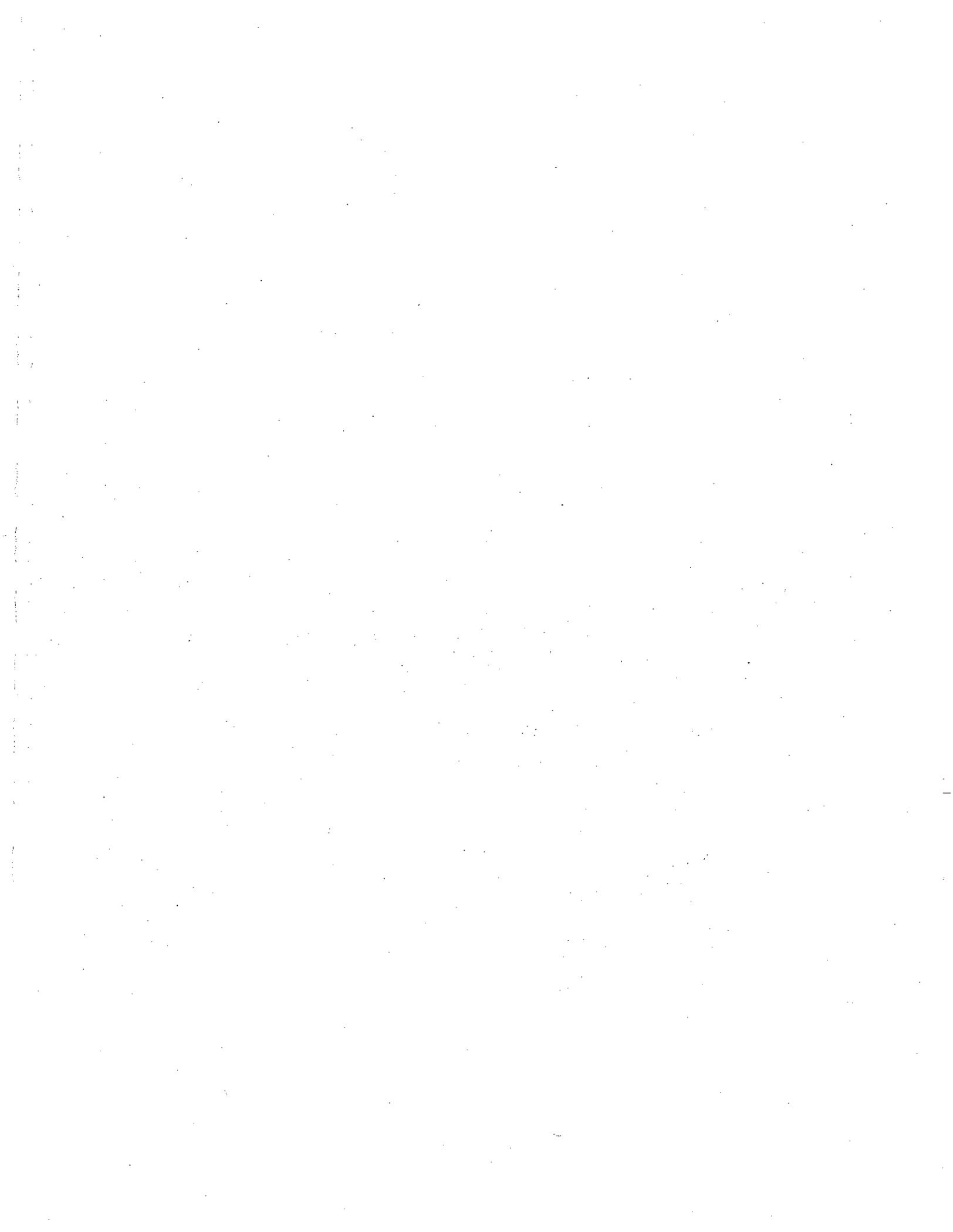
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Organization

Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary

A Cooperative Study by

California Department of Water Resources
State Water Resources Control Board
U.S. Bureau of Reclamation

U.S. Army Corps of Engineers

California Department of Fish and Game
U.S. Fish and Wildlife Service
U.S. Geological Survey

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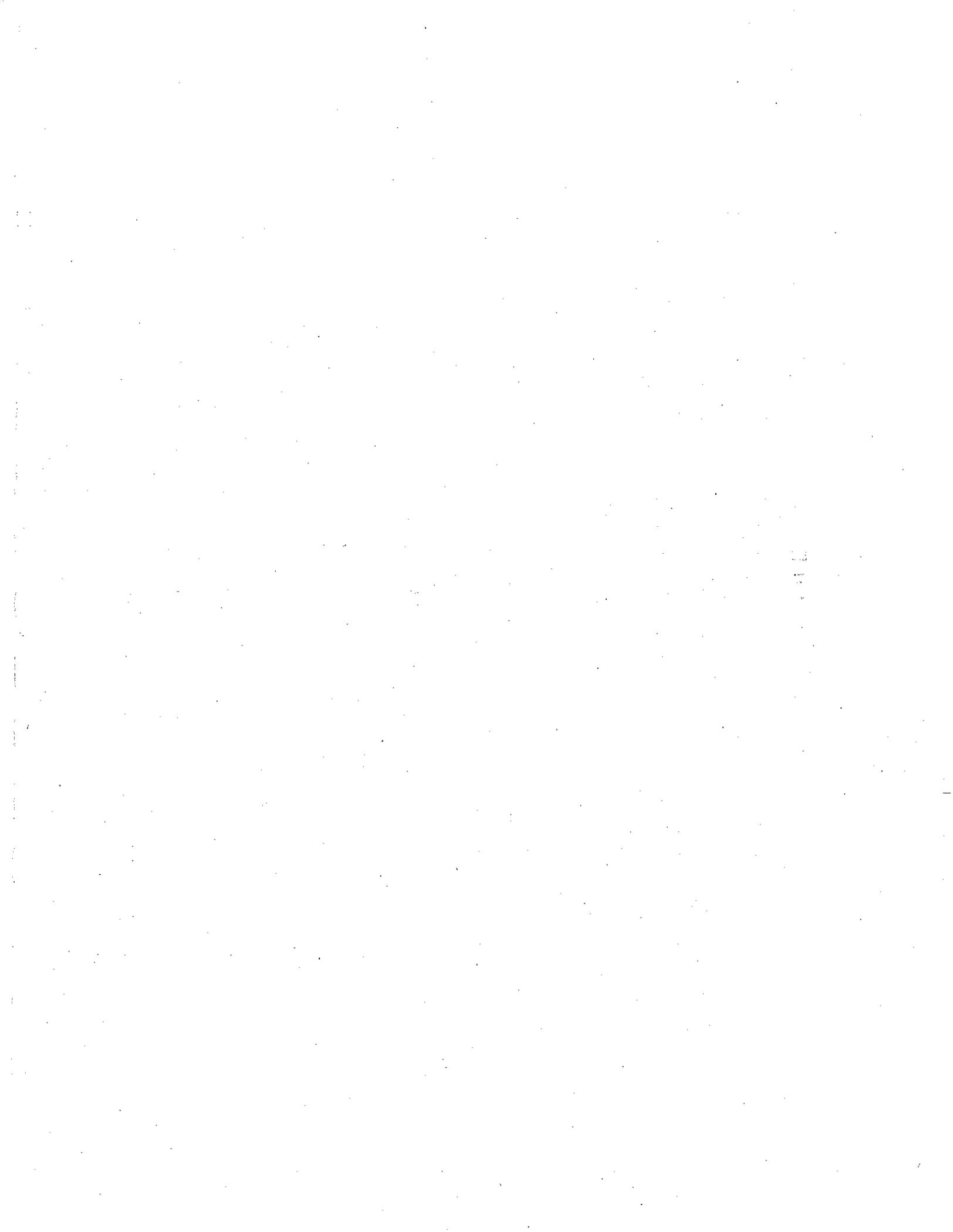
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Laboratory Tests of Predation by the Introduced Clam *Potamocorbula* on Larval Stages of the Zooplankters *Eurytemora affinis* and *Pseudodiaptomus* sp.

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June 1990

Abstract: The objective was a preliminary test of the hypothesis that the clam *Potamocorbula* could directly affect abundance of common copepods through predation. Experiments were conducted in 1-liter beakers using the nauplii of two abundant copepods, *Eurytemora affinis* and *Pseudodiaptomus* sp. Significant differences between experimental beakers and controls without clams for *Eurytemora* revealed that the clam could consume these nauplii; no significant consumption was observed for *Pseudodiaptomus*.

Introduction

The recent invasion of the San Francisco Bay estuary by the euryhaline clam *Potamocorbula* has caused concern over its ecological impact. In particular, scientists at the U.S. Geological Survey believe filtration by the clam is the cause of extremely low values of chlorophyll in the bay in 1988. The high filtration rate and enormously high abundance of the clam support this belief. Also, the high growth rate of phytoplankton suggests that phytoplankton biomass is controlled by consumption rather than by limits on production.

Our *Eurytemora affinis* egg production experiments so far show that food has not been limiting to the reproductive rate of the copepod at specific conductance levels of 2,500 and 5,000 $\mu\text{S}/\text{cm}$ (microSeimens per centimeter). However, in 1988 abundance of *Eurytemora* was extremely low, and abundance of a copepod of the genus *Pseudodiaptomus*, apparently a recent introduction, was extremely high. Since food limitation of *Eurytemora* is unlikely, it is difficult to invoke a hypothesis of competition for food.

An alternative hypothesis is that there has been an increase in predation on *Eurytemora* that is not affecting *Pseudodiaptomus* as much. The only

major recent change in the system has been the introduction of *Potamocorbula*. Therefore, we suspected that filtration by the clams could directly affect the copepods by killing nauplii.

The objective was to make a preliminary test of the hypothesis that the clam *Potamocorbula* could directly affect abundance of common copepods through predation. Copepods chosen for this test were *Eurytemora affinis* and *Pseudodiaptomus* sp.

Methods

On October 24, 1988, we collected copepods near Pacific Gas and Electric Company's power plant at Pittsburg, where specific conductance was about 10,000 $\mu\text{S}/\text{cm}$. We towed a 0.5-meter-diameter net of 250-micrometer mesh at about 3 meters depth while the boat drifted. We immediately placed the samples in a cooler of water from the same depth and took them to the Department of Fish and Game's laboratory at Elk Grove. There, adult females of both species were sorted out under a dissecting microscope and placed in 1-liter jars of water containing cultured phytoplankton (*Skeletonema costatum*, about 10 $\mu\text{g}/\text{L}$ chlorophyll). The copepods were allowed to reproduce for 3 days, after which the adults were screened out, leaving only nauplii. The samples were then taken to the

Bureau of Reclamation's laboratory in Sacramento.

On September 2 and October 26, Doug Ball used a Ponar grab sampler to collect clams, which were then maintained on cultured phytoplankton until they were used in experiments.

To begin the experiments, 200-milliliter subsamples of the water containing nauplii were split in half by pouring between two beakers. Each half-subsample was put in a 1-liter beaker containing 500 mL of Delta water (10,000 $\mu\text{S}/\text{cm}$ specific conductance) and 200 mL of the phytoplankton culture (10 $\mu\text{g}/\text{L}$ chlorophyll). Eight batches of 12 clams were sorted from the samples. Clams ranged from 10- to 18-mm shell length (Table 1), and care was taken to match sizes among batches.

Table 1
SIZES OF CLAMS USED IN EXPERIMENTS FOR
EURYTEMORA ONLY
(mm shell length)

	Treatment			
	Eury 1	Eury 2	Eury 3	Eury 4
16	18	18	18	18
17	18	16	16	16
16	14	14	15	15
13	14	14	14	14
13	12	13	14	14
12	12	13	13	13
13	12	13	13	13
12	11	13	12	12
11	11	13	12	12
11	11	12	11	11
11	11	11	10	10
10	11	10	10	10
Mean	13	13	13	13

Each batch contained about 3.45 grams wet weight of clams (Table 2). One batch of clams, chosen at random, was then added to one of the pairs of beakers.

Samples were allowed to incubate for about 2 hours. At the beginning and every 15 minutes, the contents of the beakers were gently stirred to reduce settling of the phytoplankton. At half-hour intervals, 5-mL samples were taken for *in vivo* fluorescence measurement. At the end of the experiment, some of the water from an experimental beaker and some from a control beaker was filtered for fluorescence blanks.

At the end of the experiment, the beakers were allowed to stand for about 10 minutes, then the water was decanted off through a 37- μm mesh to collect remaining nauplii, which were stained with neutral red and preserved in ~2% formaldehyde. The clams were then rinsed, and the rinse water was treated the same as the nauplii. The clams were put into clean culture water and allowed to sit for about 8 hours to clear their guts for examination of the feces.

Samples of nauplii, rinsed material, and feces were examined under a dissecting microscope, and the nauplii were counted. Nauplii that had not taken up the stain were assumed to have died before the end of the experiment; if intact, these were not included in the counts. Clearance rates (*i.e.*, consumption rate divided by prey density, expressed as volume per time) were determined for the nauplii and, using the fluorescence data, for the phytoplankton.

Table 2
TOTAL WEIGHT OF CLAMS
USED IN EXPERIMENTS
(g wet for 12 clams)

Replicate	<i>Eurytemora</i>	<i>Pseudodiaptomus</i>
1	3.24	3.16 *
2	3.74	3.16 *
3	3.72	3.24
4	3.66	3.67

* Two samples were inadvertently combined before the clams were weighed.

Results

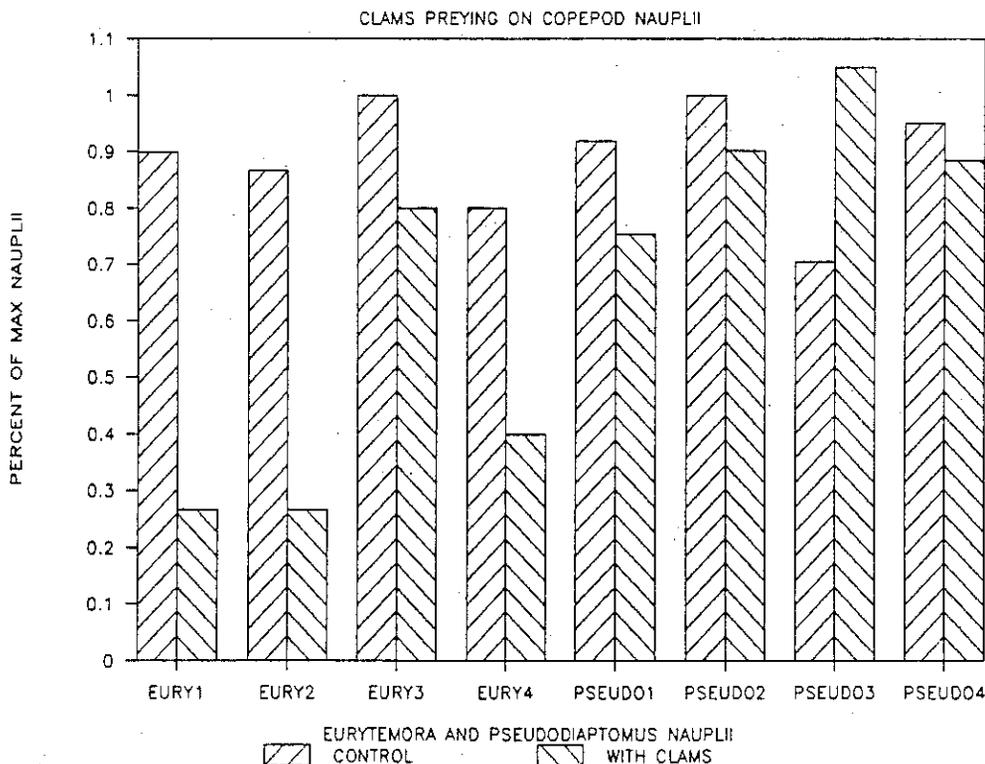
The clams apparently consumed nauplii of *Eurytemora*, but not those of *Pseudodiaptomus*. Figure 1 shows the differences in the numbers of nauplii remaining in each pair of control and experimental beakers. Except for one replicate that had a large number of nauplii in the experimental container, all of the *Eurytemora* replicates showed substantial differences between control and experimental beakers. The apparent heterogeneity of results was not significant (Chi-square test, 3 df, $p > 0.05$), so results were pooled. The number of nauplii retrieved differed significantly between experimental and control (Chi-square test, 1 df, $p < 0.01$). The same result was obtained without pooling the replicates. Clams reduced the *Eurytemora* population by 51 percent within 2 hours.

Results for *Pseudodiaptomus* were also pooled, and the result was not significant (Chi-square test,

1 df, $p < 0.1$). Removing the one replicate with the experimental higher than the control did not alter that result. I conclude that the clams were not eating this species to any great extent.

Clearance rates on *Eurytemora* averaged 0.37 L/hour, which was significantly different from 0. Clearance rates on the phytoplankton evidently decreased with time, as revealed by the changing slope of concentration on a log scale (Figure 2). This could have occurred because the clams reduced their filtration rate during the tests, although a similar effect would have resulted from the values approaching the limit of detection of the measurement technique. Average clearance rates in the beakers containing *Eurytemora* were 1.8 L/hour over the 2-hour period and 2.5 L/hour over the initial hour. Clearance rates per gram of wet clam tissue were 96 mL/hour (2.3 liters/day) for *Eurytemora* nauplii and 460 or 630 mL/hour for phytoplankton. Clearance rates on nauplii were

Figure 1
NAUPLII REMAINING



28 mL/clam/hour. Thus the phytoplankton were consumed five to ten times as fast as the copepods.

Remains of nauplii were not found in the clam feces. However, the experimental design was not well suited for finding naupliar remains, since most of the food the clams ate during the experiment was phytoplankton. The decrease in abundance of nauplii is sufficient to establish predation by the clams.

Discussion

This is apparently not the first time bivalves have been seen to filter zooplankton, although the phenomenon is not well known. In addition, this experiment does not show that they do so in the field — only that they could. If they do, and if the observed filtration rates can be scaled to field conditions, then clam predation could have significant effects on the population dynamics of the copepods. The high filtration rate on *Eurytemora* and apparent absence of filtration on *Pseudodiaptomus* suggest (but are far from proof) that this

clam could be responsible for the huge change in community structure of the zooplankton of the upper estuary.

There should be general concern over this possibility, since the clam appears to be euryhaline and to be able to grow and disperse rapidly. It could have a profound, long-lasting effect on San Francisco Bay and on neighboring bays and estuaries. These effects could even extend to striped bass.

Results of these experiments suggest that additional work should be done soon on effects of the clam on pelagic components of the Delta and Bay ecosystems. At present the U.S. Geological Survey is investigating distribution and abundance of the clam and is beginning to use a flume to investigate its effect on phytoplankton.

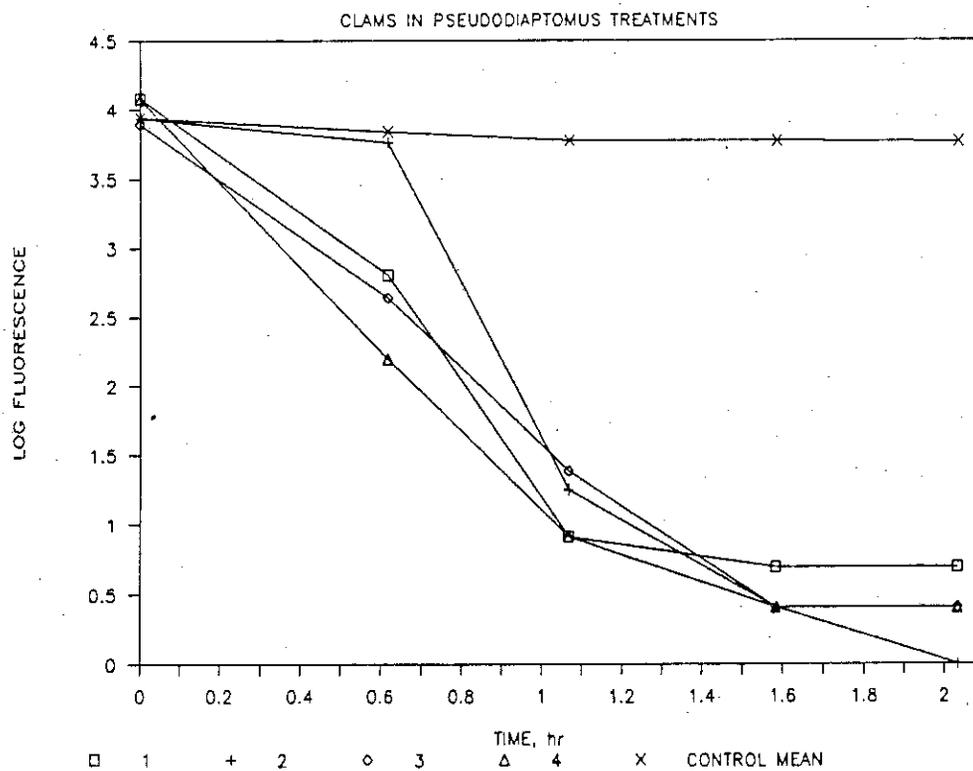
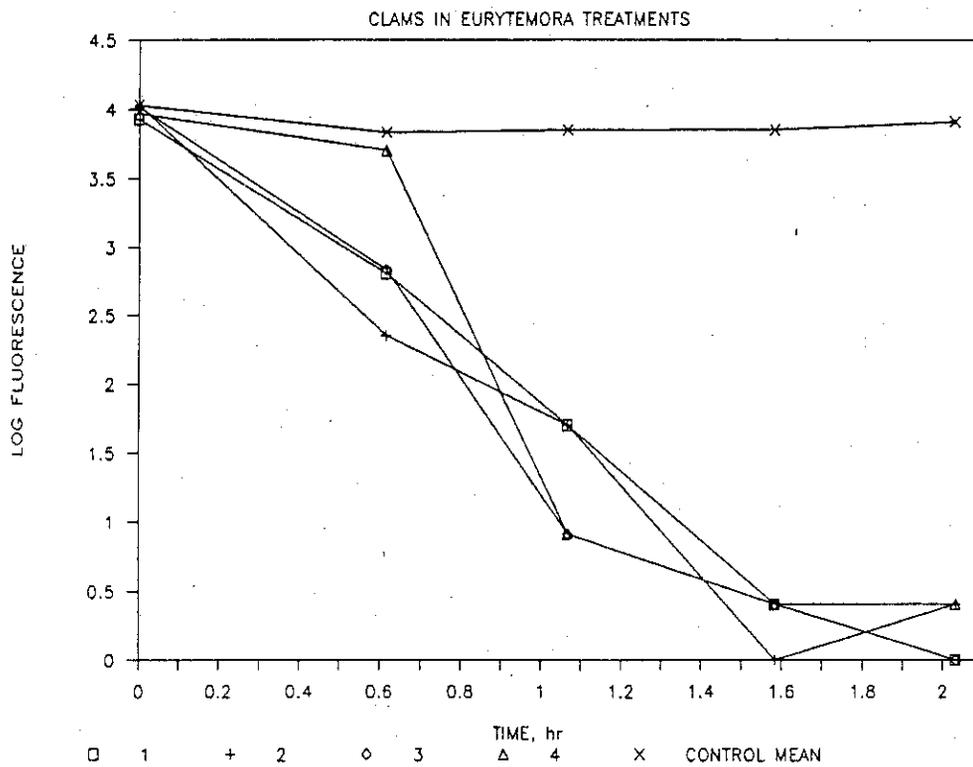
I recommend further investigations of the effect of *Potamocorbula* on the zooplankton. I also recommend that a field effort be planned for the spring spawning time of the clams to provide information on their ability to disperse into other systems.

Acknowledgments

Laboratory experiments discussed here were funded under U.S. Bureau of Reclamation Contract 9-PG-20-00700. Experiments were run as a cooperative effort with Doug Ball and the paper was submitted to Jim Arthur, both of the Bureau of Reclamation in Sacramento.

We are grateful to the California Department of Fish and Game for logistic support and laboratory facilities.

Figure 2
CLEARANCE OF PHYTOPLANKTON



Comments of the Food Chain Group

Dr. Kimmerer's finding that *Potamocorbula* sp. rapidly filtered out and consumed large numbers of *Eurytemora* but not *Pseudodiaptomus* from Delta water in 1-liter beakers adds to the work of the U.S. Geological Survey in Menlo Park on the role of this new clam in the Sacramento-San Joaquin estuary. The Fisheries and Water Quality Committee is funding additional tests in larger containers during the summer of 1990.

To better determine how much *Potamocorbula* has spread and define its present geographical distribution, the Department of Water Resources is also extensively sampling the benthos throughout Suisun Bay and the Delta. The combination of this work with that of the Geological Survey will provide information that will allow us to estimate the probable effect of *Potamocorbula*. We suspect the effect may be very significant.

D. W. Kelley, Chairman
Food Chain Group

Tests on Effects of Food Limitation on Reproduction in Two Copepod Species Important in the Diet of Larval Striped Bass

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June 1990

Abstract: A series of experiments was conducted in summer to early fall 1988 to test the hypothesis that common zooplankton in the Delta are limited by food. Reproductive rates of the copepods *Eurytemora affinis* and *Sinocalanus doerri* were determined in natural water with and without added phytoplankton. Results for *Eurytemora* showed no sign of food limitation, in that egg production rates did not differ between experimental and control treatments. For *Sinocalanus* there was a significant increase in reproductive rate in containers with added phytoplankton. Since 1988 was a year of low phytoplankton abundance, this implies that *Eurytemora* is not generally limited by food, at least in the adult stage. It further implies that competition between these species for food is not a common phenomenon in the Delta and that other mechanisms must be found to explain changes in the zooplankton species composition and abundance patterns.

Introduction

Scientific interest in the zooplankton of the Sacramento-San Joaquin River Delta and San Francisco Bay estuary has arisen out of a general interest in understanding system function and out of a more specific interest in explaining the decline in abundance of striped bass. Striped bass larvae feed on zooplankton, and the most common dietary component is the copepod *Eurytemora affinis*. A decline in *Eurytemora* abundance, roughly parallel to that of striped bass, suggests that food limitation may be at least part of the problem.

The reason for the decline in *Eurytemora* abundance is equally unclear. Shortly after the decline began in 1977, an introduced copepod, *Sinocalanus doerri*, became abundant at the upstream end of the range of *Eurytemora* and appeared to displace it in some areas. This led to the belief that competition between these two species could account for the changes.

Competition

Competition in natural systems is most often observed directly when competitors are vying for space. When the competition is for food or other raw materials, it cannot be observed directly but must be inferred from observation and experiment. This is often difficult, because the effect of one competitor on the other must be observed through its effect on the resource, and all of the intervening effects on both species and on the resource must be taken into account.

Among zooplankton, food is the only resource for which there can realistically be competition. Competition requires that food must be limiting — at least to the inferior competitor — and that both species must have an influence on the food supply. Thus, food limitation is a necessary but insufficient condition for competition.

Scope of This Study

The objective was to determine whether food is limiting to zooplankton in the Delta. This study was confined to the species *Eurytemora affinis* and *Sinocalanus doerri*. In addition, food limitation was tested only by its effect on reproductive rate, not on growth or survival. Growth rate of juveniles is related to reproductive rate (Sekiguchi *et al.*, 1980), although there is no information on which rate is affected first by food limitation. Juvenile growth rate has a higher threshold for food saturation in later than earlier life stages (Vidal, 1980), so if egg production is merely adult growth expressed as eggs instead of body weight (Sekiguchi *et al.*, 1980), one would expect that food limitation would affect egg production before it affected juvenile growth.

Scope of the study also had to be limited for logistical reasons. It was, therefore, set at five experiments over one summer and fall, with tests at (initially) three values of specific conductance and at two levels of food concentration: natural and enhanced with phytoplankton.

Methods

Experiment dates and conditions are summarized in Table 1. The number of sampling sites was reduced from three to two because of the low abundance of *Eurytemora*, which slowed the sort-

ing process considerably. Additional modifications to the experiments are discussed below.

Experiment Design

The basic design was factorial: there were two specific conductance values, control and experimental diets, and different experiment dates. Species were not used as a factor, since it was clear in all experiments that a huge difference existed between the egg production rates of these species. The principal test of interest was on the dietary factor (food added vs. control), either as a single factor or in an interaction with date. Initially, five replicates were planned for each species and treatment, but some of these were eliminated because of difficulty obtaining enough animals, because of errors in handling samples, or because of high mortality in some bottles.

Egg production of *Sinocalanus* was low in all experiments. In Experiment 5, egg production rates of this copepod in natural water at specific conductance of 500 and 2,500 $\mu\text{S}/\text{cm}$ (microSiemens per centimeter) were compared without added phytoplankton to determine if saline water suppressed reproduction of this species.

Sample Collection

Zooplankton samples were collected at sites in the Sacramento River chosen to represent nominal specific conductance levels of 500, 2,500, and 5,000

Table 1
DATES AND CONDITIONS OF EXPERIMENTS

Experiment	Date	Specific Conductance ($\mu\text{S}/\text{cm}$)	Water Temp. ($^{\circ}\text{C}$)	Incubation Temp. ($^{\circ}\text{C}$)	Pre-Incubation Time (days)	Males Present	Ambient Chlorophyll ($\mu\text{g}/\text{L}$)	Chlorophyll in Experimental Containers ($\mu\text{g}/\text{L}$)	Phytoplankton Species Added
1	7/13/88	5000	22	20	1	No	2.4	3.8	<i>Cyclotella</i> sp., <i>S. potamos</i>
		2500					4.0	7.6	
2	7/26/88	5000	22	19	1	No	5.3	16.8	<i>S. potamos</i>
		2500					4.0	13.5	
3	8/8/88	5000	21	20	1	No		7.5	<i>S. potamos</i>
		2500						5.8	
4	8/23/88	5000	20	17	2	Yes	3.3	23.2	<i>Thalassiosira</i> , <i>S. potamos</i>
		2500					3.6	13.2	
5	9/19/88	5000	19	17	2	Yes	2.0	11.6	<i>Thalassiosira</i> , <i>S. potamos</i>
		2500					2.1	11.4	

$\mu\text{S}/\text{cm}$. Sorting took so long in Experiment 1 that the sample from the upstream site ($500\mu\text{S}/\text{cm}$) was not processed, so this site was dropped in subsequent experiments. Samples were collected between 0800 and 1000 to avoid midday heat. At each site, water temperature was determined with a hand-held thermometer.

Samples were collected with a 0.5-meter-diameter conical net of 250-micrometer (μm) mesh, with a solid cod-end jar. The net was towed about 3 to 5 meters below the surface from a boat either drifting before the wind or underway with minimum power. This technique minimizes damage to the copepods. At the end of each tow the cod end of the net was lifted quickly out of the water and placed in a foam ice chest two-thirds full of water pumped from 3-5 meters depth. The cod end was unscrewed to dilute the sample to about 15 liters, and the sample was examined for sufficient animals. Typically a 5-minute tow provided a moderate density of animals in the ice chests. This was more than sufficient in the first three experiments, marginally sufficient in Experiment 4, and insufficient in Experiment 5 because of the declining relative abundance of *Eurytemora*. Water for use in the experiments was pumped from the same depth into 20-liter carboys.

Sample Processing

The samples were transported to the California Department of Fish and Game's Elk Grove laboratory for processing. The increase in temperature in the ice chests and carboys during transport was not over about 1°C . Contents of the ice chests were allowed to settle to reduce interference by detritus, and the supernatant was siphoned off and concentrated through a $265\text{-}\mu\text{m}$ mesh screen, using upward flow to minimize stress on the copepods.

Small subsamples of the concentrate were examined under a dissecting microscope, and adult females of *Eurytemora* and *Sinocalanus* were sorted out using Pasteur pipets. In Experiment 1, egg sacs on the *Eurytemora* females were aborted using fine needles, but this practice was abandoned

in subsequent experiments because of the time involved and the mortality induced. Groups of 3-5 females in the first experiment and 10-20 females in the later experiments were placed in 1-liter polyethylene bottles containing water of the same specific conductance that had been strained through a $52\text{-}\mu\text{m}$ mesh screen to remove eggs and nauplii. In some experiments, one or two males were also added.

When sorting was completed, phytoplankton from batch cultures was added to half the bottles, selected at random. The culture consisted of *Cyclotella* sp., *Skeletonema costatum*, *S. potamos*, *Thalassiosira* sp., or a mixture of two of these. Batch phytoplankton cultures were grown by Doug Ball in the U.S. Bureau of Reclamation laboratory in Sacramento or by Peggy Lehman in the Department of Water Resources laboratory in Bryte. All cultures were reported to be in log phase (*i.e.*, before or at the biomass peak) at the time of experiments. Chlorophyll concentration estimated from fluorescence measurements of the cultures was used to calculate how much phytoplankton culture should be added to each bottle. Typically, 200-250 mL was added to obtain a final chlorophyll concentration of $15\text{-}20\mu\text{g}/\text{L}$, compared to $2\text{-}5\mu\text{g}/\text{L}$ in the controls.

Experimental containers were filled to the top and capped, usually with a few milliliters of air remaining inside. They were then put on a plankton wheel that rotated the bottles end-over-end at about 1 rpm. The samples were incubated in a constant-temperature room near ambient temperature, with a light/dark cycle near the natural cycle. Initially, animals were incubated for 1 day to allow egg production rate to equilibrate. However, in *Eurytemora affinis* that may take up to 2 days (Heinle and Flemer, 1975), so incubation time was increased to 2 days in the last two experiments.

After incubation, samples were strained and rinsed through a $200\text{-}\mu\text{m}$ mesh screen using reverse flow to remove nauplii and loose eggs and retain adults, while minimizing damage. Adults were inspected, and dead copepods were removed

but not replaced. Bottles were again filled with the experimental or control water and incubated for about 24 hours. The samples were then concentrated using a 35- μm mesh screen, placed in small vials with some neutral red stain, and preserved with a few drops of formaldehyde.

Subsamples of the water used for incubation (and, in some experiments, of the water from some of the bottles after pre-incubation) were taken for chlorophyll analysis. Doug Ball did this analysis using acetone extraction and fluorometry with a Turner™ model 111 fluorometer (Strickland and Parsons, 1972). For some samples, water was strained through a 10- μm mesh screen, and the smaller fraction was analyzed for chlorophyll to determine a rough size distribution. These copepods generally feed efficiently only on cells larger than about 10 μm (Heinle and Flemer, 1975).

Analysis

Samples of zooplankton were examined within a week after the end of the experiment. Numbers of adults, eggs, and nauplii of each species were recorded. Adults were listed as either alive or dead, as indicated by the presence of the neutral red stain, and ripe or unripe, as determined from examination of the ovaries. In addition, lengths and gut fullness indices were recorded for each adult. The indices were: 0 (empty), 1 (< 1/4 full), 2 (1/4 to 1/2 full), 3 (1/2 to 3/4 full), 4 (3/4 full to full).

For *Sinocalanus*, the egg production rate was calculated as the number of eggs and nauplii of that species present at the end of the experiment divided by the number of days from the beginning of incubation to the end of the experiment. Calculations for *Eurytemora* were complicated by the fact that they carry their eggs, so screening after pre-incubation did not remove many eggs. Results for *Eurytemora* were, therefore, expressed either as the egg ratio (eggs per female) or the egg production rate (nauplii divided by females, corrected for incubation time). This gives the number of eggs hatching during the incubation, which is equal to

the egg production rate in steady state. For Experiment 1, in which egg sacs were aborted, it was assumed that no egg production took place during the first 24 hours.

Data were analyzed using t-tests or Analysis of Variance (ANOVA) on log-transformed egg production rates or egg ratios.

Results

In each experiment in which ambient chlorophyll was measured, chlorophyll in the experimental containers (to which chlorophyll had been added) exceeded that in the controls, usually by more than 10 $\mu\text{g/L}$. Perhaps of more importance were the greater numbers of phytoplankters large enough for efficient capture by the zooplankton in the experimental containers. On average, 30 percent of the chlorophyll in the ambient samples was retained on a 10- μm screen; in the experimental containers, the larger fraction comprised 69 percent of the chlorophyll. Thus, most of the added chlorophyll was larger than 10 micrometers, and the increase in > 10- μm chlorophyll was several-fold in the experiments in which it was measured.

The egg production rate of both species was highly variable. This is typical and is attributable to the fact that each copepod lays eggs in clutches, with a long interval (on the order of a day) between clutches. Therefore, most of the eggs produced in any one container would be from only a few females. Means in treatments for *Eurytemora* varied from 3 to 43 eggs/female/day; for *Sinocalanus* the range of means was 0.3 to 4.1.

Results of all experiments are reported in Tables 2 through 11. Because of the differences in treatment of *Eurytemora* during Experiment 1 and of *Sinocalanus* in Experiment 5, those results are reported slightly differently from the others. In Experiment 1, the heterogeneity of variance in egg production rates of *Eurytemora* prevented the use of parametric statistical tests; however, examination of the results (Table 2) shows little consistent difference in egg production rate between control

Table 2
EURYTEMORA EXPERIMENT 1,
EGG PRODUCTION RATES

Specific Conductance ($\mu\text{S/cm}$)	Treatment	Females Recovered	Dead Females	Egg Production Rate (Eggs/Female/Day)
5000	Control	5	0	18.8
5000	Control	3	0	9.3
5000	Control	5	0	14.0
5000	Control	5	0	0.2
Mean				10.6
5000	+ Food	4	0	12.3
5000	+ Food	3	0	16.5
5000	+ Food	4	1	14.0
5000	+ Food	4	0	21.0
Mean				16.0
2500	Control	4	0	7.5
2500	Control	3	1	6.1
2500	Control	4	0	21.9
2500	Control	4	0	0.0
2500	Control	5	0	0.2
Mean				7.1
2500	+ Food	2	1	0.0
2500	+ Food	3	0	1.0
2500	+ Food	3	0	3.0
2500	+ Food	4	1	9.7
2500	+ Food	3	1	1.3
Mean				3.0

Table 3
SINOCALANUS EXPERIMENT 1,
EGG PRODUCTION RATES

Specific Conductance ($\mu\text{S/cm}$)	Treatment	Females Recovered	Dead Females	Egg Production Rate (Eggs/Female/Day)
5000	Control	5	0	1.4
5000	Control	3	0	0
5000	Control	5	0	1.4
5000	Control	5	0	0
Mean				0.7
5000	+ Food	4	1	2
5000	+ Food	5	0	0.8
5000	+ Food	5	0	1
5000	+ Food	5	0	1
Mean				1.2
2500	Control	3	0	0
2500	Control	4	1	1.5
2500	Control	5	0	1.9
2500	Control	5	0	1.5
2500	Control	5	0	1
Mean				1.2
2500	+ Food	5	0	0.4
2500	+ Food	4	0	2.5
2500	+ Food	3	0	0
2500	+ Food	5	0	3.4
2500	+ Food	4	0	0.2
Mean				1.3

Table 4
EURYTEMORA EXPERIMENT 2,
EGG RATIOS AND EGG PRODUCTION RATES

Specific Conductance ($\mu\text{S/cm}$)	Treatment	Females Recovered	Dead Females	Egg Ratio	Egg Production Rate (Eggs/Female/Day)
5000	Control	9	0	16.3	14.8
5000	Control	10	0	6.6	20.8
5000	Control	11	0	13.0	13.5
5000	Control	6	2	12.5	19.0
Mean				12.1	17.0
5000	+ Food	11	0	8.2	18.5
5000	+ Food	7	0	7.1	19.0
5000	+ Food	6	1	0.2	22.0
5000	+ Food	6	2	0.7	25.0
Mean				4.0	21.1
2500	Control	10	0	8.7	9.1
2500	Control	7	0	3.7	13.1
2500	Control	9	0	2.3	13.3
2500	Control	9	0	3.6	11.7
Mean				4.6	11.8
2500	+ Food	10	0	4.8	8.3
2500	+ Food	9	0	3.9	13.1
2500	+ Food	10	0	8.7	10.3
2500	+ Food	8	1	15.8	9.5
Mean				8.3	10.3

Table 5
SINOCALANUS EXPERIMENT 2,
EGG PRODUCTION RATES

Specific Conductance ($\mu\text{S/cm}$)	Treatment	Females Recovered	Dead Females	Egg Production Rate (Eggs/Female/Day)
5000	Control	10	0	0.6
5000	Control	9	1	4.4
5000	Control	11	0	2.6
5000	Control	11	0	1.3
Mean				2.2
5000	+ Food	10	0	1.0
5000	+ Food	11	0	2.8
5000	+ Food	12	2	2.0
5000	+ Food	10	0	6.2
Mean				3.0
2500	Control	7	0	2.4
2500	Control	10	0	1.9
2500	Control	11	0	1.2
2500	Control	8	1	2.3
Mean				2.0
2500	+ Food	13	0	3.8
2500	+ Food	10	0	4.0
2500	+ Food	10	0	4.6
2500	+ Food	10	0	4.0
Mean				4.1

Table 6
EURYTEMORA EXPERIMENT 3,
EGG RATIOS AND EGG PRODUCTION RATES

Specific Conductance (μ S/cm)	Treatment	Females Recovered	Dead Females	Egg Ratio	Egg Production Rate (Eggs/Female/Day)
5000	Control	4	1	2.3	18.6
5000	Control	5	0	5.4	2.6
5000	Control	8	1	3.3	0.3
Mean				3.6	7.2
5000	+ Food	6	0	0.0	4.5
5000	+ Food	8	1	0.0	4.4
Mean				0.0	4.5
2500	Control	8	0	0.0	14.1
2500	Control	6	1	2.7	18.5
2500	Control	8	0	5.1	15.6
Mean				2.6	16.1
2500	+ Food	6	0	0.0	7.0
2500	+ Food	6	0	7.7	18.8
Mean				3.8	12.9

Table 7
SINOCALANUS EXPERIMENT 3,
EGG PRODUCTION RATES

Specific Conductance (μ S/cm)	Treatment	Females Recovered	Dead Females	Egg Production Rate (Eggs/Female/Day)
5000	Control	9	0	1.5
5000	Control	11	0	1.3
5000	Control	11	0	0.5
5000	Control	8	0	0.0
Mean				0.8
5000	+ Food	9	2	1.6
5000	+ Food	9	0	0.9
5000	+ Food	10	0	1.3
Mean				1.3
2500	Control	7	0	1.2
2500	Control	9	0	0.5
2500	Control	6	0	3.8
2500	Control	9	0	3.1
Mean				2.2
2500	+ Food	10	2	2.5
2500	+ Food	12	0	4.1
2500	+ Food	9	1	4.8
2500	+ Food	10	0	2.0
Mean				3.4

Table 8
EURYTEMORA EXPERIMENT 4,
EGG RATIOS AND EGG PRODUCTION RATES

Specific Conductance (μ S/cm)	Treatment	Females Recovered	Dead Females	Egg Ratio	Egg Production Rate (Eggs/Female/Day)
5000	Control	10	1	3.5	49.7
5000	Control	10	1	0.8	43.7
5000	Control	13	2	3.9	26.0
5000	Control	11	1	12.8	36.6
Mean				5.3	39.0
5000	+ Food	9	2	9.1	46.4
5000	+ Food	13	1	7.9	38.0
5000	+ Food	11	1	6.3	48.4
5000	+ Food	13	2	2.8	38.2
Mean				6.5	42.8
2500	Control	13	1	9.4	14.8
2500	Control	12	0	8.6	14.0
2500	Control	12	1	5.8	14.8
2500	Control	9	1	4.0	12.7
Mean				7.0	14.1
2500	+ Food	14	0	10.0	23.8
2500	+ Food	12	0	10.3	14.2
2500	+ Food	11	2	1.5	19.3
2500	+ Food	12	0	0.9	8.8
Mean				5.7	16.5

Table 9
SINOCALANUS EXPERIMENT 4,
EGG PRODUCTION RATES

Specific Conductance (μ S/cm)	Treatment	Females Recovered	Dead Females	Egg Production Rate (Eggs/Female/Day)
5000	Control	11	0	0.3
5000	Control	13	0	0.4
5000	Control	12	0	0.2
5000	Control	11	1	0.3
Mean				0.3
5000	+ Food	11	0	2.9
5000	+ Food	11	0	4.8
5000	+ Food	12	0	1.7
5000	+ Food	13	0	1.5
Mean				2.7
2500	Control	12	3	0.8
2500	Control	11	0	0.5
2500	Control	12	0	0.2
2500	Control	10	0	0.0
Mean				0.4
2500	+ Food	11	0	4.1
2500	+ Food	10	1	0.9
2500	+ Food	8	0	1.3
2500	+ Food	11	1	0.9
Mean				1.8

Table 10
EURYTEMORA EXPERIMENT 5
EGG RATIOS AND EGG PRODUCTION RATES

Specific Conductance ($\mu\text{S/cm}$)	Treatment	Females Recovered	Dead Females	Egg Ratio	Egg Production Rate (Eggs/Female/Day)
5000	Control	7	2	14.4	44.9
5000	Control	12	0	2.0	18.9
5000	Control	13	1	1.2	12.8
5000	Control	13	0	4.8	22.0
Mean				5.6	24.7
5000	+ Food	10	3	25.0	21.4
5000	+ Food	13	1	19.4	20.9
5000	+ Food	9	1	0.0	15.3
5000	+ Food	11	0	29.9	30.1
Mean				18.6	21.9
2500	Control	10	1	5.2	15.8
2500	Control	10	2	7.0	25.2
2500	Control	10	0	4.2	19.4
Mean				5.5	20.1
2500	+ Food	9	0	20.8	24.0
2500	+ Food	11	0	12.4	17.4
2500	+ Food	11	0	6.3	11.4
Mean				13.1	17.6

Table 11
SINOCALANUS EXPERIMENT 5
EGG PRODUCTION RATE
WITHOUT ADDED FOOD
AT SPECIFIC CONDUCTANCE OF
2500 AND 500 MICROSIEMENS

Specific Conductance ($\mu\text{S/cm}$)	Females Recovered	Dead Females	Egg Production Rate (Eggs/Female/Day)
2500	15	1	0.28
2500	17	0	0.31
500	18	0	0.20
500	19	0	0.41
500	20	0	0.73

and experimental containers. Also, values tended to be higher for specific conductance of 5,000 $\mu\text{S/cm}$ than for 2,500 $\mu\text{S/cm}$. Values for *Sinocalanus* did not show a consistent pattern (Table 3).

In Experiment 2 (Tables 4 and 5), the means for specific conductance of 5,000 $\mu\text{S/cm}$ were higher than for 2,500 $\mu\text{S/cm}$ for *Eurytemora* but not for *Sinocalanus*. A food effect was apparent only for *Sinocalanus*.

Experiment 3 (Tables 6 and 7), had excessive mortality among the *Eurytemora*, resulting in some replicates being discarded and inconclusive results, but the egg production rate was higher at

specific conductance of 2,500 $\mu\text{S/cm}$ than at 5,000 $\mu\text{S/cm}$. This experiment was, therefore, excluded from the overall statistical test (see below). Results for *Sinocalanus* were consistent, with higher means in the experimental containers.

In Experiment 4 (Tables 8 and 9), the means for *Eurytemora* depended only on specific conductance and not on food.

Experiment 5, for *Eurytemora* only, showed no strong effect of either food or specific conductance (Table 10). Egg production rate of *Sinocalanus* (Table 11) was not higher at specific conductance of 500 $\mu\text{S/cm}$ than at 2,500 $\mu\text{S/cm}$.

Gut fullness indices were higher in the controls than in the experimental samples. These are shown for two of the experiments (Tables 12 and 13). Chi-square tests showed a highly significant difference between control and experimental treatments.

Table 12
EXPERIMENT 4
GUT FULLNESS INDICES FOR BOTH SPECIES,
POOLED SAMPLES AND
SPECIFIC CONDUCTANCES

Gut Fullness Index	Frequencies of Gut Fullness Index			
	<i>Eurytemora</i>		<i>Sinocalanus</i>	
	Control	+ Food	Control	+ Food
0	4	40	21	42
1	21	32	34	37
2	30	19	31	7
3-4	35	4	18	3
Chi-square (4 df) =	58.76 ($p < 0.01$)		52.88 ($p < 0.01$)	

Table 13
EURYTEMORA EXPERIMENT 5
GUT FULLNESS INDICES, POOLED SAMPLES
AND SPECIFIC CONDUCTANCES

Gut Fullness Index	Frequencies of Gut Fullness Index	
	<i>Eurytemora</i>	
	Control	+ Food
0	14	1
1	25	11
2	24	19
3	8	30
4	3	14
Chi-square (4 df) =	37.1 ($p < 0.01$)	

Figures 1 and 2 show egg production rates of each species in all similar experiments. Results for *Eurytemora* (Experiments 2, 4, and 5 only) show no significant difference between controls and experimental treatments. This was confirmed by ANOVA; the only significant effects were date (*i.e.*, experiment), specific conductance, and interaction between date and specific conductance (Table 14). Presence or absence of food was not significant as a main effect or in any interaction. The direction of the specific conductance effect was for egg production to be higher at 5,000 $\mu\text{S}/\text{cm}$ than at 2,500 $\mu\text{S}/\text{cm}$, but the interaction term shows that this varied by experiment so the main effects cannot be interpreted.

Results for *Sinocalanus* (Figure 2) illustrate the lower values and larger error terms for that species. With one exception, experimental values

were higher than controls, although in most cases the difference was well within the 95 percent confidence limits. ANOVA (Table 15) gave two significant effects — food and date — with no significant interaction term. Although both main effects were significant, the R^2 value was only 0.375, indicating the poor explanatory power of the model. In other words, although the food effect was statistically significant, it was small compared to the experimental error.

Discussion

To summarize these results, *Eurytemora* showed no evidence of food limitation, although on some occasions a significant effect of specific conductance was noted, and the egg production rate varied among dates. For *Sinocalanus*, there was a small but significant effect of food on reproductive rate. Chlorophyll values in 1988 were far lower than typical for the western Delta, where levels over 10 $\mu\text{g}/\text{L}$ were the rule, and 100 $\mu\text{g}/\text{L}$ were common. Thus, if food limitation were to occur, it should have been expected in 1988.

Food Limitation of *Eurytemora*

Food limitation of copepod growth or reproduction in coastal waters is actually quite common but is usually episodic. That is, on one occasion there might be enough food for growth to proceed at a maximum rate; on another, growth rate might be reduced by a large proportion (Kimmerer and McKinnon, 1987). The absence of food limitation

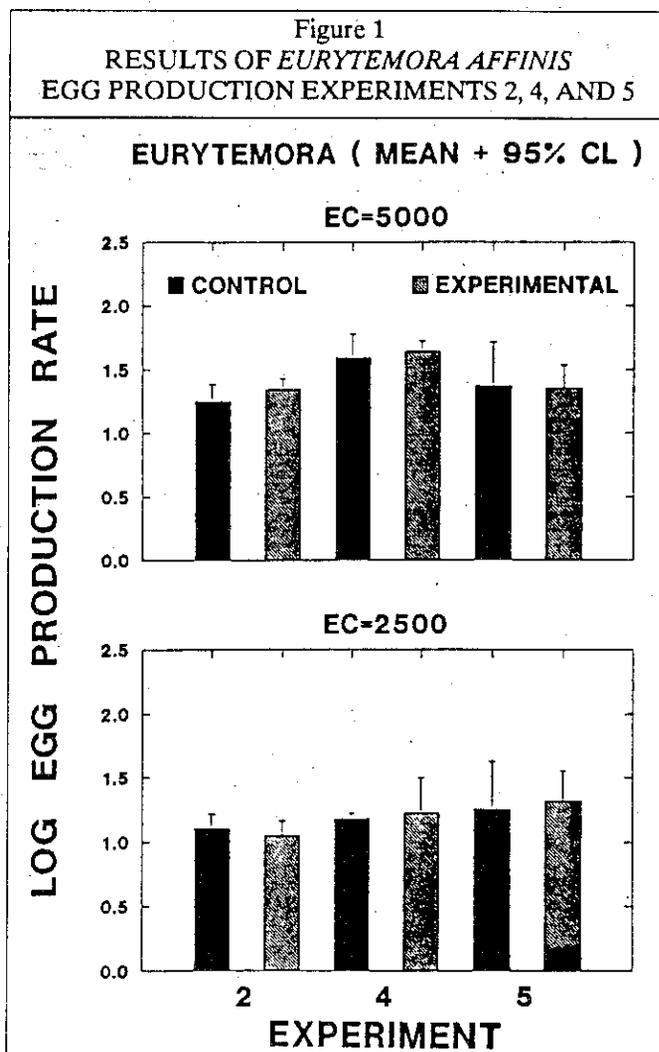


Table 14
EURYTEMORA EXPERIMENTS 2, 4, AND 5,
ANALYSIS OF VARIANCE FOR ESTIMATING
EFFECTS OF FOOD ON EGG PRODUCTION

N = 46 Squared Multiple R = 0.707

Source	Sum of Squares	DF	Mean Square	F-Ratio	P
Date	1.712	2	0.856	12.061	0.000
Specific Conductance	3.578	1	3.578	50.409	0.000
Date * Specific Conductance	1.294	2	0.647	9.117	0.001
Error	2.839	40	0.071		

NOTE: Analysis presented includes all significant effects. The dependent variable is the natural log of the egg production rate.

in any of the experiments on *Eurytemora* strongly suggests that this species always or nearly always had enough food.

Two factors suggest use of caution in extrapolating these results:

- Only three of the five experiments could be called successful. Experiment 1 had high variability owing mainly to the small numbers used per replicate, and Experiment 3 had high mortality (for unknown reasons) and, therefore, high variability.
- Measurements were made only on egg production rate, not on growth or survival.

Although the growth rate of juveniles should show the same response as the egg production rate, this has not been the case for this species. Thus, similar experiments should be run on growth rate of juveniles. Direct measurement of survival, on the other hand, is neither feasible nor necessary. It is infeasible in an experimental context because natural mortality is usually much higher than it is in the laboratory. It is not necessary because survival should be closely and directly related to growth rate.

Possible Role of *Sinocalanus*

The low egg production of *Sinocalanus* was surprising because other species of this genus can produce over 40 eggs per day on cultured phytoplankton (Kimoto *et al.*, 1986). The maximum rate in all experiments was about 4 eggs/female/day – well below typical values for other species with or

without food limitation. The adults could have cannibalized the eggs, resulting in a low apparent egg production rate. However, to obtain an order-of-magnitude decrease in apparent egg production rate would require a clearance rate of eggs on the order of 1 liter/female/day – too high for a copepod of this size. A more reasonable clearance rate of 50 milliliters/female/day would give an *apparent* egg production about 80 percent of *actual* egg production, which is not a substantial reduction.

Mouthparts of *Sinocalanus* are characteristic of omnivorous copepods, so they may require animal food. However, gut content analysis did not reveal any animal remains (J. Orsi, pers. comm.), and other species of the genus reproduce well on phytoplankton only. If they are omnivorous, they could be responsible for suppressing the abundance of *Eurytemora* at the freshwater end of its range.

Figure 2
RESULTS OF *SINOCALANUS DOERRI*
EGG PRODUCTION EXPERIMENTS 1-4

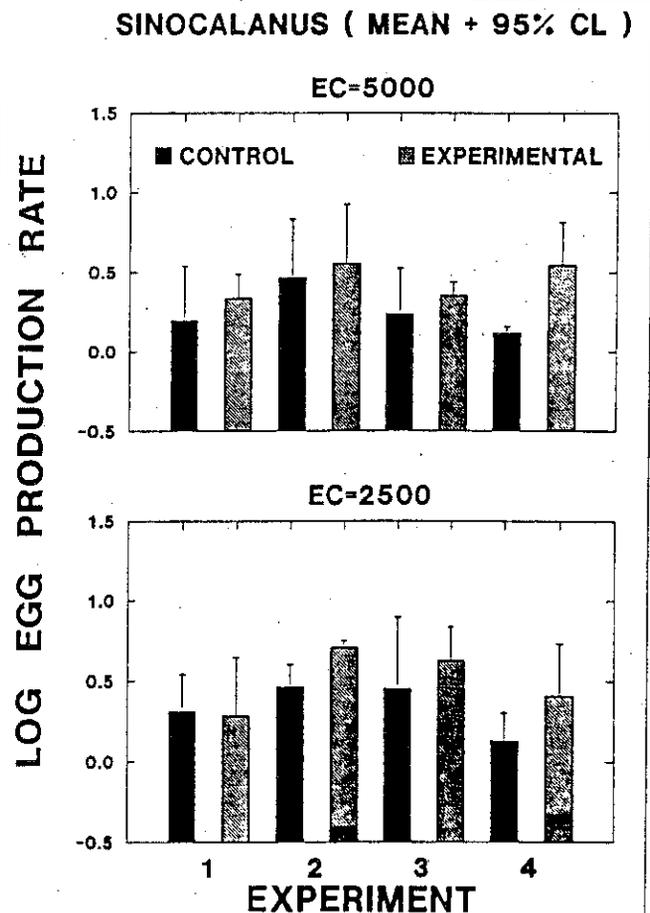


Table 15
SINOCALANUS EXPERIMENTS 1 TO 4 ONLY
ANALYSIS OF VARIANCE FOR ESTIMATING
EFFECTS OF FOOD ON EGG PRODUCTION

N = 65

Squared Multiple R = 0.375

Source	Sum of Squares	DF	Mean Square	F-Ratio	P
Date	4.018	3	1.339	7.131	0.000
Food	2.775	1	2.775	14.775	0.000
Error	11.268	60	0.188		

NOTE: Analysis presented includes all significant effects. The dependent variable is the natural log of the egg production rate.

Further experimental work is needed to determine the role of *Sinocalanus* in the ecosystem and the reason for its low egg production rate.

Variation in *Eurytemora*

If the egg production rate of *Eurytemora* was not affected by food, then why did it vary among experiments? The answer to this may lie in the age structure of the populations of females. As females age, their output of eggs decreases. At times when mortality is relatively low, the population would tend to have more older females and to show a lower egg production rate than a younger population. In addition, the effect of salinity indicates either that salinity directly influences egg production or that differences in population age structure with location cause differences in reproductive rate.

More perplexing is the mechanism for the decline of *Eurytemora*. Without food limitation, the only reasonable mechanism is an increase in predation. Predation by *Sinocalanus* is a possibility, but since the initial decline of *Eurytemora* preceded the spread of *Sinocalanus*, it seemed, instead, that *Sinocalanus* was filling a niche no longer fully occupied by *Eurytemora*.

The decline in *Eurytemora* and rise of *Pseudodiaptomus* in the Delta in late summer and fall of 1988 is an interesting and possibly important phenomenon. A possible cause of the decline in *Eurytemora*, predation by an introduced clam, is discussed in Food Chain Group Working Paper 1 (Kimmerer, 1990). However, interference by *Pseudodiaptomus* in experimental work on *Eurytemora*, caused simply by its high abundance, may make future experiments with *Eurytemora* difficult. More important is its possible effect on

striped bass larvae; at present there are no data on the ability of the larvae to catch and consume this species.

Recommendations

Several reasonable courses of action are suggested by these results. Future experimental work should confirm or contradict the results that indicate food is not limiting to *Eurytemora* and may be limiting to *Sinocalanus*. The role of *Sinocalanus*, including its possible predation on *Eurytemora*, should be examined, and the role of the newly introduced *Pseudodiaptomus* should be analyzed. I recommend the following sets of experiments:

- Experiments to determine the relative rates of predation by bass larvae on all three species: *Sinocalanus*, *Eurytemora*, and *Pseudodiaptomus*.
- Additional egg production experiments with *Eurytemora*, along similar lines to those presented here, during the time the bass are hatching.
- If *Eurytemora* becomes abundant again, similar experiments using juvenile growth rate as the variable of interest.
- Predation experiments using *Sinocalanus* preying on its own nauplii and on those of *Eurytemora*.
- Similar experiments to all of the above with *Pseudodiaptomus*.

Ultimately, to provide a firmer basis for investigations of the Delta zooplankton, an investigation of the population dynamics of the important species is needed, including the sources of mortality and the importance of pumping relative to natural mortality.

Acknowledgments

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We are grateful to Greg Schmidt for assistance in sampling and logistics and for building a magnificent plankton wheel, to Sally Skelton for counting all of the samples, to Peggy Lehman for providing phytoplankton samples, to the staff of the California Department of Fish and Game Elk Grove laboratory for allowing us to use their facility and for their patience and assistance, and to the other members of the Food Chain Group for their helpful suggestions.

Literature Cited

- Heinle, D.R., and D.A. Flemer. 1975. "Carbon requirements of a population of the estuarine copepod *Eurytemora affinis*." *Mar. Biol.* 31:235-247.
- Kimmerer, W.J. 1990. "Laboratory tests of predation by the introduced clam *Potamocorbula* on larval stages of the zooplankters *Eurytemora affinis* and *Pseudodiaptomus* sp." Food Chain Group Working Paper FCG-90-1.
- Kimmerer, W.J., and A.D. McKinnon. 1987. "Growth, mortality, and secondary production of the copepod *Acartia tranteri* in Westernport Bay, Australia." *Limnol. Oceanogr.* 32:14-28.
- Kimoto, K., S. Uye, and T. Onbe. 1986. "Egg production of a brackish-water calanoid copepod *Sinocalanus tenellus* in relation to food abundance and temperature." *Bull. Plankt. Soc. Japan* 33:133-145.
- Sekiguchi, H., I.A. McLaren, and C.J. Corkett. 1980. "Relationship between growth rate and egg production in the copepod *Acartia clausi hudsonica*." *Mar. Biol.* 58:133-138.
- Strickland, J.D.H., and T.R. Parsons. 1972. *A Practical Handbook of Seawater Analysis*. Fisheries Res. Bd. Canada, Ottawa.
- Vidal, J. 1980. "Physioecology of zooplankton. I. Effects of phytoplankton concentration, temperature, and body size on the growth rates of *Calanus pacificus* and *Pseudocalanus* sp." *Mar. Biol.* 56:111-134.

Comments of the Food Chain Group

Dr. Kimmerer's experiments reported in this second working paper illustrate the kind of work we believe is much needed to answer questions raised by analysis of the long-term database resulting from years of monitoring the estuary. His finding that the copepod *Eurytemora*, a staple of the larval striped bass diet, did not produce more eggs per female when exposed to more phytoplankton food was somewhat unexpected. Because both desirable phytoplankton and *Eurytemora* had declined, some of us suspected the declines were related. They may well be, but Kimmerer's experiments are evidence they are not cause and effect. They suggest that, even at the low phytoplankton levels of 1988, *Eurytemora* had enough food — at least enough to reproduce well.

In these experiments, the recently introduced copepod *Sinocalanus*, which is not a good larval bass food, did respond positively to more than ambient levels of phytoplankton and may, therefore, be food-limited. The surprise was that egg production rates were extremely low for this copepod, which has spread so quickly and become so abundant since 1979.

If *Sinocalanus* populations are both less productive and limited by the low phytoplankton stocks, why have they done so well? On the other hand, if *Eurytemora* reproduces faster and is not limited by the same low phytoplankton stocks, why have they declined? It does not seem they would suffer competition from *Sinocalanus*.

Dr. Kimmerer, scientists of the U.S. Geological Survey in Menlo Park, and others suspect the new clam *Potamocorbula*, which has suddenly become very abundant and appears to be a vigorous feeder on plankton that cannot avoid the currents of its intake siphon. *Potamocorbula* was introduced in 1986, several years after the *Eurytemora* decline began but long enough before the "*Eurytemora* crash of 1988" to be a prime suspect. Much good work is being done to pursue that.

We share Dr. Kimmerer's concern that these experiments must be interpreted cautiously. They are hardly enough to warrant a conclusion that the low 1988 levels of phytoplankton were not limiting *Eurytemora* populations, although they point in that direction. We agree with his recommendations that the experiments should be repeated during spring, when striped bass larvae are abundant, and that growth rates and *Sinocalanus* predation on nauplii should be measured. The new copepod *Pseudodiaptomus*, which now appears to be of major importance, should also be tested.

D. W. Kelley, Chairman
Food Chain Group

Observations on Factors Affecting the Young Striped Bass Index in the Sacramento-San Joaquin Estuary

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Abstract: The adult striped bass population in the San Francisco Bay and Sacramento-San Joaquin Delta estuary is less than a quarter of what it was 20 years ago. The annual measure of young abundance has also shown a major decline. The young population has declined at a much faster rate in the Delta portion of the estuary than in the Suisun Bay portion. About 35 percent of the variability of number of young in midsummer can be accounted for by the number of eggs spawned; another 50 percent of the variability can be accounted for during the period that the larvae grow from 7 to 8 millimeters. The number of 6-mm larvae transported into Suisun Bay over a recent 4-year period for which data are available agrees closely with total young abundance in midsummer. High outflows down the lower San Joaquin River appear to have transported a large portion of the 6-mm larvae into Suisun Bay in 1986. *Eurytemora affinis* was a major food organism selected by 5- to 10-mm larval striped bass, and it makes up a high percentage of their stomach contents. *E. affinis* concentrations decline rapidly proceeding upstream of the zone of initial mixing of fresh water and salt water. Annual May/June concentrations of *E. affinis* in this zone have declined an average of 83 percent in the 1980s compared to the 1970s.

Introduction

The striped bass fishery is the major sport fishery in the San Francisco Bay and Sacramento-San Joaquin Delta estuary. Striped bass anglers fish from Pacific Ocean beaches near San Francisco upstream through the estuary into the Sacramento and San Joaquin rivers some 225 kilometers above their junction. Fishing is allowed all year, but success varies with the season and is determined largely by migration patterns of the adult fish.

The adult striped bass population has declined substantially over the past 20 years. Stevens *et al.* (1985) estimated that the adult population is less than one-quarter of what it was 20 years ago. In addition, a measure of the annual abundance of young-of-the-year striped bass in their first summer has declined from the high levels in the mid-1960s (Figure 1). The population of young bass has been particularly low every year since 1976, except in 1986.

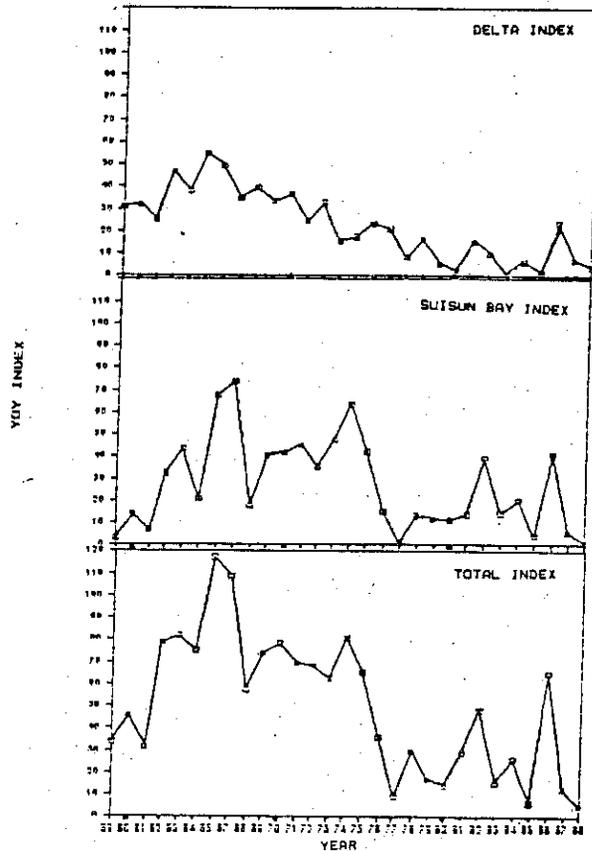
These poor year classes of young bass will further depress the numbers of adult fish as they grow old enough to enter the fishery. The striped bass population and the fishery it supports are in serious trouble.

Recent studies by the Department of Fish and Game (1987) have shown a significant relationship between annual abundance of young striped bass and recruitment to the fishery 4 years later. This suggests year class strength of the population is determined early in life and the number of future adult bass is a function of young bass survival during their first summer.

The objective of this study is to evaluate early life stages of larval striped bass so possibly we can determine reasons for the decline in the young-of-the-year index by:

- Better defining the period when size of the index is determined.
- Locating the problem geographically.

Figure 1
ANNUAL INDEX OF
YOUNG-OF-THE-YEAR STRIPED BASS IN THE
DELTA AND SUISUN BAY AND
THE COMBINED TOTAL



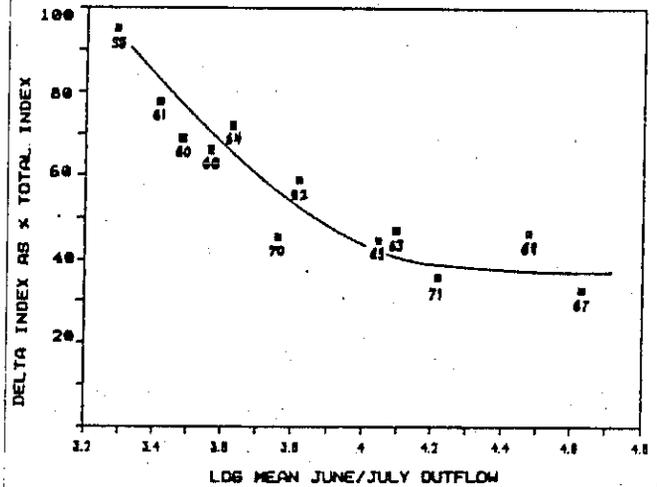
Source: Department of Fish and Game, 1987.

- Suggesting possible causes for the decline.
- Recommending management options and suggesting further studies.

Changes in Delta Index of Young Bass

The annual DFG Delta Index of young striped bass has been steadily declining since the mid-1960s. Figures 2 and 3 show the relationship between outflow and the Delta Index as a percent of the Total Index. Figure 2 shows that the Delta Index from 1959 to 1971 was closely related to outflow. This is because more young bass are farther upstream during years of low outflow than in years of high outflow.

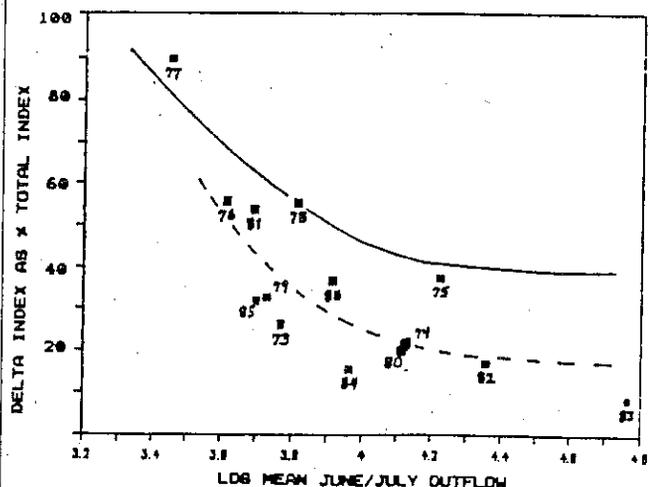
Figure 2
RELATIONSHIP BETWEEN OUTFLOW PAST
CHIPPS ISLAND AND THE DELTA INDEX OF
YOUNG STRIPED BASS AS A
PERCENT OF THE TOTAL INDEX, 1959 TO 1971



Source: Turner and Chadwick, 1972.

The line in Figure 2 is reproduced in Figure 3, along with another line and the data points from 1973 to 1986. In Figure 3, all points fall below the line except for 1977 and 1978 (which is on the line), demonstrating that at a given outflow, the fraction of young bass population upstream of Collinsville

Figure 3
RELATIONSHIP BETWEEN OUTFLOW PAST
CHIPPS ISLAND AND THE DELTA INDEX OF
YOUNG STRIPED BASS AS A
PERCENT OF THE TOTAL INDEX, 1973 TO 1986



Solid line copied from Figure 2.

Source: Department of Fish and Game, 1987.

is much less now than it was in the past. A reduction has also occurred in the Suisun Bay Index for any given amount of flow, but it has not been as severe as the Delta Index. Because this has happened during an overall decline in young bass population, I conclude that the major reduction has been in the Delta.

Time of Young-of-the-Year Index Determination

One method of defining the life phase most important in determining the size of the YOY Index is to compare the indices of abundance of different sized larvae each year with the estimated YOY Index for that year, assuming annual abundance of young is determined when the relationship becomes significant.

The Department of Fish and Game has conducted a number of striped bass egg and larval surveys before the annual measurement of young-of-the-year in midsummer and has estimated indices of the number of larval striped bass at 1-mm length increments from 4 to 10 mm for each of the years sampled (not all years were sampled) (Table 1). Annual abundance of eggs is estimated by the fecundity method, in which the abundance estimate of each age class of adults (based on a tagging

and recapture study) is multiplied by estimated fecundity for the particular age, then all the estimates for a particular year are summed.

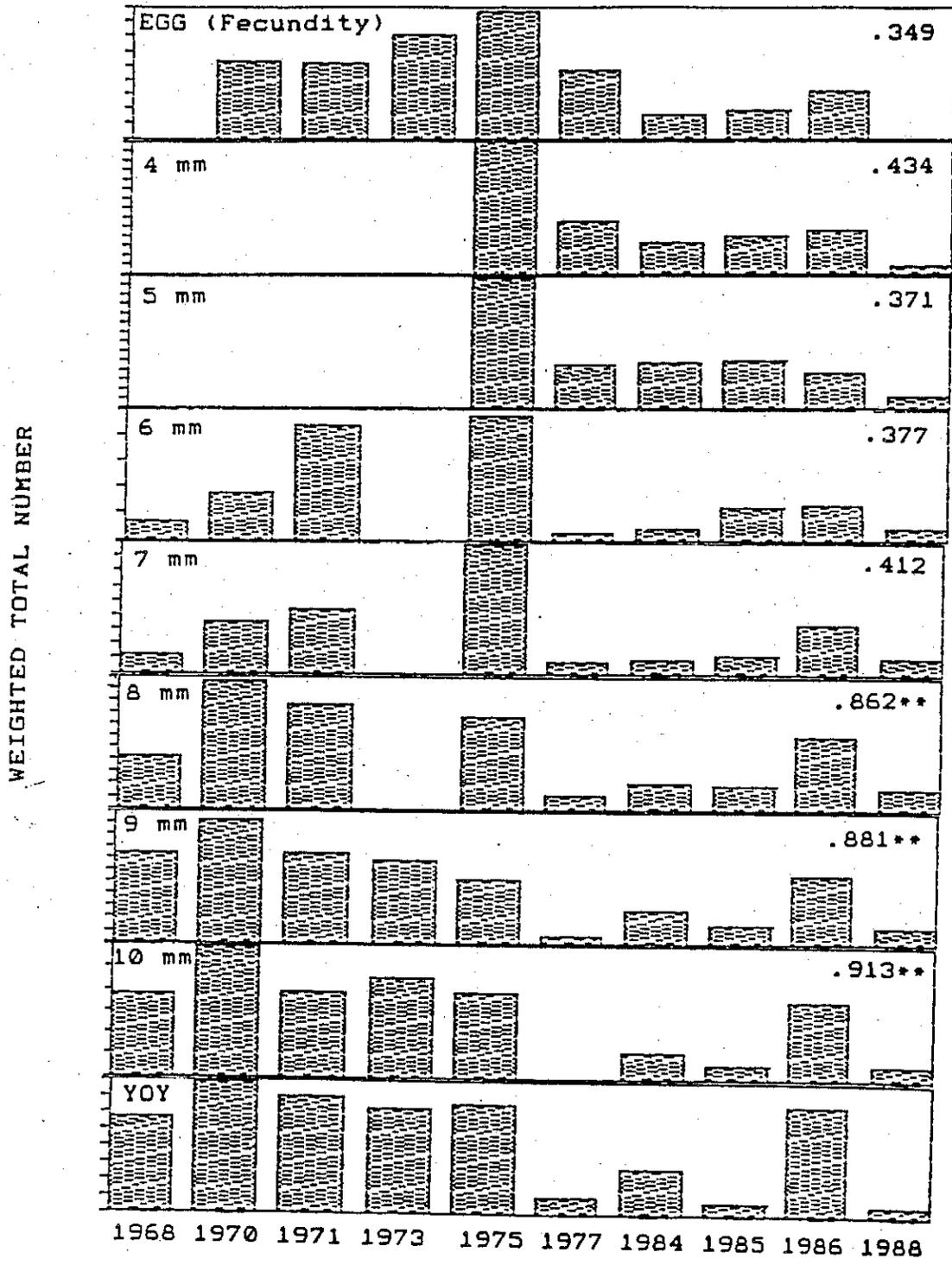
Figure 4 is a comparison of the estimated index of egg abundance, the estimated number of larvae from 4 to 10 mm, and the YOY Index for years with data from 1968 to 1988. Blank spaces indicate that no samples of the particular size groups were available. The YOY Index for all the years is at the bottom of the figure. The coefficient of determination (R^2) between the YOY indices and the index of each size group is noted. This relationship becomes significant at 8 mm and suggests that 86 percent of the variability in the YOY Index can be accounted for by the annual number of 8-mm larvae.

Figure 5 is a plot of R^2 values for the relationship between the number of each life stage with the YOY Index from Figure 4. The results suggest that about 35 percent of the variability in the YOY Index is associated with the number of striped bass eggs spawned each year. This value remains much the same for all stages through 7-mm larvae. However, an additional 50 percent of the variability can be accounted for during the change in length from 7 to 8 mm.

Table 1
INDICES OF LIVE EGGS ESTIMATED BY THE FECUNDITY METHOD,
ESTIMATED NUMBERS OF LARVAL STRIPED BASS, AND
MIDSUMMER ABUNDANCE INDEX OF YOUNG-OF-THE-YEAR STRIPED BASS, 1968 TO 1988
(Note That Not All Years Were Sampled)

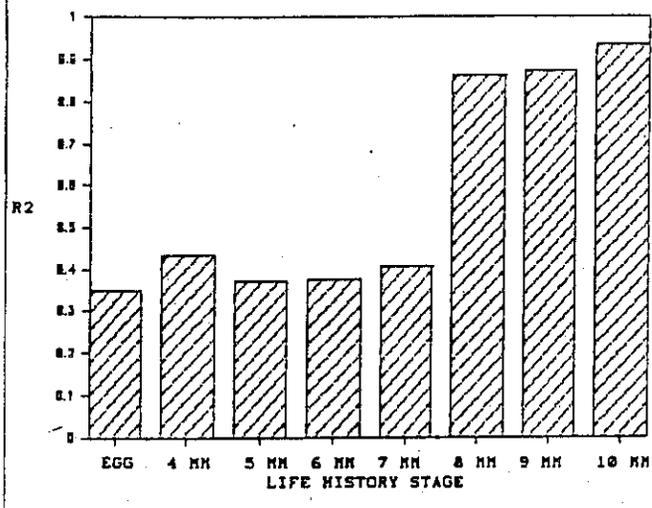
Year	Egg Fecundity	Number of Striped Bass Larvae							Young-of-the-Year Index
		4 mm	5 mm	6 mm	7 mm	8 mm	9 mm	10 mm	
1968				661,630	123,547	85,754	73,705	37,378	57.3
1970	267			1,727,485	351,958	212,673	102,207	59,253	78.5
1971	255			4,408,569	428,529	171,836	73,877	38,165	69.6
1973	354						69,290	44,806	62.7
1975	434	279,996	1,383,871	4,768,749	891,010	150,705	51,775	38,054	65.5
1977	231	107,878	449,950	231,126	73,659	21,285	6,085		9.0
1984	77	65,655	456,065	453,711	91,640	43,061	25,953	11,410	26.3
1985	97	81,142	496,489	1,254,491	128,009	36,790	14,905	6,229	6.3
1986	161	88,428	369,550	1,330,763	328,383	119,562	57,108	34,966	64.9
1988		12,458	121,250	396,903	113,309	35,777	13,624	5,523	4.6

Figure 4
 HISTOGRAMS OF ESTIMATED ANNUAL NUMBER OF EGGS,
 ESTIMATED NUMBER OF LARVAE, AND
 YOUNG-OF-THE-YEAR INDEX FOR SAMPLED YEARS, 1968 TO 1988



Coefficient of determination (R^2) between YOY Index and weighted number is noted in upper right corner.
 ** is significant at 1 percent level.

Figure 5
 COEFFICIENT OF DETERMINATION (R^2)
 BETWEEN YOUNG-OF-THE-YEAR INDEX AND
 NUMBER OF STRIPED BASS EGGS
 BASED ON THE FECUNDITY METHOD AND
 NUMBER OF LARVAE FROM 7 TO 10 MM



What happens to the young striped bass from the time the egg is spawned until it reaches 8 millimeters, especially from the 6-mm to 8-mm stage? Hunter (1972) and Fortier and Leggett (1984) have reported that swimming activities of larval fish do not increase significantly until active feeding begins. Based on stomach content analysis of larval striped bass, active feeding begins at a length of 5 to 6 mm. Striped bass eggs and yolk-sac larvae would be expected to disperse passively until the transition to external feeding. The numbers and location of eggs and 4-, 5-, and 6-mm larvae, then, would be a function of:

- The number of eggs spawned,
- Where and when they were spawned,
- The river and tidal flow area in which they remained,
- The location and amount of diversions,
- The rate of development of eggs and larvae, which is affected by water temperature, and
- The mortality rate during these various stages of development.

The Department of Water Resources has started to develop a transport model to simulate abundance and distribution of 6-mm larvae based on most of these hydrological factors, assuming constant mortality rates and water temperature (Rayej, 1989). If the model could simulate distribution of 6-mm larvae, we would be in a position to determine hydrological conditions necessary to move larval bass into various areas of the system and to test the effects of doing so. The first question is: "Where do we want to transport the early larvae?"

Recent Distribution of Larval Bass

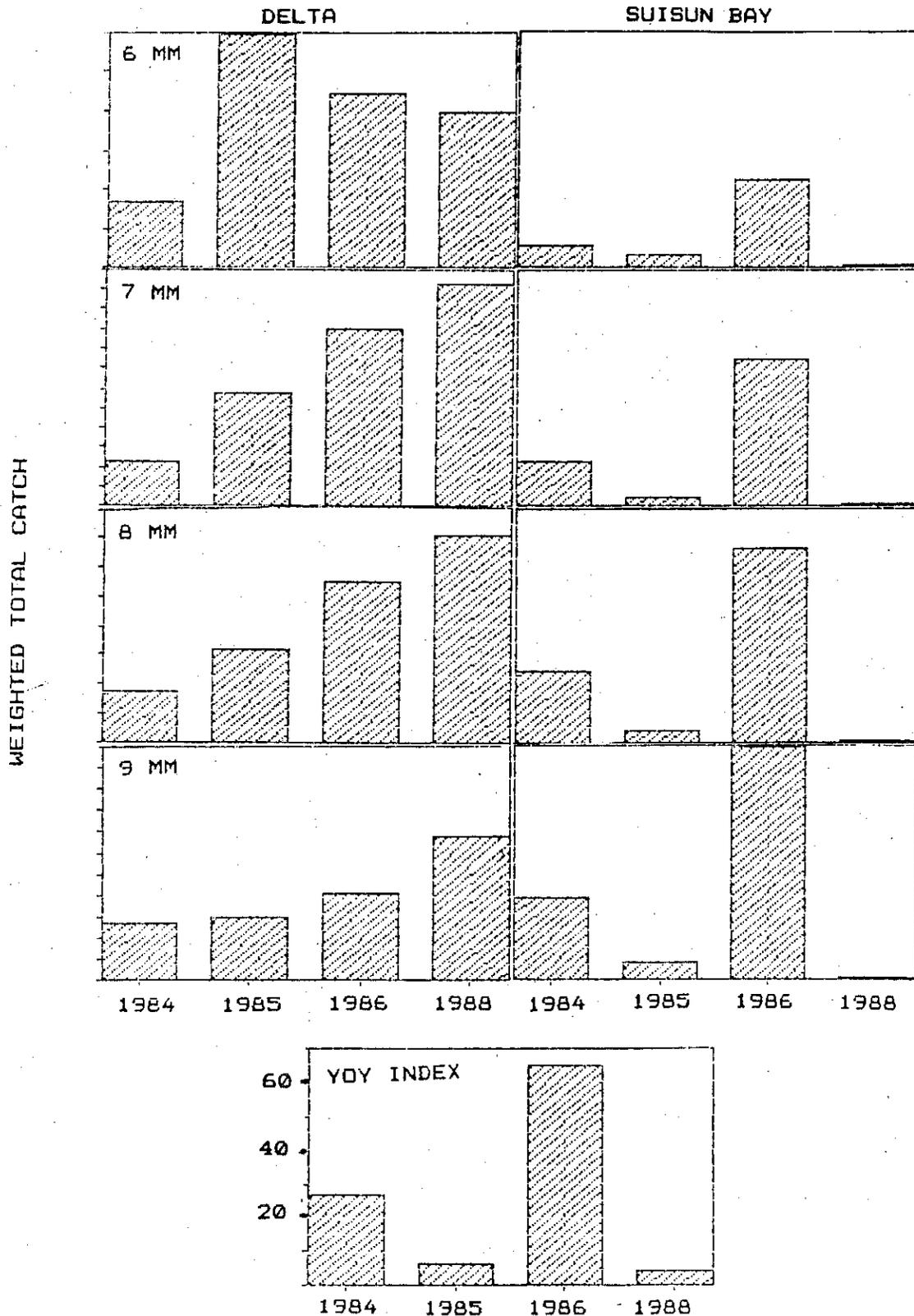
Since the drought of 1976 and 1977, the Department of Fish and Game has studied larval bass distribution in 1984, 1985, 1986, and 1988. The YOY Index for these four years was 26.3, 6.3, 64.9, and 3.9, respectively; 1986 had the highest index of the past 13 years.

Figure 6 shows the estimated total number, by year, of each size group of 6- to 9-mm larval bass in the Delta and Suisun Bay portion of the estuary. Note the variable ranking of the years for the Delta estimates. At 6 mm, 1985 had the largest catch, followed by 1986, 1988, and 1984. However, at 9 mm, 1988 had the largest catch, followed by 1986, 1985 and 1984. Numbers of larvae in the Delta do not appear to be related to the subsequent YOY indices.

In Suisun Bay, the relative ranking of all four years remains the same throughout all size groups; 1986 is largest, followed by 1984, 1985, and 1988. Notice that the relative number of 6- to 9-mm larvae for the four years is closely related to the YOY indices in midsummer, as shown in the bottom graph in Figure 6.

If much of the YOY Index is determined by the time larval bass reach 8, 9, or 10 millimeters (Figure 5), then the differences in larval bass populations may be determined by the number of larval striped bass in Suisun Bay. Since the relative ranking of the 4 years in Suisun Bay was the same

Figure 6
 CHANGES IN WEIGHTED CATCH OF 6- TO 9-MM LARVAL STRIPED BASS IN THE
 DELTA AND SUISUN BAY COMPARED TO THE
 YOUNG OF THE YEAR INDEX FOR 1984, 1985, 1986, AND 1988



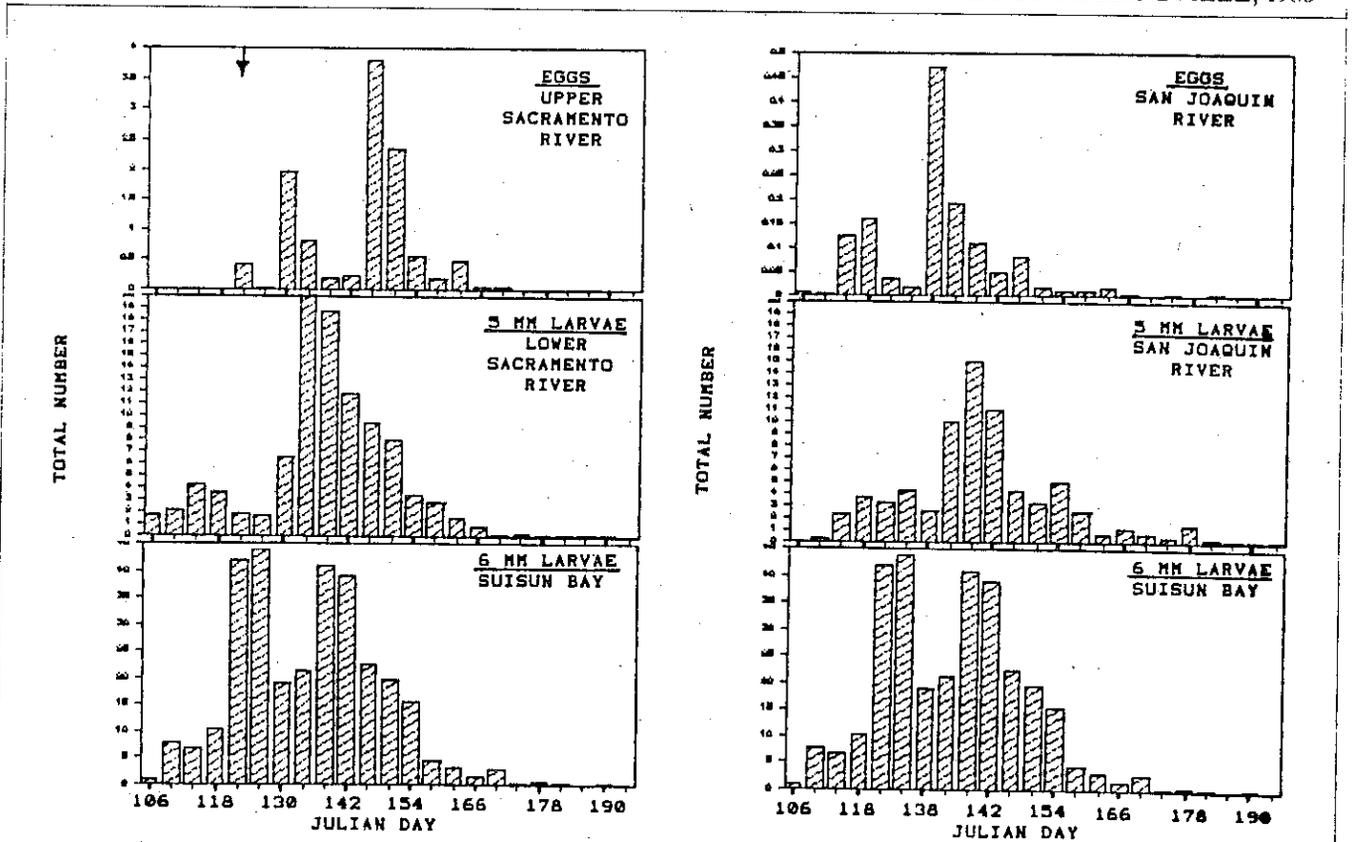
starting with the 6-mm larvae, then the number of 6-mm larvae making it to Suisun Bay in a particular year could be a major factor in determining the YOY Index. This theory is compatible with the previous analysis suggesting that the Delta is no longer a suitable environment for young bass.

As in the past, the major central California striped bass spawning areas in 1984 to 1988 were in the Sacramento River from the mouth of the Feather River upstream to Colusa and in the lower San Joaquin River from Antioch upstream to Venice Island.

Eggs and larvae were sampled every fourth day in 1986. I compared the daily catch rate of striped bass eggs in the upper Sacramento River and in the

lower San Joaquin River with the catch rate of 6-mm larvae in Suisun Bay 8 days later (Figure 7). It takes about 8 days from time of spawning until bass larvae reach 6 mm (Eldridge *et al.*, 1981). Sampling started on Julian day 106 in all areas except in the upper Sacramento River, where it started on day 122. There are two major spawning peaks in the upper Sacramento River. The early peak (day 130-134) corresponds with the peak of 6-mm larvae 8 days later in Suisun Bay (day 138-142), but there is little evidence of a second peak in the catch in Suisun Bay. The two spawning peaks in the lower San Joaquin River (day 114-118 and day 130-134) correspond with peaks of 6-mm larvae in Suisun Bay 8 days later (day 122-128 and day 138-142).

Figure 7
TIMING OF STRIPED BASS SPAWNING AND THE CATCH OF 5-MM LARVAE IN THE LOWER SACRAMENTO RIVER AND LOWER SAN JOAQUIN RIVER COMPARED WITH TIMING OF THE CATCH OF 6-MM LARVAE IN SUISUN BAY DOWNSTREAM OF COLLINSVILLE, 1986



Timing of striped bass spawning is based on catch of striped bass eggs in the upper Sacramento River and lower San Joaquin River. Sampling started on the same date except in the upper Sacramento River, where an arrow marks the start of sampling.

Figure 7 also shows the timing of 5-mm larvae in the lower Sacramento River and the lower San Joaquin River. Some 5-mm larvae were present early in the lower Sacramento River, probably from early spawning in the upper Sacramento. The large peak of 5-mm larvae in the lower Sacramento River on day 134-138 corresponds with the second peak of 6-mm larvae 4 days later in Suisun Bay. Similar results are evident from the timing of 5-mm larvae in the lower San Joaquin River.

To quantify the results, I ran a multiple regression between daily number of 6-mm larvae caught in Suisun Bay as the dependent variable and, as the independent variables:

- Daily catch of eggs 8 days earlier.
- Daily midpoint of where the eggs were caught (expressed as river kilometer).

No significant relationship was apparent for egg catch in the upper Sacramento River (Table 2).

I also examined the relationship between the catch of 6-mm larvae in Suisun Bay and that of 5-mm larvae in the lower Sacramento River 4 days earlier. The relationship was significant but accounted for only 38.4 percent of the variability of 6-mm larvae.

Results were quite different for the lower San Joaquin River (Table 2). The daily catch of eggs in

the lower San Joaquin 8 days earlier could account for 74.1 percent of the variability of 6-mm larvae in Suisun Bay and adding a second variable, the daily midpoint of where the eggs were caught in the river, accounted for 89.2 percent of 6-mm larvae.

I examined the data during the same period eggs were sampled in the upper Sacramento in case the relationship was being driven by the first large peak of spawning in the lower San Joaquin River. Egg catch and midpoint of spawning in the lower San Joaquin River still accounted for 88.5 percent of the variability of 6-mm larvae in Suisun Bay.

Results of using the catch of 5-mm larvae 4 days earlier in the San Joaquin River were not much different than in the lower Sacramento River. The relationship was significant, but would account for only 47.4 percent of the variability of 6-mm larvae in Suisun Bay. These results suggest that spawning in the lower San Joaquin River was important in determining the number of 6-mm larvae in Suisun Bay in 1986.

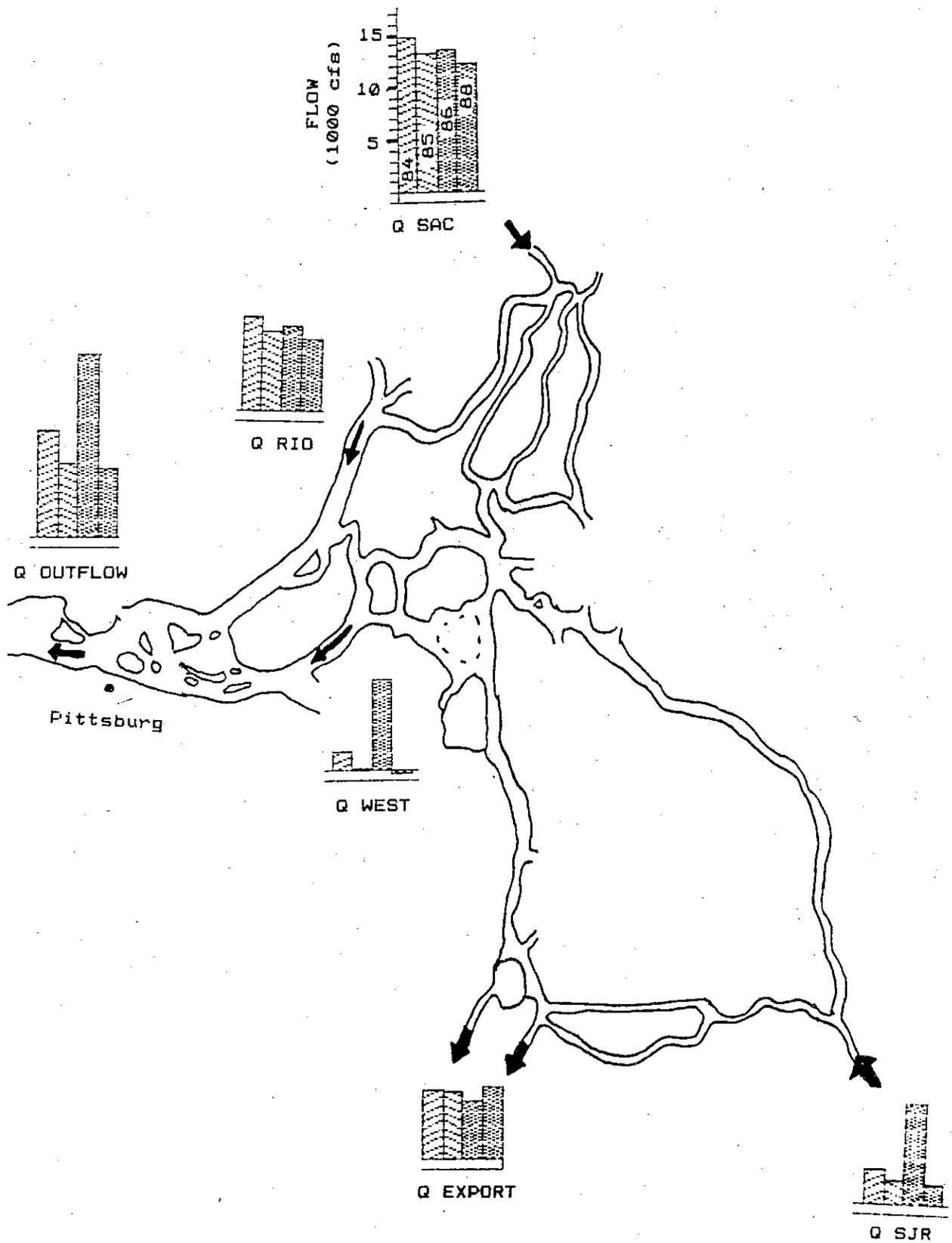
Why then, were there more 6-mm larval bass in Suisun Bay in 1986 than in 1984, 1985, or 1988? Figure 8 shows mean flows (*in cfs*) at various points in the estuary from April 19 (day 110) to June 10 (day 162), the period most of the 6-mm larvae appeared in Suisun Bay. Note that there was:

Table 2
RELATIONSHIP BETWEEN DAILY CATCH OF 6-MM LARVAL STRIPED BASS IN SUISUN BAY AND:
(1) DAILY CATCH AND LOCATION OF EGGS IN THE SACRAMENTO AND SAN JOAQUIN RIVERS
8 DAYS EARLIER
(2) DAILY CATCH OF 5-MM LARVAE IN THE TWO RIVERS 4 DAYS EARLIER

River System	Variables	R ²	Sign	Samples
Sacramento	Egg Catch	0.038	NS	13
	Egg Catch/Location	0.165	NS	13
	5-mm Larval Catch	0.384	1%	22
San Joaquin	Egg Catch	0.741	1%	18
	Egg Catch/Location	0.892	1%	18
	Egg/Catch/Location*	0.885	1%	13
	5-mm Larval Catch	0.474	1%	22

*Used the same sampling dates as in the Sacramento River.

Figure 8
 MEAN FLOWS (cfs) AT VARIOUS POINTS IN THE SACRAMENTO-SAN JOAQUIN ESTUARY,
 APRIL 19 TO JUNE 10, 1984, 1985, 1986, AND 1988



- Little difference in Sacramento River flows (QSAC) from the striped bass spawning area over the four years,
- Little difference in flows passing Rio Vista (QRIO), the avenue most Sacramento River eggs and larvae would be expected to take, and
- Little difference in total exports at the SWP and CVP pumping plants (QEXPORT).

However, San Joaquin River flows into the Delta (QSJR) were much higher in 1986 than in the other three years. This resulted in much higher flows in the San Joaquin River at Jersey Point (QWEST). I believe it was these higher flows in the lower San Joaquin River in 1986 that moved a significant portion of the striped bass eggs and larvae that were spawned there down into Suisun Bay.

The values of QWEST flows in Figure 8 mimic the YOY Indices in Figure 6, with 1986 the highest, followed by 1984, 1985, and 1988. There was a calculated mean flow reversal in QWEST in 1988.

High flows were also present in the lower San Joaquin River in 1978, 1982, and 1983, but larvae were not sampled in those years. The 1983 YOY Index was low, as a large number of fish were believed to have been swept out of the sampling area by high flows (DFG, 1987). The 1978 and 1982 YOY indices were lower than expected, although the 1982 index was still the second highest since the 1976/1977 drought (Figure 1).

The 1986 results suggest we should look for ways to flush eggs and larvae produced in the lower San Joaquin River down into Suisun Bay. More specifically, they should be transported as near as possible to the zone where fresh water and salt water mix – an important area for development of larval striped bass. The location of this zone is a function of freshwater outflow, and it is farther downstream in high outflow years.

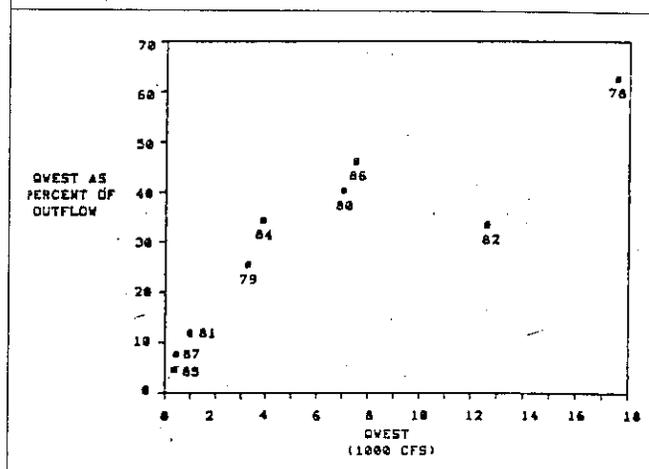
The number of eggs and larvae spawned in the lower San Joaquin River that make it to the mixing zone is a function of total flow down the lower San

Joaquin River (QWEST) and the percent of total outflow (QOUT) that is from the San Joaquin River (QWEST). For example, freshwater outflow from the system could be quite high, but if it is primarily from the Sacramento River (QRIO), eggs spawned in the lower San Joaquin would not make it to the mixing zone.

Figure 9 is a plot of QWEST against the percent of total outflow that is QWEST flow for each year from 1978 to 1988, except 1983. There is a close relationship between QWEST flow and percent of total outflow composed of QWEST for all years except 1978 and 1982. For those two years, the percent increase of QWEST water was much less due to the high Sacramento River flow (QRIO). Perhaps in 1978 and 1982 the mixing area was too far downstream for larval striped bass spawned in the lower San Joaquin River despite these being high QWEST years.

These results do not infer that young bass survival is driven solely by what happens with the eggs and larval bass in the lower San Joaquin River, although in recent years it appears to be of major importance. We should look at ways to move eggs and larvae from the Sacramento River into Suisun Bay as well.

Figure 9
RELATIONSHIP BETWEEN
ANNUAL QWEST FLOW AND QWEST AS
PERCENT OF TOTAL OUTFLOW (QOUT)
DURING THE ANNUAL PERIOD OF
HIGHEST LARVAL BASS ABUNDANCE



Major Food Items of Early-Feeding Larvae

Food organisms selected by larval bass from 1984 to 1986 were determined by relating food items in stomachs of the larvae with available food in the environment, based on a method by Ivlev (1961). Values in Ivlev's formula range from +1 (eaten whenever encountered in the environment) to -1 (avoided by larvae regardless of abundance in the environment).

Zooplankton in the environment were counted at the same time numbers of organisms per stomach were determined for specific areas (Fusfeld and Miller, 1985; Miller, 1987). Numbers of various zooplankton species were converted to dry weight estimates based on average dry weight values or estimated dry weights of similar organisms from the literature (Miller and Orsi, DFG, correspondence).

Eurytemora affinis and *Cyclopidae* adults were selected most often as food by larval striped bass 5 to 10 millimeters long (Figure 10). This was true for all areas sampled from 1984 to 1986. *Daphnia* sp. were selected at a level slightly higher than its abundance in the environment. *Bosmina* sp. were selected a substantial amount of time but only by 5- and 6-mm larvae. *Sinocalanus doerrii*, calanoid copepodids, cyclopoid copepodids, and *Harpacticoid* species were seldom selected by 5- to 10-mm larvae.

E. affinis also made up a high percentage of bass stomach contents, but there was considerable variability between areas (Figure 11). Adult copepods other than *E. affinis* or *S. doerrii* also made up a fairly high percentage. *S. doerrii* generally comprised less than 10 percent of food for all lengths of larvae in all areas of the system. The importance of *Bosmina* and *Daphnia* species decreased with increasing bass length. *Neomysis* sp. were important for larger larvae.

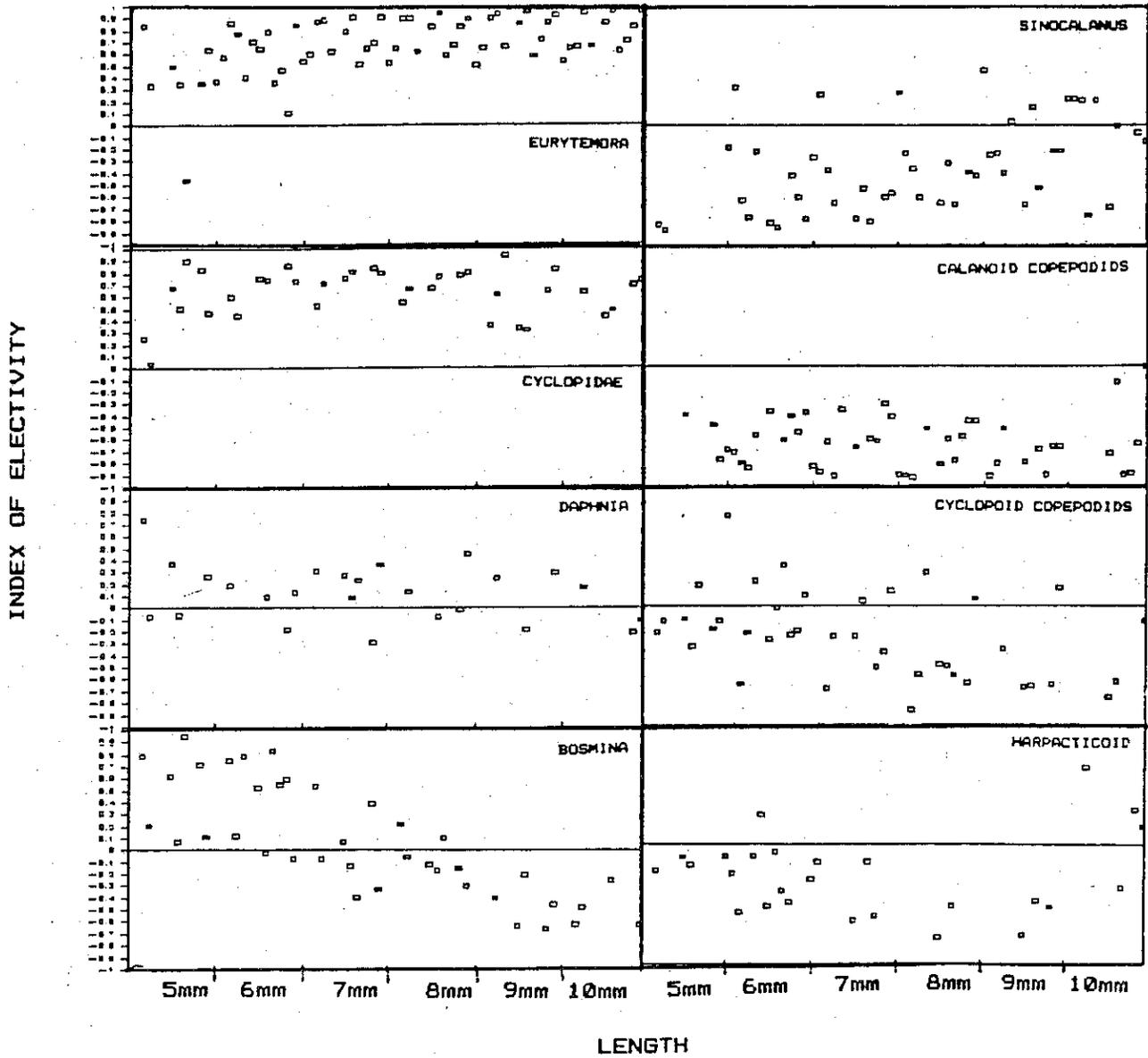
In some areas, larval fish consumed large numbers of organisms smaller than *E. affinis* and *Cyclopidae* adults. An important question is whether a feeding environment composed mainly of smaller organisms is as good as one with a higher proportion of larger organisms. To answer this question, I compared the estimated total dry weight of food in bass stomachs with the estimated percentage of dry weight of smaller organisms in the stomachs. I considered *Harpacticoid*, *Daphnia*, calanoid copepodids, cyclopoid copepodids, and *Bosmina* to be small species.

For all size groups of larval bass combined, estimated total dry weight of stomach contents in an area decreased in a curvilinear fashion as the percent of smaller organisms increased (Figure 12). A more linear relationship resulted by applying a log₁₀ transformation of the data (Figure 13). Since larger larvae would be expected to consume larger prey, I calculated this relationship for each size group to eliminate length bias. Results (Table 3) showed that estimated dry weight per stomach was less when there was a large percentage of small organisms in the stomachs. I conclude that a feeding environment composed mainly of small organisms is not as good as one with a higher proportion of larger organisms.

Table 3
RELATIONSHIP BETWEEN
ESTIMATED DRY WEIGHT PER STOMACH
AND THE LOG OF THE PERCENT OF
SMALLER ORGANISMS PER STOMACH FOR
EACH SIZE GROUP OF LARVAL BASS
FROM 5 MM TO 10 MM, 1984, 1985, AND 1986

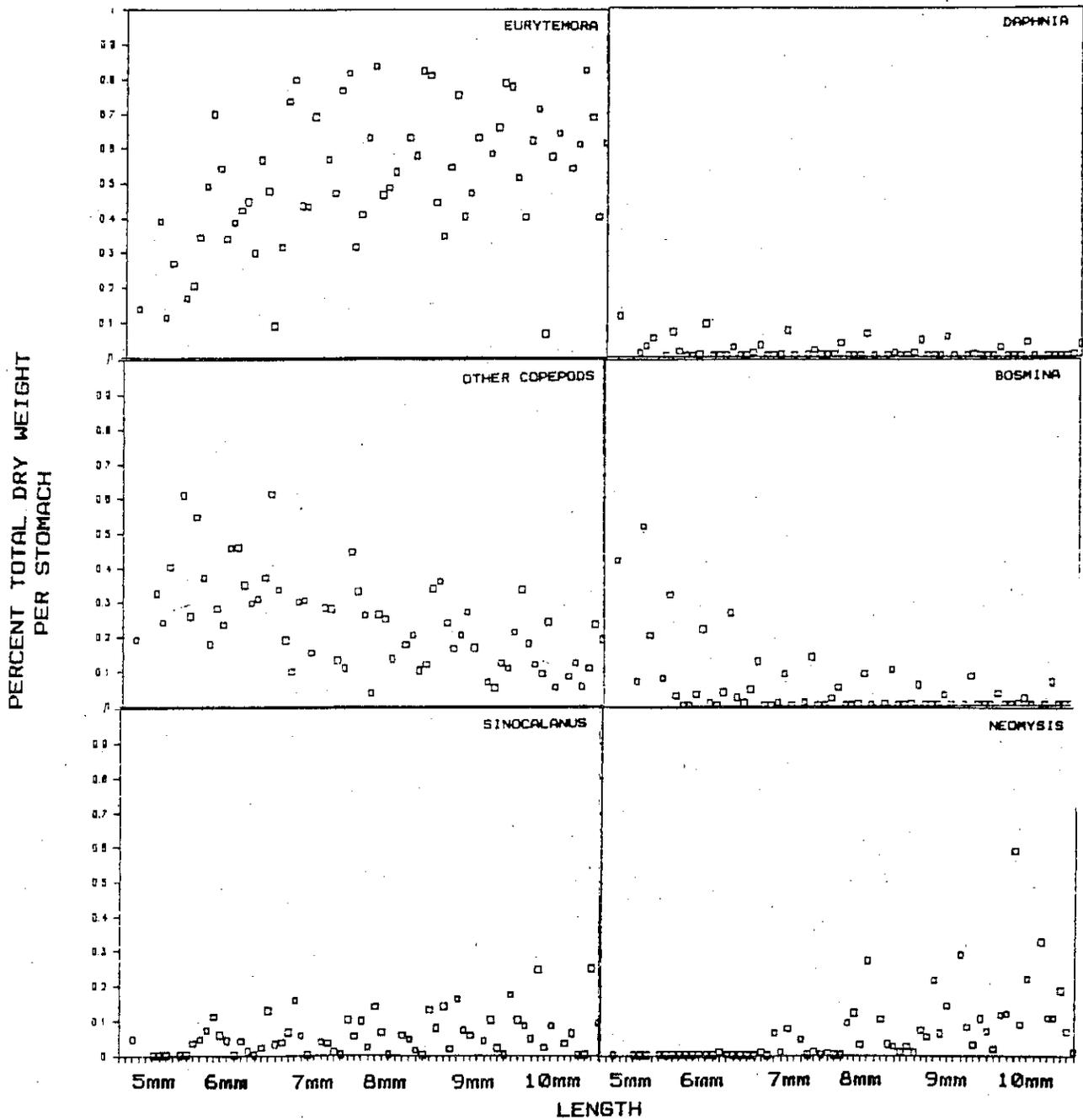
Size Group	Number of Samples	R	Significance
5 mm	7	0.867	0.01
6 mm	12	0.665	0.05
7 mm	11	0.673	0.05
8 mm	11	0.714	0.01
9 mm	9	0.645	0.05
10 mm	8	0.758	0.05

Figure 10
 COMPARISON OF IVLEV'S INDEX OF ELECTIVITY, BY MAJOR FOOD ITEM, FOR
 5- TO 10-MM LARVAL STRIPED BASS FOR ALL SAMPLING AREAS IN THE
 SACRAMENTO-SAN JOAQUIN ESTUARY, 1984, 1985, AND 1986



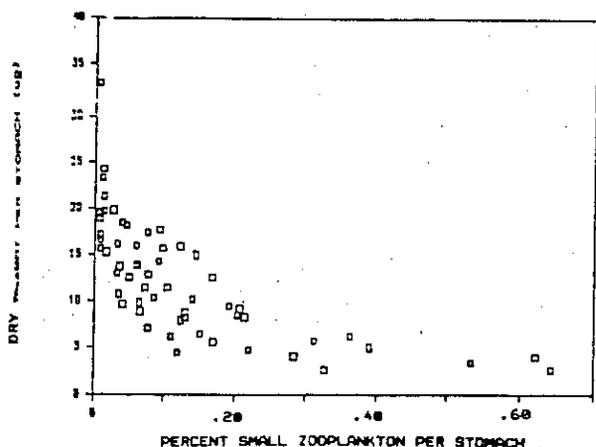
Each data point represents the value from a sampling area.
 Sampling areas are defined by Fusfeld and Miller (1985).

Figure 11
 CHANGES IN ESTIMATED MEAN DRY WEIGHT OF VARIOUS FOOD ORGANISMS, BY AREA,
 AS A PERCENT OF TOTAL STOMACH CONTENTS OF 5- TO 10-MM LARVAL STRIPED BASS,
 1984, 1985, AND 1986



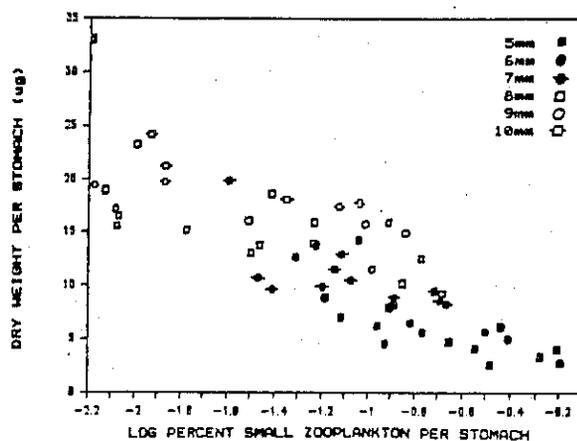
Only sample sizes of at least 10 fish with food were used.
 Each data point represents the mean of a sampling area.

Figure 12
COMPARISON BETWEEN
ESTIMATED DRY WEIGHT PER STOMACH
AND
PERCENT OF SMALLER ORGANISMS IN THE
STOMACHS OF 5- TO 10-MM LARVAL BASS,
1984, 1985, AND 1986



Daphnia sp., Harpacticoid sp., calanoid copepodids, cyclopoid copepodids, and Bosmina sp. were classified as smaller organisms.

Figure 13
COMPARISON BETWEEN
ESTIMATED DRY WEIGHT PER STOMACH
AND THE LOG OF THE
PERCENT OF SMALLER ORGANISMS IN THE
STOMACHS OF 5- TO 10-MM LARVAL BASS,
1984, 1985, AND 1986



Daphnia sp., Harpacticoid sp., calanoid copepodids, cyclopoid copepodids, and Bosmina sp. were classified as smaller organisms.

Abundance and Distribution of *E. Affinis*

I concentrated on *E. affinis* as the food species because of its importance to larval striped bass. *E. affinis* is an estuarine species and its life history is closely linked with the zone of initial fresh water and salt water mixing — the so-called *entrapment zone*. During early-feeding stages, larval striped bass are most common just upstream of the entrapment zone (Miller and Fujimura, 1989), so I chose the specific conductance value of 1,000 $\mu\text{S}/\text{cm}$ as an indicator of the upstream edge of this zone and compared population density of *E. affinis* at and above this point.

The position of the entrapment zone is a function of freshwater flow rates — the higher the freshwater flow, the farther downstream the entrapment zone. The entrapment zone is in Suisun Bay during high and normal freshwater flows but moves up into the Delta under low-flow conditions.

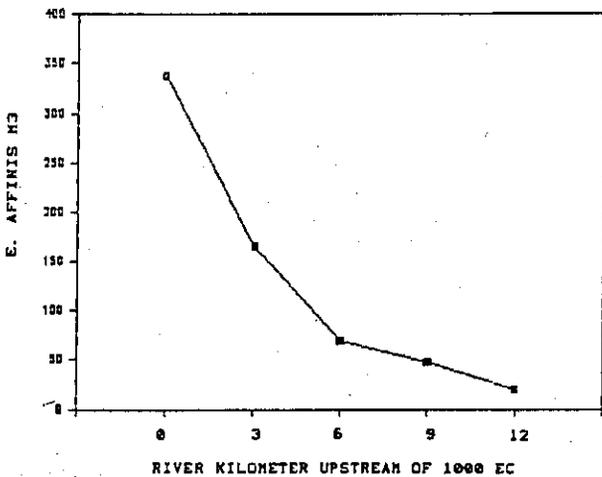
Samples were from DFG zooplankton surveys in the deep-water channels from Martinez in Suisun Bay to just above Rio Vista on the Sacramento River and to Venice Island on the San Joaquin River. I assumed the sampling stations were 3 kilometers apart for some of the analysis.

Figure 14 shows the antilog of the mean log of *E. affinis* concentrations from 1972 to 1987 at equal distances upstream of 1,000 $\mu\text{S}/\text{cm}$ specific conductance. Mean concentrations decline rapidly proceeding upstream. Compared to concentrations where specific conductance was 1,000 $\mu\text{S}/\text{cm}$, concentrations were:

- 50.1 percent at 3 kilometers,
- 20.4 percent at 6 kilometers,
- 13.9 percent at 9 kilometers, and
- 5.7 percent at 12 kilometers.

Because a large proportion of early-feeding larvae are just upstream of 1,000 $\mu\text{S}/\text{cm}$ specific conductance (Miller and Fujimura, 1989), the closer the

Figure 14
 CHANGES IN MEAN CONCENTRATIONS OF *E. AFFINIS* UPSTREAM OF 1000 $\mu\text{S}/\text{cm}$ SPECIFIC CONDUCTANCE DURING MAY AND JUNE, 1972 TO 1988



larvae are transported to that zone, the higher the concentrations of *E. affinis* available as food.

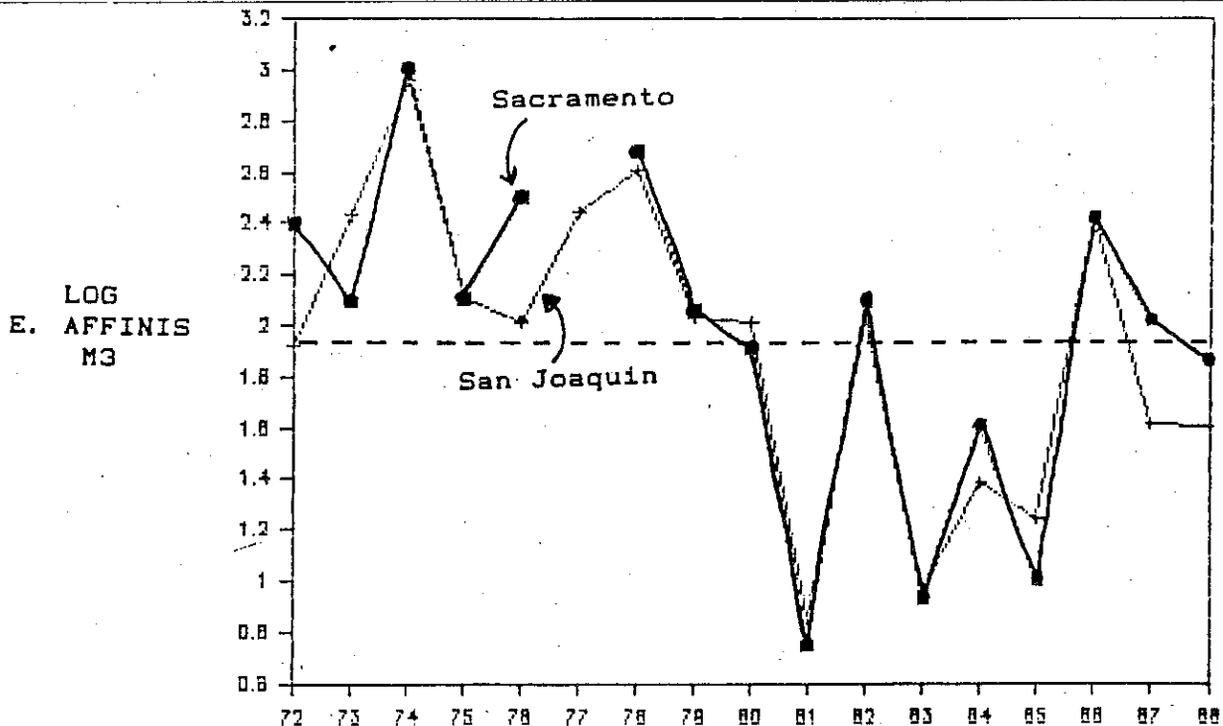
Annual differences in concentrations of *E. affinis* were determined by comparing mean concentra-

tions at sampling stations just upstream of 1,000 $\mu\text{S}/\text{cm}$ specific conductance for May and June, 1972 to 1987. Figure 15 is based on *E. affinis* concentrations calculated by Miller (1989) and shows annual log concentrations for the Sacramento and San Joaquin rivers. Major annual differences are evident, but differences between the two river systems are small.

In the Sacramento River, zooplankton concentrations upstream of 1,000 $\mu\text{S}/\text{cm}$ specific conductance were higher than average from 1972 to 1979 and lower than average from 1980 to 1988 except for 1982, 1986, and 1987. Average concentration in 1986 was the highest in the last 10 years. Similar differences were evident in the San Joaquin River, except 1980 and 1987 were switched.

Mean log concentration of *E. affinis* was 2.40997 (257.0 m³) from 1972 to 1978 and 1.64217 (43.8 m³) from 1979 to 1988. This is a mean annual density decline of 83 percent just upstream of the entrapment zone since the 1970s.

Figure 15
 ANNUAL MEAN OF THE LOG OF *E. AFFINIS* CONCENTRATIONS UPSTREAM OF 1000 $\mu\text{S}/\text{cm}$ SPECIFIC CONDUCTANCE DURING MAY AND JUNE, 1972 TO 1988



Data from Miller, 1989.

Possible Losses of *E. Affinis* to Export Pumps in High Outflow Years

Recent studies have shown that losses of striped bass eggs and larvae in water diverted to the SWP and CVP pumps are much higher than thought (DFG, 1987). Losses of important food organisms such as *E. affinis* could also be quite high, especially during low outflow years. It is difficult to see how pumping could affect concentrations of *E. affinis* during a high outflow year, because the population is far downstream of the Delta in those years. However, data from 1986, a high outflow year, might shed some light on the subject.

The first zooplankton survey in 1986 was March 18 and 19 (Julian days 77 and 78). Figure 16 shows concentrations of *E. affinis* from the main channel at the west end of San Pablo Bay to sampling station 58, just upstream of the confluence of the Sacramento and San Joaquin rivers at Collinsville. *E. affinis* were collected only in San Pablo Bay; the 11 stations upstream of the east end of San Pablo Bay produced none. Specific conductance values in San Pablo Bay were low, so the entrapment area was still downstream of the sampling area.

The second 1986 survey was April 1, 2, 3, 4, and 7 (Julian days 91-94 and 97). Highest concentrations of *E. affinis* were in the Carquinez Strait area, where specific conductance was high (Figure 17). A few *E. affinis* were taken upstream, at station 74 (Antioch) and station 78 (Jersey Point), but none at other stations upstream of Collinsville.

The egg and larval bass survey started April 16 (Julian day 106), when the entrapment zone had moved upstream into Suisun Bay and the highest concentrations of *E. affinis* were downstream of Collinsville. Low numbers of *E. affinis* were caught throughout the lower San Joaquin River at the easternmost stations.

Figure 18 shows mean *E. affinis* concentrations at stations upstream of the mouth of False River from Julian day 90 to 175. The zero catch value on day 91 is from the second zooplankton survey.

Figure 19 shows daily streamflow values in the lower Sacramento River (QRIO) and lower San Joaquin River (QWEST). Figure 20 shows specific conductance at Collinsville, and Figure 21 shows daily exports at the CVP and SWP pumps. Note that *E. affinis* were caught in the central and eastern Delta, even during high outflows in the lower San Joaquin River (QWEST, Figure 19) when the entrapment zone was well downstream of Collinsville (Figure 20). The first *E. affinis* were taken when the streamflows were decreasing and pumping had been increased.

Why would *E. affinis* consistently be found so far up the San Joaquin River? Figure 22 shows mean log concentrations of *E. affinis* for stations at equal distances upstream of the confluence of the two rivers for the same period. Concentrations are much higher in the San Joaquin River than in the Sacramento River at comparable distances upstream under similar streamflows during a high outflow period. *E. affinis* are present throughout the San Joaquin River to the uppermost sampling station near the junction with Old River.

These results suggest upstream movement of low concentrations of *E. affinis* into the San Joaquin River even during high outflows. Their presence in the San Joaquin but not the Sacramento may be the result of export pumping. An evaluation of the importance of export pumping on the *E. affinis* population is needed.

Discussion

From 1959 to 1970, abundance of young striped bass (YOY Index) was highly correlated with both freshwater outflow and percent of water diverted from the Delta during spring and early summer (Turner and Chadwick, 1972). Bass abundance was high in springs that had high outflows and low percent diversions. In the early and mid-1970s, this relationship was no longer valid, especially in the Delta portion of the estuary. The change coincided with higher diversion rates by the SWP and CVP (Chadwick *et al.*, 1977).

Figure 16
 CONCENTRATIONS OF E. AFFINIS AND SPECIFIC CONDUCTANCE VALUES IN THE
 MAIN CHANNEL FROM THE WEST END OF SAN PABLO BAY TO THE SWP PUMPING PLANT,
 MARCH 18 AND 19, 1986

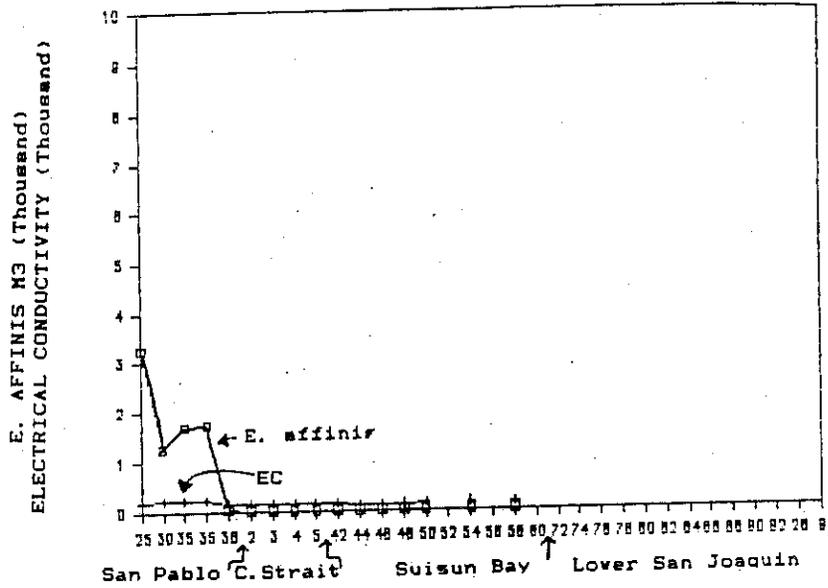


Figure 17
 CONCENTRATIONS OF E. AFFINIS AND SPECIFIC CONDUCTANCE VALUES IN THE
 MAIN CHANNEL FROM THE WEST END OF SAN PABLO BAY TO THE SWP PUMPING PLANT,
 APRIL 1-7, 1986

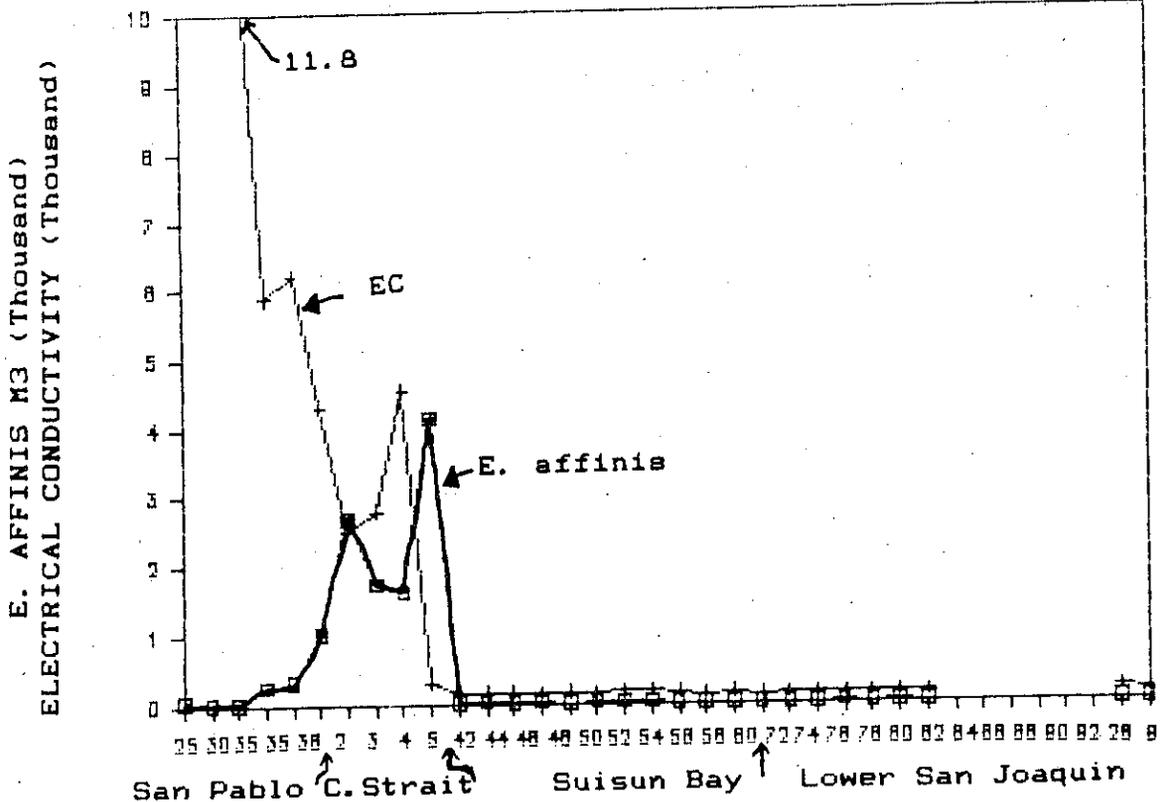


Figure 18
 E. AFFINIS CONCENTRATIONS UPSTREAM OF THE MOUTH OF FALSE RIVER IN THE
 LOWER SAN JOAQUIN RIVER, JULIAN DAY 90-175 (MARCH 31-JUNE 24) 1986

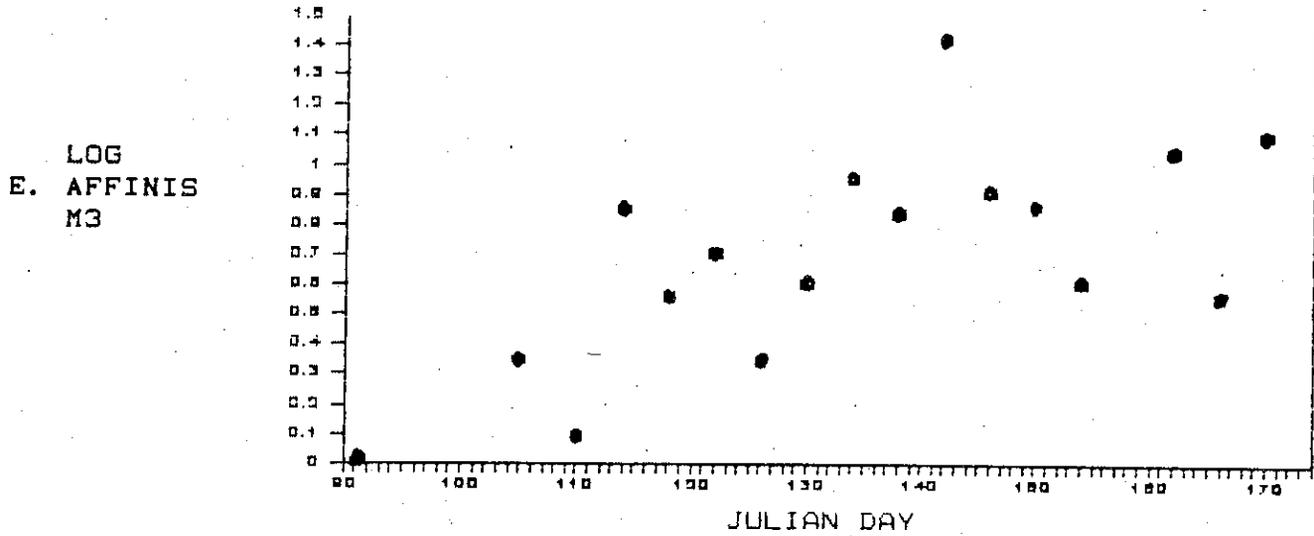


Figure 19
 FLOWS IN THE LOWER SACRAMENTO RIVER (ORIO) AND LOWER SAN JOAQUIN RIVER (QWEST),
 JULIAN DAY 90-175 (MARCH 31-JUNE 24) 1986

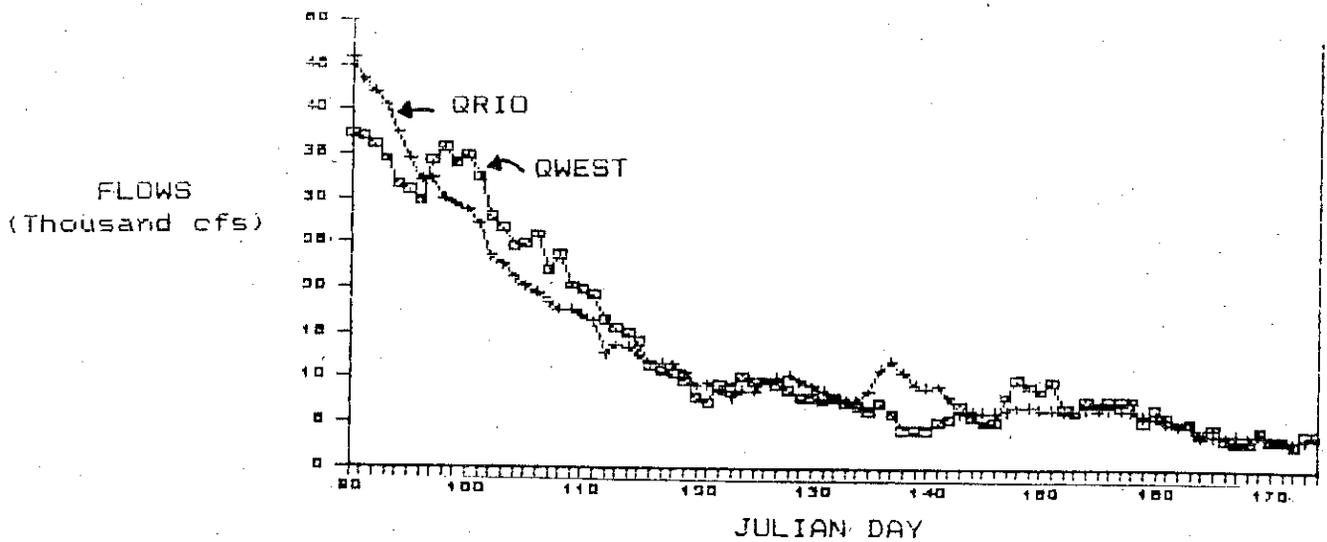


Figure 20
SPECIFIC CONDUCTANCE AT COLLINSVILLE, JULIAN DAY 90-175 (MARCH 31-JUNE 24) 1986

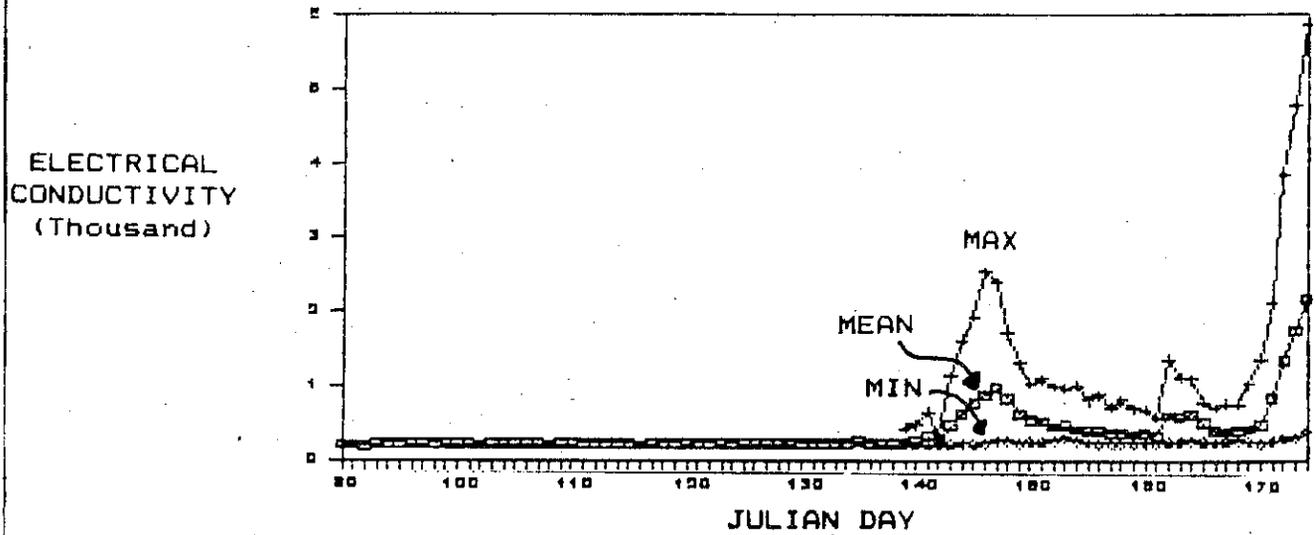


Figure 21
SWP AND CVP EXPORTS, JULIAN DAY 90-175 (MARCH 31-JUNE 24) 1986

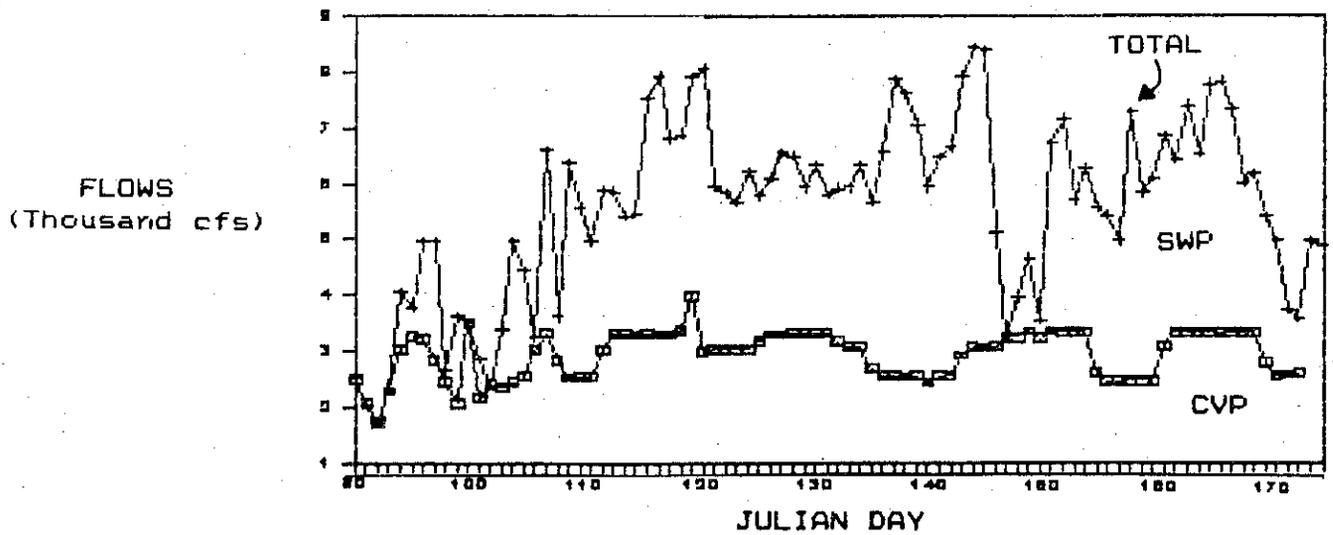
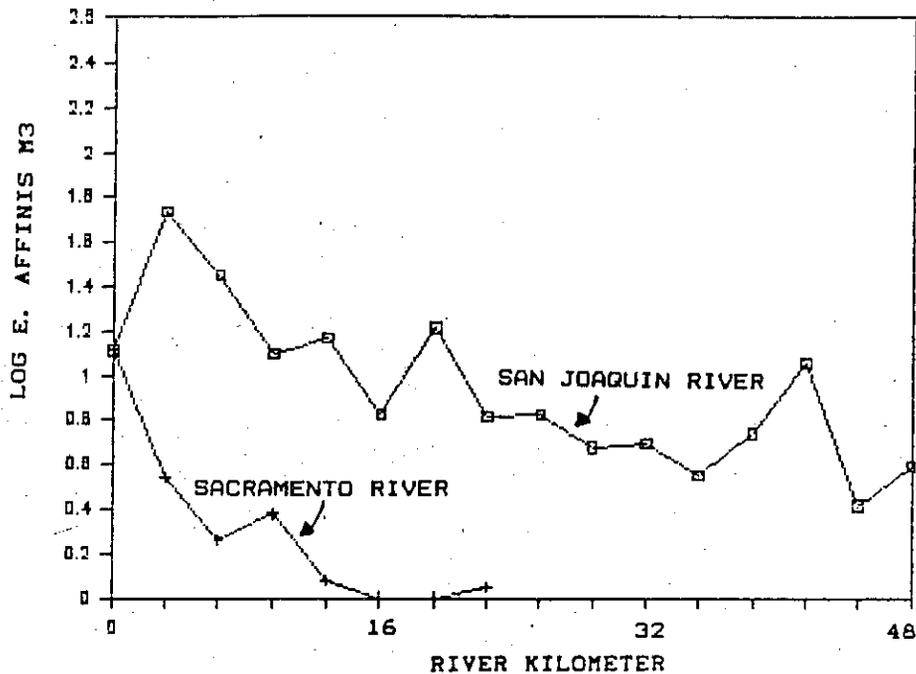


Figure 22
 MEAN LOG OF *E. AFFINIS* CONCENTRATIONS IN THE
 LOWER SACRAMENTO RIVER AND LOWER SAN JOAQUIN RIVER UPSTREAM OF
 THEIR CONFLUENCE, JULIAN DAY 106-142 (APRIL 16-MAY 22) 1986



A new relationship between May/June outflow and diversion rate could predict the YOY Index at a lower level. These new correlations were used to develop some of the standards for State Water Resources Control Board Water Right Decision 1485. Since 1977, however, abundance of young bass has been even lower than the reduced prediction (DFG, 1987). The only exception was 1986, when the YOY Index was equal to the index predicted from the early 1970s relationship.

Recent studies have shown that losses of eggs and larval bass to the pumps are much higher than believed (DFG, 1987), and there seems to have been a major reduction in ability of the Delta to support larvae. Since the drought of 1976 and 1977, we have witnessed:

- A decline in the numbers of larval striped bass,
- A decline in concentrations of *E. affinis*,
- A decline in concentrations of *Neomysis* sp.,

- A decline of phytoplankton in the entrapment zone for most years, and
- An apparent decline in concentrations of particulate matter entering the estuary, as suggested by clearer water in the Delta.

Something is either affecting the base of the food chain and organisms are declining at each trophic level, or something is affecting all levels of the food chain at the same time.

Continued high pumping rates in the southern Delta may be causing the deterioration of the Delta environment. High pumping rates have a twofold effect by causing:

- Direct loss of striped bass eggs and larvae to the pumps and
- Loss of their food supply (especially *E. affinis*) either by direct losses to the pumps or through declining hydrologic conditions that used to favor the production of *E. affinis*, which, in turn,

would affect survival of the remaining larval bass.

Possible management options to improve survival of eggs and larval striped bass in the Delta include:

- Stopping or greatly restricting pumping when larval bass are upstream of Collinsville,
- Flushing eggs and larval bass downstream to below Collinsville and holding them there during their early development, and
- Modifying water diversions through the central Delta so that *E. affinis* and larval striped bass are not carried out of the system.

Recommendations

To further our understanding of this problem, we need:

- Information on sources of basic and secondary productivity of the entrapment zone and how this affects the area immediately upstream. Just how important is phytoplankton in providing energy to zooplankton (*E. affinis*) in the entrapment zone? How important is detritus production from within the system and from the inflowing river systems? We need to understand and measure the importance of these sources and whatever other sources of energy may be important in *E. affinis* production.
- Knowledge of the rate at which suspended materials and organisms are lost from the entrapment zone due to export pumping under varying Delta outflow and QWEST flows.
- A measure of *E. affinis* production in the entrapment zone. Studies of their growth rates, reproduction rates, and total mortality rates are necessary to evaluate causes of mortality.
- An understanding of the stratified flow mechanism that may enable *E. affinis* to move upstream during high outflows, as may have

occurred in the lower San Joaquin River in 1986. A special study of the interaction between vertical and horizontal position of *E. affinis* and effects of tide, flow, depth, time of day or night, water transparency, and pumping is suggested at sampling stations in the eastern part of the lower San Joaquin River during various types of flow.

- A sampling device at the export pumps to continually sample losses of larval striped bass as well as losses of *E. affinis* and other zooplankton. Larval striped bass are now sampled at the pumps with a 10-minute net tow every 2 or 4 days at about the same time each day. The sampling schedule is not adequate to detect slugs of larval bass that may pass to the pumps. *E. affinis* have been sampled at the pumps only once to determine losses, and these data have not been analyzed. They should be sampled at the same time and directly from the water taken into Clifton Court Forebay (SWP) and the CVP facility. USBR is developing a continuous sampling device for eggs and larval bass at the CVP facility. A device should be developed for sampling zooplankton.
- A transport model to simulate abundance and distribution of larval bass based on hydrological conditions. If the model were successful, we could determine conditions necessary to move larvae into various areas and to test the effects of doing so. We should accelerate development of a transport model, as started by DWR, to simulate the abundance and distribution of 6-mm larvae.
- Determination of the feasibility of using flow and diversion structures to transport eggs and larval bass into Suisun Bay near or into the zone of initial mixing of fresh water and salt water — the entrapment zone.
- Test results of transporting larval bass to the entrapment zone.

Acknowledgments

Special thanks are due the California Department of Fish and Game in Stockton for generously sharing data whenever requested and to the computer programmers at the U.S. Bureau of Reclamation who did the major computer programming for me.

Literature Cited

- Chadwick, H.K., D.E. Stevens, and L.W. Miller. 1977. "Some Factors Regulating the Striped Bass Population in the Sacramento-San Joaquin Estuary, California", *Proceedings of the Conference on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations*. W. Van Winkle, editor. Pergamon Press, New York. pp.18-35.
- Department of Fish and Game. 1987. *Factors Affecting Striped Bass Abundance in the Sacramento-San Joaquin River System*. Exhibit 25, State Water Resources Control Board Water Quality/Water Right Proceedings on the San Francisco Bay and Sacramento-San Joaquin Delta. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Technical Report 20. 149 p.
- Eldridge, M.B., J.A. Whipple, D. Eng, M.J. Bowers, and B.M. Jarvis. 1981. "Effects of Food and Feeding Factors on Laboratory-Reared Striped Bass Larvae." *Trans. Amer. Fish. Soc.* 110:111-120.
- Fusfeld, A., and L.W. Miller. 1985. *Final Report on 1984 Striped Bass Egg and Larva Survey in the Sacramento-San Joaquin Estuary*. Mimeo. Rept., DFG, Stockton, CA.
- Fortier, L., and W.C. Leggett. 1984. "Small-Scale Covariability in the Abundance of Fish Larvae and Their Prey." *Can. J. Fish. Aquat. Sci.* 41:502-512.
- Hunter, J.R. 1972. "Swimming and Feeding Behavior of Larval Anchovy, *Engraulis mordax*." *Fish. Bull. (U.S.)*70:821-838.
- Ivlev, V.S. 1961. *Experimental Ecology of the Feeding of Fishes*. New Haven, CN. Yale University Press.
- Miller, L.W. 1989. *Analysis of Secular Trends in *Eurytemora* from 1972-1988 in the Sacramento-San Joaquin Estuary*. Working Paper. DFG, Stockton, CA.
- _____. 1987. *Analysis of Larval Striped Bass Food Habits in the Sacramento-San Joaquin Estuary*. Draft Report. DFG, Stockton, CA.
- Miller, L.W., and R.W. Fujimura. 1989. *Results of the 1988 Young Bass Studies Program*. Working Paper (mimeo). DFG, Stockton, CA.
- Rayej, M. 1989. *Draft Report on Hydrodynamic Simulation of Fish Egg Transport in the Sacramento-San Joaquin Delta*. DWR Division of Planning, Sacramento.
- 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." *Trans. Amer. Fish. Soc.* 114:12-30.
- 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. *Trans. Amer. Fish. Soc.* 101:442-452.

Comments of the Food Chain Group

In this paper, Mr. Turner reviews historical data and findings of the California Department of Fish and Game:

- That the major reduction in the striped bass index has been in the Delta and less so in Suisun Bay.
- That there is a good correlation between past indexes of 8-mm and larger larvae and the summer indexes of 38-mm young-of-the-year bass.
- That the correlation between smaller-than-8-mm larvae and the young-of-the-year index is weak, but these indexes of smaller larvae are correlated with the numbers of eggs produced.

Mr. Turner believes environmental problems affecting the larvae between 7 and 8 millimeters may have greatly influenced the young-of-the-year index and, therefore, year class strength.

We are all very interested in 1986 because, in spite of low egg production, the 38-mm index was, for that year only, restored to a level predicted with the earlier relationships between the index and outflow and diversions. Mr. Turner suggests that the higher 1986 indexes of larger larvae and young-of-the-year may have been the result of higher San Joaquin River flows that moved eggs spawned in the San Joaquin down to Suisun Bay. He suggests possible explanations of why equally high or higher spring outflows in 1978, 1982, and 1983 did not produce larger indexes.

Mr. Turner examines data gathered during 1986 and suggests that, even though flows in the San Joaquin River were high, there may have been significant entrainment of the important food organism *Eurytemora affinis* from San Francisco Bay into the western and central Delta because of hydrological conditions related to export pumping.

Mr. Turner recommends additional studies to determine the source of basic and secondary production in the entrapment zone, the rate at which suspended materials and organisms are lost from the area in which striped bass larvae are feeding, the development of some measure of *Eurytemora affinis* production, and the mechanisms associated with movement of *Eurytemora* in stratified flows.

Over the 2 years the Food Chain Group has been meeting, Mr. Turner has presented these and other ideas reported in this paper. They are, in a true sense, working hypotheses to be critically reviewed, tested, and modified, and that process is taking place. Dr. Tim Hollibaugh of the Romberg Tiburon Center and colleagues in the U.S. Geological Survey, Menlo Park, are working on questions of basic and secondary productivity. Jim Orsi of California Department of Fish and Game has developed detailed hypotheses about the way stratified flow influences the behavior and distribution of zooplankton in the entrapment zone. All of these ideas are being pursued.

Mr. Turner also recommends developing a transport model to evaluate how flows in various Delta channels affect the ultimate distribution of eggs and larvae. He believes such a model would enable project operations to at least partially control the distribution of bass eggs and

larvae, with the purpose of reducing mortality and increasing the young-of-the-year index. At the very least, such a model would define how much control is possible and at what cost. The Food Chain Group believes this could be a valuable, practical tool.

D. W. Kelley, Chairman
Food Chain Group

Concentration of Food in the Sacramento-San Joaquin Estuary Compared with Other Estuaries Inhabited by Striped Bass

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November 1990

Introduction

Insufficient food for larval striped bass has been identified as one factor that may be causing the striped bass decline in California's Sacramento-San Joaquin estuary. In fact, the Interagency Food Chain Group was formed on the basis that this hypothesis has standing. One question not yet discussed is how the food supply in this estuary compares to that in other estuaries inhabited by striped bass.

To answer the question, I compiled information from a quick review of literature available to me. Most comparisons are with Chesapeake Bay, the major striped bass habitat on the East Coast. At a striped bass workshop (August 1989) in Columbia, South Carolina, I asked John Young, a biologist with Consolidated Edison of New York, if there was a zooplankton database for the Hudson River, another major striped bass estuary. He indicated that some samples had been taken at specific sites, but no longitudinal transects had been made to measure density or abundance over large areas. Other information on zooplankton density could probably be found if more searching were done.

Methods

I compared zooplankton concentrations for the spring nursery periods and areas where striped bass are abundant (Table 1). Most data were from a report by Houde *et al.* (1988). Using Houde's

graphs, I estimated concentrations in areas and for times that bass were present (Table 2).

One problem with all such comparisons is that methods and groupings of taxa or stages are different. It is difficult for me to assess how the results are influenced by methodology. *Neomysis* are not included in any of the studies.

Results and Discussion

Eurytemora concentrations are difficult to compare directly because in our system, we have historically used adult counts to monitor the populations. In other systems, it appears that copepodite and adult concentrations are combined (Table 1). Perhaps further communication with Ed Houde and others could result in obtaining data for direct comparison.

Bosmina concentrations in Chesapeake Bay are about seven times greater than in the Sacramento-San Joaquin estuary.

Concentrations of large zooplankton in the Sacramento-San Joaquin estuary are lower than in Chesapeake Bay but higher than in the Roanoke River system (Table 1).

This information does not show whether food is limiting or not, but it does suggest that food limitation could be a problem in this estuary. Further exploration of the food hypothesis seems to be appropriate.

Table 1
ZOOPLANKTON CONCENTRATIONS IN ESTUARINE STRIPED BASS NURSERY AREAS

Location and Reference	Number · L ⁻¹
<i>Eurytemora</i>	
Chesapeake Bay, Potomac River (Houde et al., 1988)	7 (Adults and Copepodites)
Chesapeake Bay, Sassafras River (Miller, 1978), Fresh Water	23-50 (Probably Adults and Copepodites)
Chesapeake Bay, Pamunkey River (McGovern and Olney, 1988), Calanoids, Mostly <i>Eurytemora</i>	0.006-11.6
Sacramento-San Joaquin, Specific Conductance < 1,000 μ S/cm	0.04-0.08 (Adults)
Sacramento-San Joaquin, Specific Conductance > 1,000 μ S/cm	0.4-0.9 (Adults)
Sacramento-San Joaquin*	0.6-0.9 (Adults)
<i>Bosmina</i>	
Chesapeake Bay, Potomac River (Houde et al., 1988)	55
Sacramento-San Joaquin, Specific Conductance < 1,000 μ S/cm	2-8
Large Zooplankton	
Chesapeake Bay, Potomac River (Martin et al., 1985), Copepods and Cladocerans	12-100
Chesapeake Bay, Potomac River (Houde et al., 1988) Adult Copepods, Copepodites and Cladocerans	88, 39-102
Chesapeake Bay, Sassafras River, (Cladoceran (16), Calanoids (36), Cyclopoids (92)) in 24-Hour Sampling	144
Roanoke River, North Carolina (Rulifson and Stanley, 1985)	0.4-0.8
Sacramento-San Joaquin, Specific Conductance > 1,000 μ S/cm	4-11
Sacramento-San Joaquin, Specific Conductance < 1,000 μ S/cm	2-7
Copepod Nauplii	
Chesapeake Bay, Potomac River (Houde et al., 1988)	57
Chesapeake Bay, Sassafras River	353-542
Sacramento-San Joaquin, Specific Conductance < 1,000 μ S/cm	5.8-9.8
Sacramento-San Joaquin, Specific Conductance > 1,000 μ S/cm	13-54

* Based on 1984-1986 densities where half of the 10-mm bass population was located. Other Sacramento-San Joaquin estimates are for stations used in food analysis for 1984, 1985, 1986, and 1988.

Table 2
CALCULATION OF MEAN MACROZOOPLANKTON CONCENTRATIONS WHERE
GREATEST CONCENTRATIONS OF BASS OCCURRED IN THE POTOMAC ESTUARY

Cruise Number	Station 2			Station 3			Station 4			Station 5			Mean		
	Clado- cerans	Cope- pods	Nauplii												
4	7	3	40	20	5	70	12	4	40	36	10	50	19	6	50
5	5	35	100	40	15	70	80	5	80	180	10	30	76	16	70
6	50	15	45	60	10	30	240	30	60	65	5	65	104	15	50
Mean	21	15	61	40	10	57	86	13	60	94	8	48	66	12	57

NOTE: *Eurytemora affinis* comprised 60.7 percent of all copepods (presumably adult and copepodites), and *Bosmina* comprised 82.6 percent of all Cladocerans, presumably for all seven sites and all seven cruises. Applying these values to the restricted sites and cruises resulted in the following approximate densities: *Eurytemora* = $0.607 \times 12 = 7.3$ or 7; *Bosmina* = $0.826 \times 66 = 54.5$ or 55.

Data are from Houde et al. (1988) using Stations 2-5 and Cruises 4-6, interpolated from Houde's Figure 22a-g.

Literature Cited

- Houde, Ed, E.J. Chesney Jr., R. Nyman, and E. Rutherford. 1988. *Mortality, Growth, and Growth Rate Variability of Striped Bass Larvae in Chesapeake Subestuaries*. Interim Report to Maryland Department of Natural Resources, Annapolis. i-iv, 127 p.
- Martin F., D. Wright, J. Means, and E. Setzler-Hamilton. 1985. *Importance of Food Supply to Nutritional State of Larval Striped Bass in the Potomac River Estuary*. Transactions of the American Fisheries Society 114:137-145.
- McGovern, J., and J. Olney. 1988. *Potential Predation by Fish and Invertebrates on Early Life History Stages of Striped Bass in the Pamunkey River, Virginia*. Transactions of the American Fisheries Society 117:152-161.
- Miller, P.E. 1978. *Food Habit Study of Striped Bass Post Yolk Sac Larvae*. Special Report 68. Chesapeake Bay Institute. The John Hopkins University. i-iv, 49 p.
- Rulifson, R., and D. Stanley. 1985. *Food and Feeding of Young Striped Bass in Roanoke River and Western Aelbemarle Sound, North Carolina*. 1984 Annual Progress Report for Project AFS-24 Segment 1. East Carolina University, Institute for Coastal and Marine Resources Technical Report 85-03. 55 p.

Comments of the Food Chain Group

Miller's finding that zooplankton concentrations in the Sacramento-San Joaquin estuary were only one-fourth to one-tenth as great as in other estuaries that support large bass populations surprised the Food Chain Group – especially because most of the data he presented from the Sacramento-San Joaquin estuary are from pre-1988 collections, before the major decline of *Eurytemora* took place.

More comparisons of this kind are needed. It will be especially interesting to compare those made where bass populations were much higher than now. The historical data base that will permit such a comparison is now being analyzed.

D. W. Kelley, Chairman
Food Chain Group

Analysis of Secular Trends in *Eurytemora affinis* in the Sacramento-San Joaquin Estuary, 1972 to 1988

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November 1990

Abstract: The copepod *Eurytemora affinis* is an important diet item of larval striped bass. Understanding its abundance trends during the early life stages of striped bass is important in evaluating whether changes in food supply are a cause of the decline in juvenile abundance since 1977. Data collected by the zooplankton monitoring project during 1972 to 1988 have been explored to determine spatial and temporal variations in *Eurytemora* concentrations. May/June trends were examined in particular, because this period corresponds to the striped bass nursery period, when the role of food is thought to be critical to bass survival. Although in 1988 concentrations declined by two orders of magnitude where specific conductance ranged from 1001 to 6000 $\mu\text{S}/\text{cm}$, there was no marked decline in this part of the estuary before 1988. In upstream areas (1000 $\mu\text{S}/\text{cm}$ or less), however, May/June concentrations were lower from 1980 to 1985 and rebounded to former levels after 1985.

Introduction

At the August 1989 Food Chain Group meeting, conflicting analyses were presented regarding time series trends in *Eurytemora* concentrations. The analysis I presented was essentially in agreement with the analysis I had presented at one of the first meetings. Both analyses indicated there has been no decline of *Eurytemora* in the entrapment zone, but there has been a decline in fresh water beginning about 1979.

After the August meeting I collaborated with Jim Orsi in developing an approach to reanalyzing the data to resolve inconsistencies and to describe trends in *Eurytemora* concentration in more detail.

Since a decline in this species has been hypothesized as an explanation for the striped bass decline, it is important to know whether *Eurytemora* has declined and, if so, when and where.

Methods

Corrections for Missing Data

Specific conductance measurements were missing for some stations and some surveys in 1982, 1986,

and 1987. These values were corrected either by entering values not originally keyed properly or by estimating missing values based on values at similar stations and accounting for flow conditions that affect the location of specific conductance values used in the analysis. A total of 255 values were missing, and most were estimated by the SAS program as the data were processed.

Geographical Scope

The analysis included stations in Carquinez Strait (02, 03, 04, 05, 338, 325) that have been sampled during some but not all surveys in high flow years since 1975. These stations were added to the survey to account for the downstream shift in population under high outflow conditions. Other stations included in all analyses were channel stations 42, 44, 46, 48, 50, 52, 56, 58, 60, 62, 64, 66, 68, 72, 74, 76, 78, 80, 82, 84, 86, 88, and D15. Stations farther upstream were excluded because they are not striped bass nursery areas. In all analyses except those where shoal and channel stations were compared, shoal stations in northern Suisun Bay were included. These stations are: 20, 22, 24, 26, 28, 36, 38, 40. Station locations are shown in Figure 1.

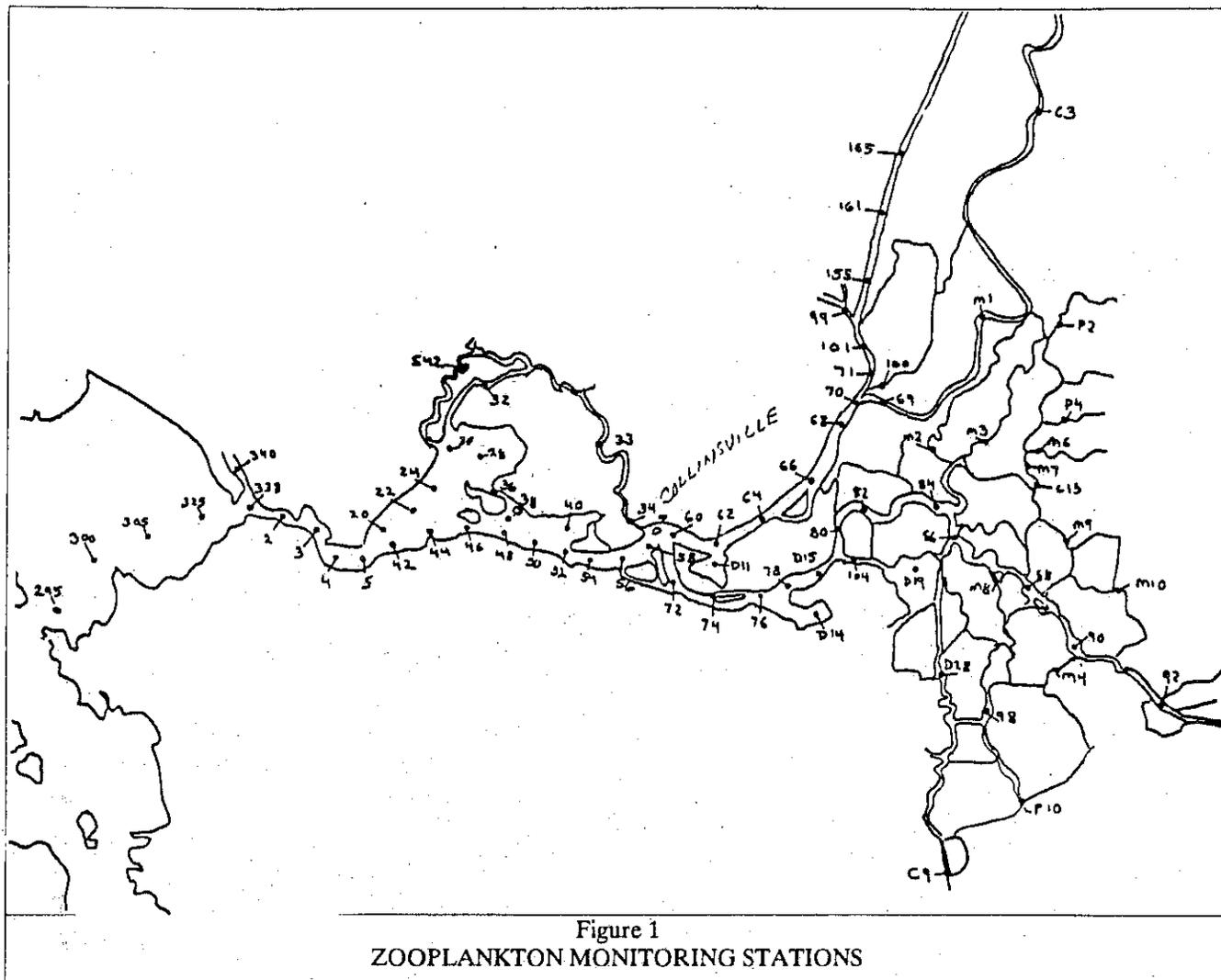


Figure 1
ZOOPLANKTON MONITORING STATIONS

Calculations

Log₁₀ *Eurytemora* concentrations were plotted with two standard error bars around the mean using SAS Graph. These are approximate confidence intervals because sample size, which varies with the number of stations in each specific conductance group, was not taken into account.

Eurytemora abundance was calculated by summing the products of the concentration at each station and water volume (*in cubic meters*) represented by each station. Mean log₁₀ concentration of the actual values plus one was calculated from the data after it was collapsed to two strata based on surface measured specific conductance ranges of 0-1000 $\mu\text{S}/\text{cm}$ (*microSiemens per centimeter*) for the freshwater portion of the estuary and 1001-6000 $\mu\text{S}/\text{cm}$ for the entrapment zone.

Results

Mean Log₁₀ Concentration versus Actual Concentration

Log₁₀ concentrations are geometric means (as explained to me by Steve Obrebski). Geometric mean values did not show the same trends as those for arithmetic means (Figure 2). This is because two populations with the same arithmetic means can have substantially different geometric means when the variation of one population is greater (Table 1).

It appears that differences in recent interpretation of some of these data are due to the type of mean calculated (Figure 2). Although arithmetic means are most commonly used, the best approach for hypothesis testing is to use transformed data,

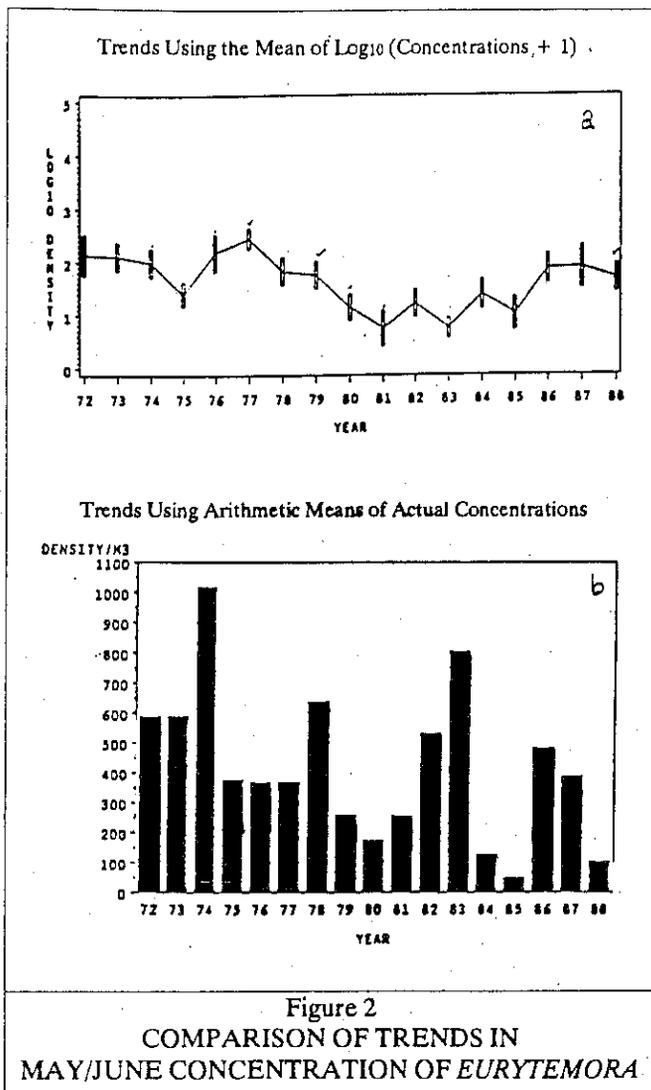


Figure 2
COMPARISON OF TRENDS IN
MAY/JUNE CONCENTRATION OF *EURYTEMORA*

which stabilizes the variance with respect to the mean and reduces the influence of outliers.

At the September 1989 meeting, Obrebski, Orsi, Kelley, and Miller agreed that this seemed the correct approach for future analyses.

Channel Concentration versus Channel plus Shoals Concentration

In the analysis presented at the August meeting, I used mean May/June concentration for channel, shoal, and two Montezuma Slough stations combined. The May/June period was used because this is when the food supply is critical to early-feeding striped bass larvae.

Table 1
COMPARISON OF
GEOMETRIC MEANS OF TWO POPULATIONS
WITH THE SAME ARITHMETIC MEAN

	P ₁	Log (P ₁ +1)	P ₂	Log (P ₂ +1)
	10,000	4.000	1,500	3.176
	5,000	3.699	2,000	3.301
	0	0	5,000	3.699
	0	0	3,000	3.477
	0	0	1,000	3.000
	0	0	2,000	3.301
	500	2.700	1,500	3.176
	1,000	3.000	500	2.699
SUM	16,500	13.399	16,500	25.830
MEAN	2,063	1.675	2,063	3.228
NUMBERS	8	8	8	8
STANDARD DEVIATION	3,629	1.83	1,399	0.30

At that time we thought including the shoal stations and Montezuma stations might account for differences between the analyses that had been presented. However, the comparison of channel plus shoal concentration with channel concentration showed no difference in average concentration or trends. Hence, including or excluding the shoal stations is not likely to affect interpretation of the data (see Figure 3).

Trends in May and June

Eurytemora concentrations in May and June were lower from 1980 to 1985 than for years prior to 1980 in fresh water, though they rebounded from 1986 to 1988 to nearly pre-1980 levels in the specific conductance range of 0-1000 $\mu\text{S}/\text{cm}$. In the entrapment zone (specific conductance of 1001 to 6000 $\mu\text{S}/\text{cm}$) no trend was evident. In 1988 *Eurytemora* declined by greater than an order of magnitude in the entrapment zone, whereas, in the fresh water portion of the estuary, concentrations were within historical levels (Figure 3).

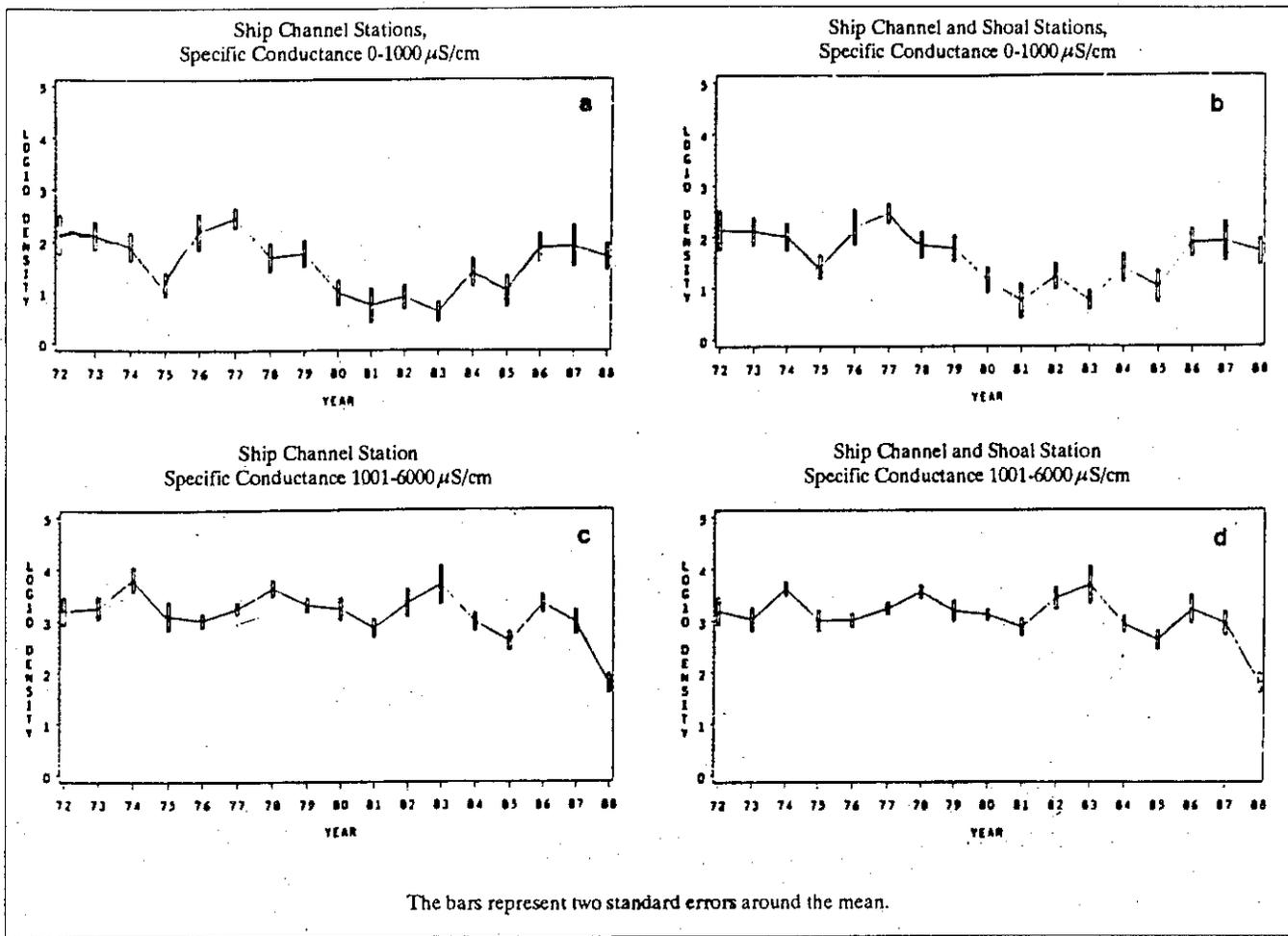


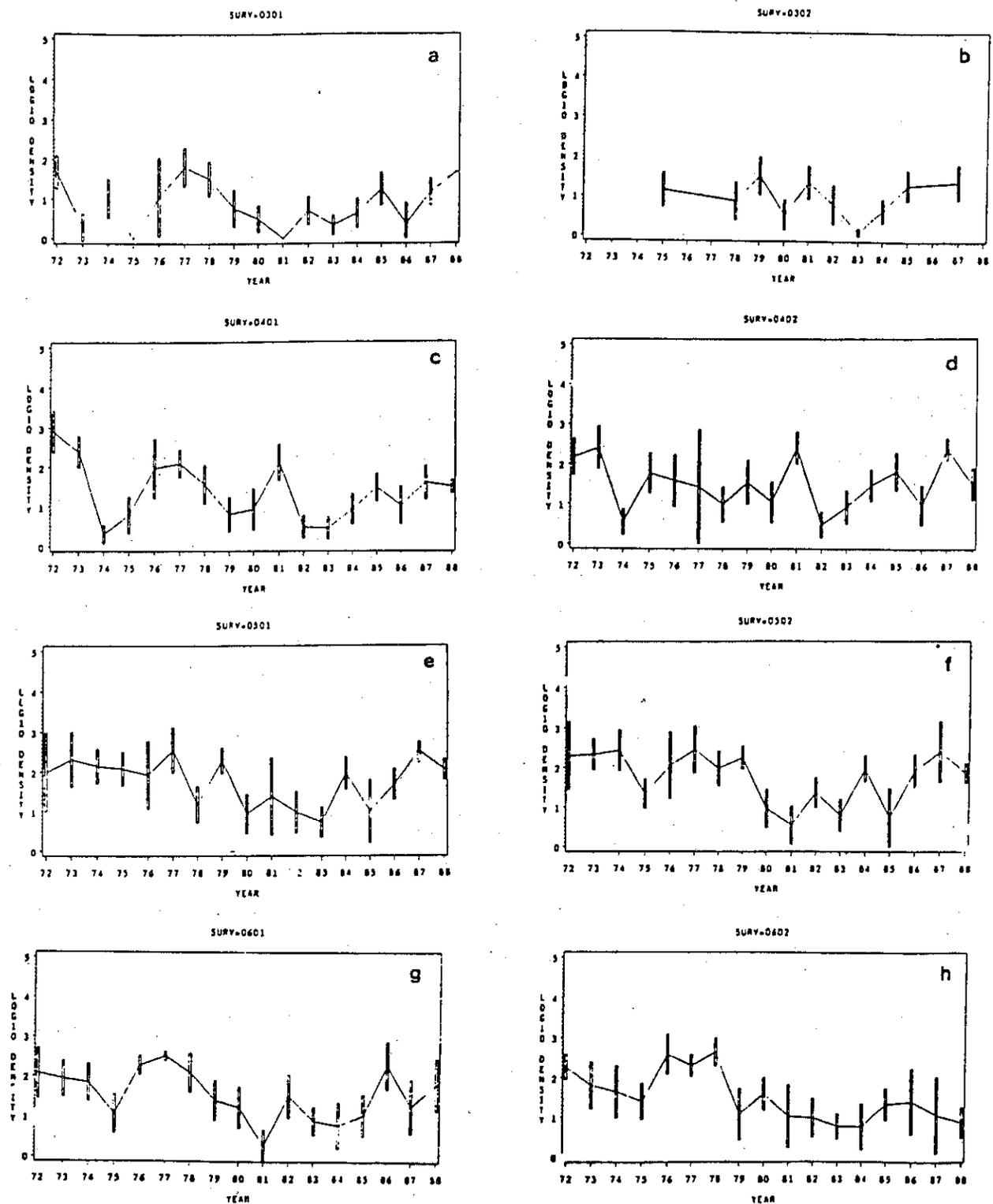
Figure 3
 MEAN LOG₁₀ MAY/JUNE CONCENTRATION OF *EURYTEMORA*, 1972-1988
 (As Measured by the Department of Fish and Game Zooplankton Monitoring Program)

Trends by Survey

I plotted log₁₀ concentrations of *Eurytemora* for each bi-weekly survey from March to October for stations stratified by specific conductance ranges 0-1000 and 1001-6000 µS/cm to determine inter-annual and seasonal trends (Figures 4 and 5).

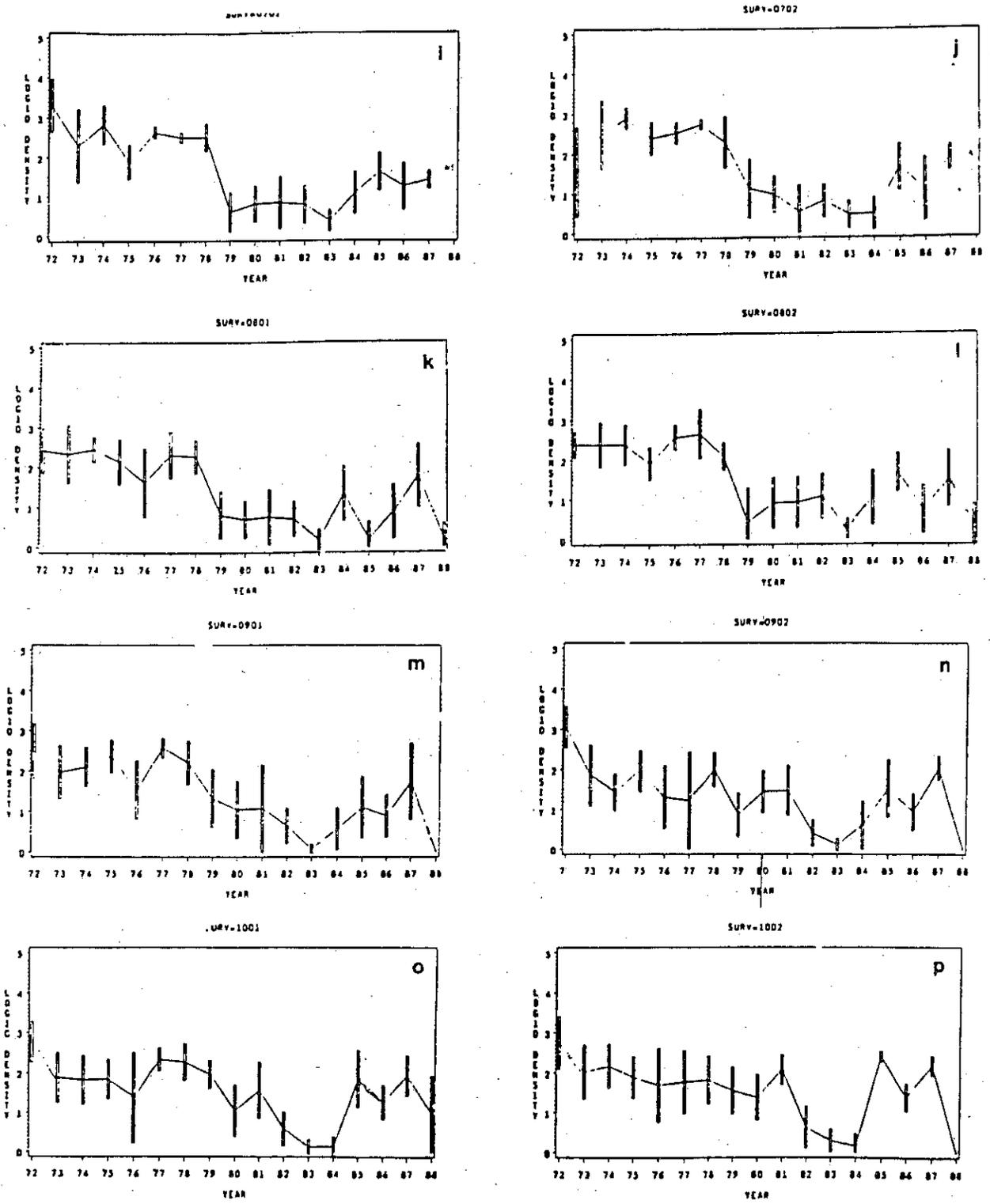
In the fresh water portion of the estuary, a decline in *Eurytemora* seemed evident beginning in 1979 or in 1980 depending on the surveys examined from 0501 to 0901.

In the entrainment zone, March concentrations varied greatly. This was apparently due to high flows putting the population beyond the sampling effort in some years. *Eurytemora* concentrations were lower after 1975 for August through September surveys. For other surveys there is considerable variation but no evident trend. The low concentration in 1988 was evident in every survey. No survey was conducted in July 1988.



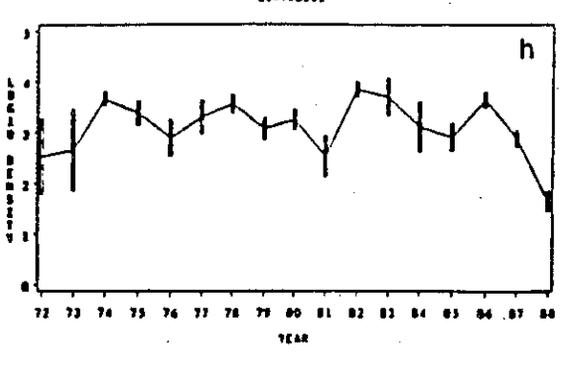
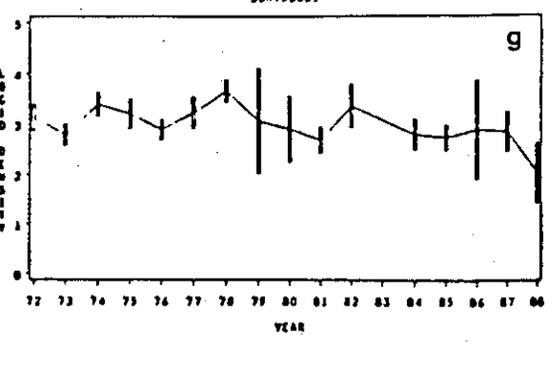
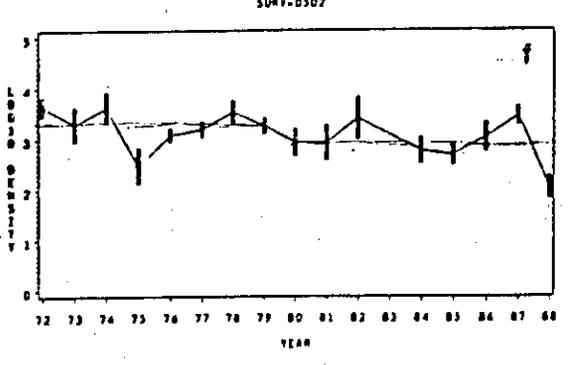
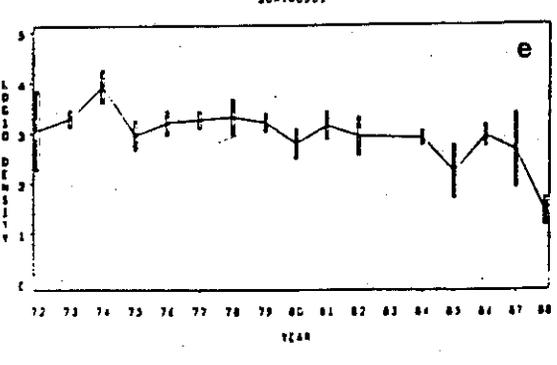
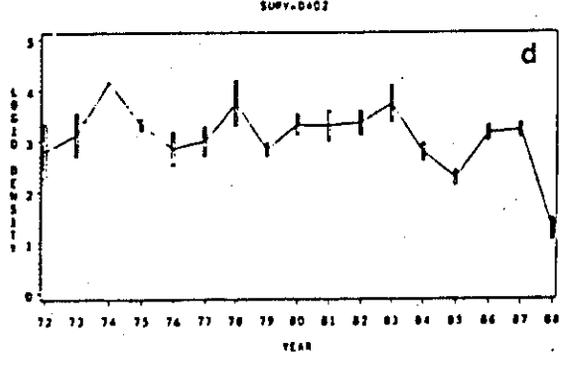
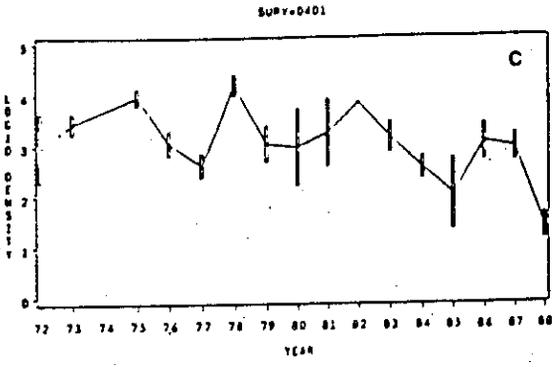
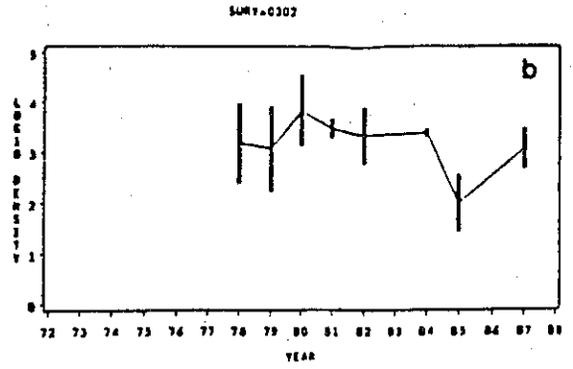
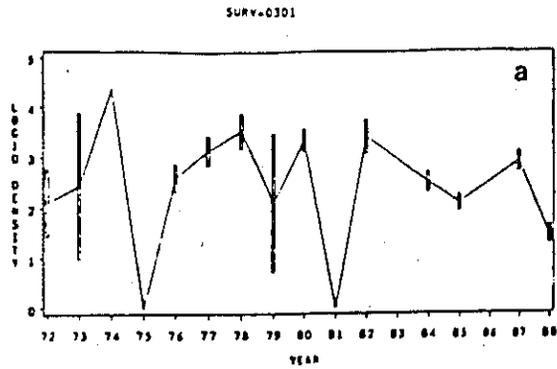
The analysis included channel and shoal stations.
 Bars represent two standard errors around the mean.

Figure 4
 MEAN LOG₁₀ CONCENTRATION OF *EURYTEMORA* FOR SPECIFIC CONDUCTANCE 0-1000 μS/cm FOR EACH ZOOPLANKTON SURVEY FROM MARCH TO OCTOBER, 1972-1988



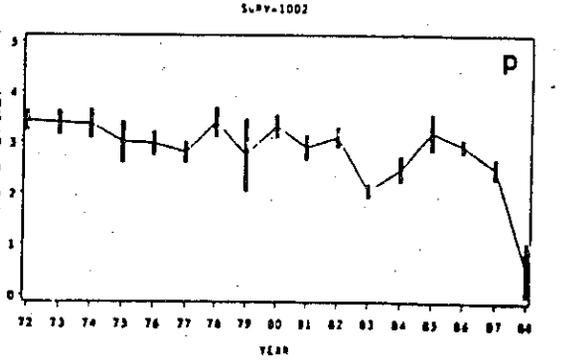
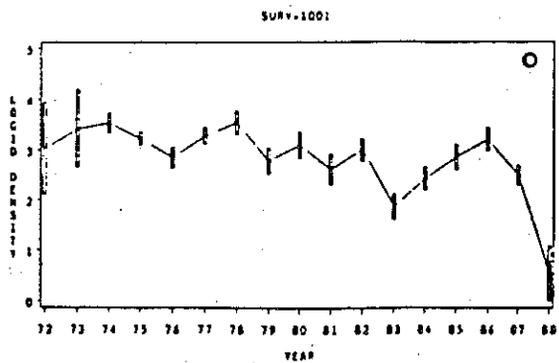
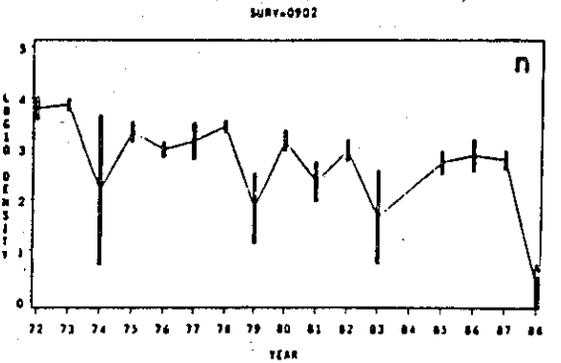
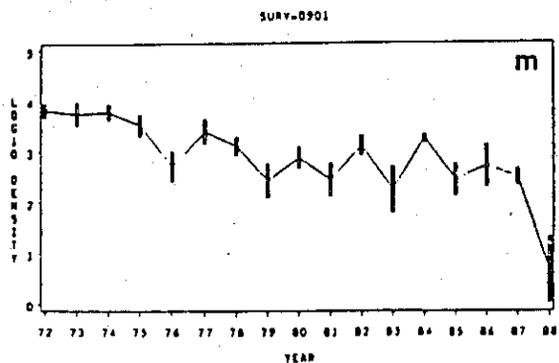
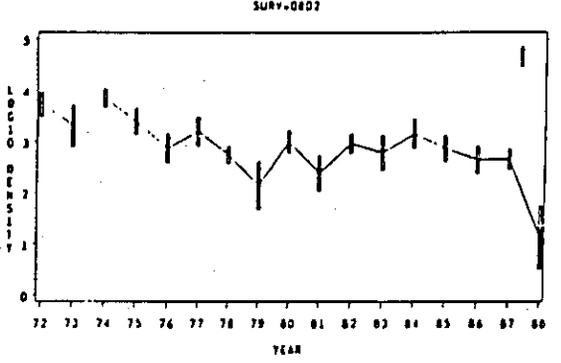
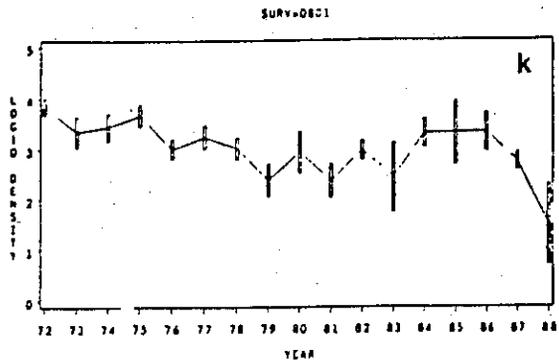
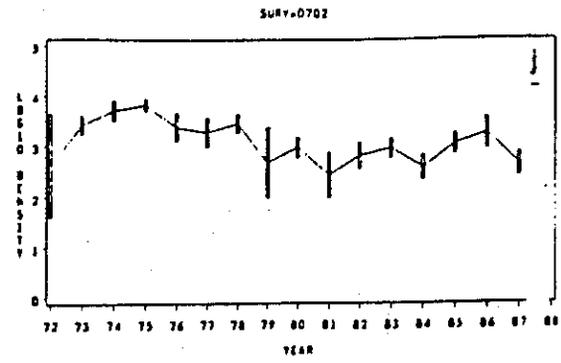
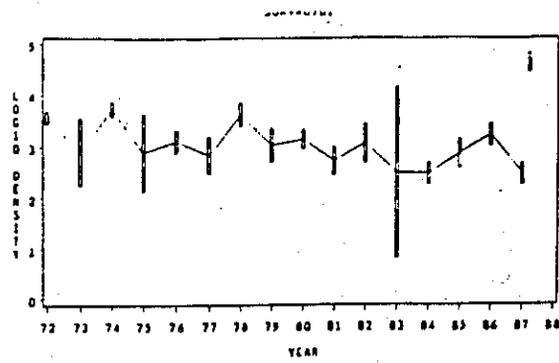
The analysis included channel and shoal stations.
 Bars represent two standard errors around the mean.

Figure 4 (continued)
 MEAN LOG₁₀ CONCENTRATION OF *EURYTEMORA* FOR SPECIFIC CONDUCTANCE 0-1000 µS/cm FOR EACH ZOOPLANKTON SURVEY FROM MARCH TO OCTOBER, 1972-1988



The analysis included channel and shoal stations.
 Bars represent two standard errors around the mean.

Figure 5
 MEAN LOG₁₀ CONCENTRATION OF *EURYTEMORA* FOR SPECIFIC CONDUCTANCE 1001-6000 $\mu\text{S}/\text{cm}$ FOR EACH ZOOPLANKTON SURVEY FROM MARCH TO OCTOBER, 1972-1988



The analysis included channel and shoal stations.
 Bars represent two standard errors around the mean.

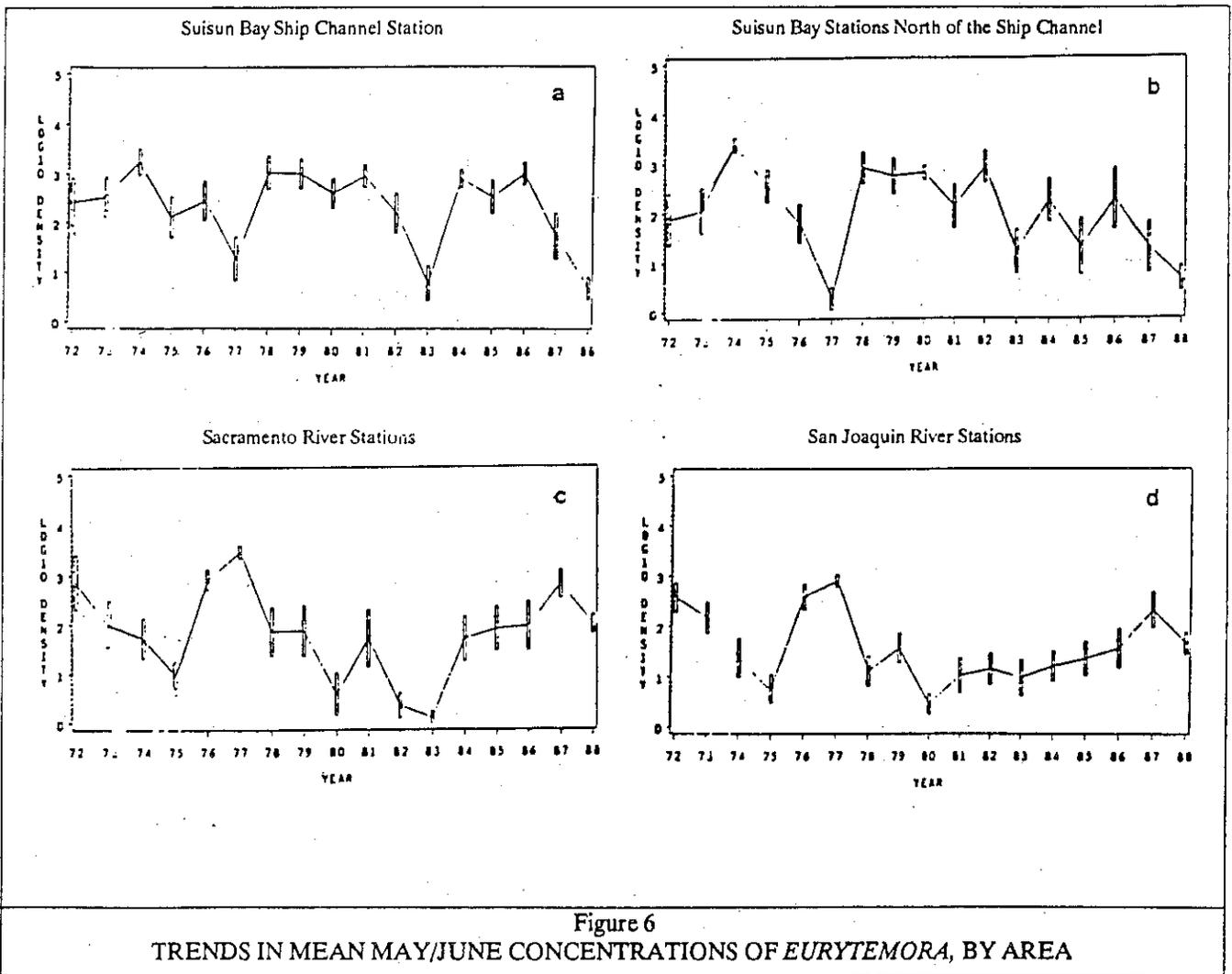
Figure 5 (continued)
 MEAN LOG₁₀ CONCENTRATION OF *EURYTEMORA* FOR SPECIFIC CONDUCTANCE 1001-6000 μ S/cm FOR EACH ZOOPLANKTON SURVEY FROM MARCH TO OCTOBER, 1972-1988

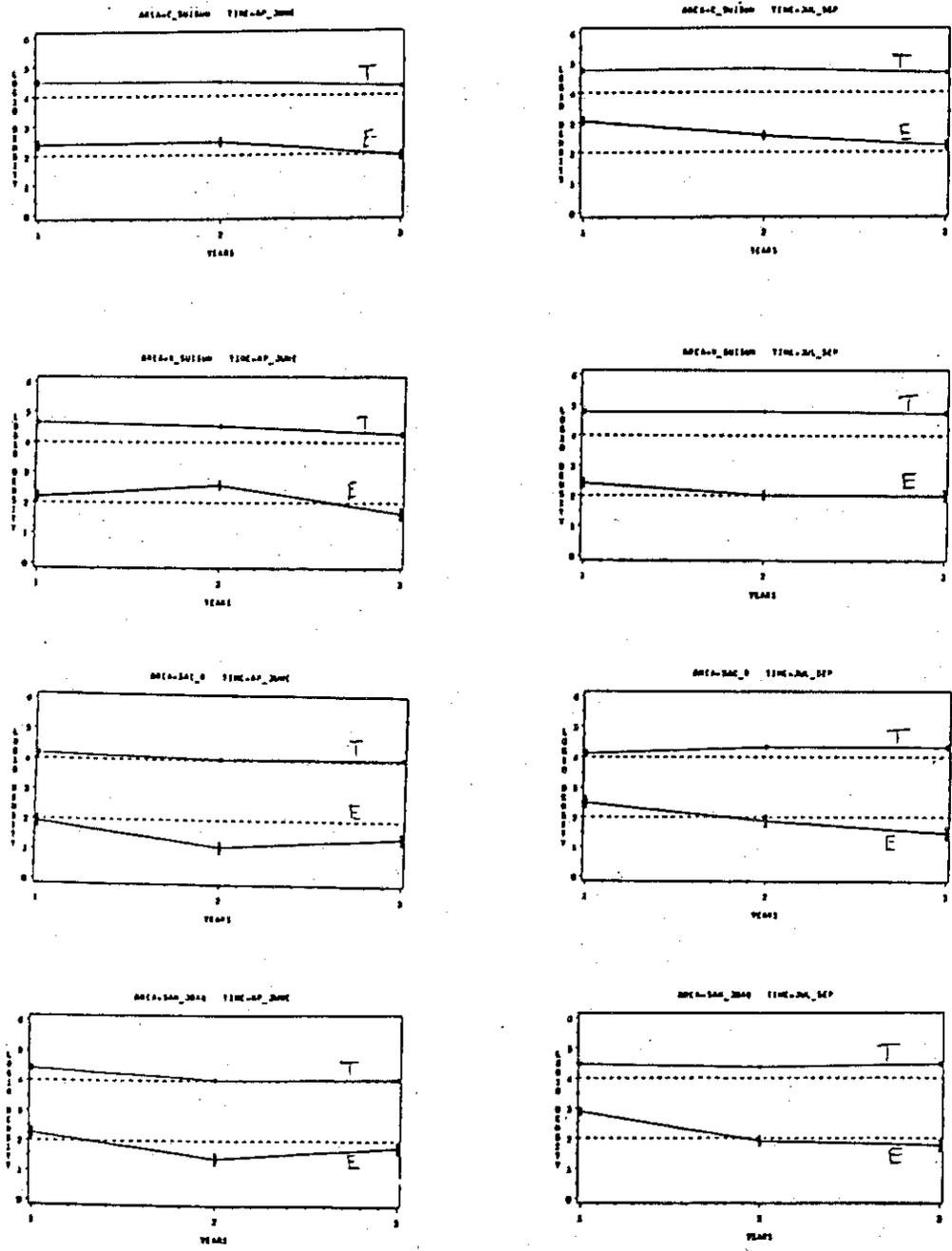
Trends by Geographical Area

There was no evidence of a trend for May/June *Eurytemora* concentrations by area (Figure 6). In low flow years, such as 1977, concentrations were low downstream in the Suisun Bay areas and higher upstream in the Delta. The opposite was true in high flow years (e.g., 1974 and 1975). However, in 1983 concentrations were low everywhere, most likely due to the extremely high outflow.

I also plotted *Eurytemora* and total zooplankton using the same approach, time periods (April-June and July-September), and year groupings as Steve

Obrebski used for 1972-1987, but with a different grouping of stations in Suisun Bay (Figure 7). This analysis indicates significant decline for *Eurytemora* in the Sacramento and San Joaquin rivers since 1976 for both time periods and a spring decline since 1982 in Suisun Bay. Total zooplankton has also declined in the San Joaquin River since 1976. One problem with this approach is the grouping of years of different flow types and averaging over several years. Nonetheless, the trends for this appear to corroborate the other, more detailed analyses. It provides a simplified summary of the data.





Area groupings, by station: C_Suisun 42-58
 N_Suisun 20-40
 Sac_R 60-68
 San-Joaquin 72-80

Year groupings: 1 1972-1976
 2 1978-1982
 3 1983-1987

Time periods: April-July
 July-September

Reference lines are at 2 and 4.

Figure 7
 TRENDS IN LOG₁₀ *EURYTEMORA* CONCENTRATION (E) AND
 LOG₁₀ TOTAL ZOOPLANKTON CONCENTRATION (T) BY
 AREAS, TIME PERIODS, AND YEAR GROUPINGS

Trends in Segments Upstream of 1000 $\mu\text{S}/\text{cm}$ Specific Conductance

In this analysis I calculated the mean concentrations of *Eurytemora*, other zooplankton food, and total zooplankton for the first six channel stations of the river upstream of where specific conductance equals 1000 $\mu\text{S}/\text{cm}$. Means for these 6-station segments were calculated using data for two river transects. Channel stations from Suisun Bay to Rio Vista (station 68) were subset for the Sacramento River transect and from Suisun Bay to Station 88 for the San Joaquin transect. This approach minimizes differences in sample size caused by the shifting location of the salinity gradient in a fixed boundary sampling area.

This approach is not completely successful, because in low flow years, the segment where specific conductance is less than 1000 $\mu\text{S}/\text{cm}$ may have only a few or no stations. For example, in 1977 (a low flow year), the mean concentration for May/June could not be calculated for the Sacramento River because there were no stations below the geographical boundary (station 68) with specific conductance less than 1000 $\mu\text{S}/\text{cm}$. In a higher flow year, when the 1000 $\mu\text{S}/\text{cm}$ boundary is shifted downstream, data from all six stations (24 data points) can be used to calculate the mean for the 6-station segment (Table 2). The effect of salinity intrusion is more critical to the calculation of a mean for the Sacramento transect, because there are only four stations upstream of Collinsville whereas for the San Joaquin River transect, there are ten stations upstream of Collinsville (see Figure 1).

Eurytemora abundance has been lower in several years since 1980 than in earlier years in both the Sacramento and the San Joaquin rivers. However, the population did rebound in 1986 to a level comparable to before 1980 (Figure 8). Other zooplankton used as food by striped bass appear to have a downward trend since 1980 in the Sacramento River but not in the San Joaquin River. Total crustacean zooplankton were relatively stable (Figure 8).

Trends in Abundance versus Trends in Concentration

Abundance of *Eurytemora* tends to be higher in some high flow years (1974, 1978, 1983, and 1986) but not in others (1975 and 1980) (Figure 9). This suggests that, even though concentrations may be relatively stable, abundance may be greater because habitat for zooplankton has increased.

It is also possible that looking at the data from the perspective of surface specific conductance may bias the analysis, because there is likely to be greater stratification under high flow than under low flow conditions. Hence, if *Eurytemora* concentrations are greater on the bottom, concentrations in the specific conductance range of 0-1000 $\mu\text{S}/\text{cm}$ are likely to be higher where the stratification is more intense in high flow years. However, since abundance tends to go up in the same years for both specific conductance ranges, perhaps it not an important factor.

The observed difference could also be related to the effects of outliers on the arithmetic mean abundances, but this was not explored further.

Table 2
 MEAN CONCENTRATION OF EURYTEMORA FOR SIX STATION RIVER SEGMENTS
 UPSTREAM OF SPECIFIC CONDUCTANCE EQUAL TO 1000 μ S/CM

OBS	YEAR	YY	BATC OUT	TYPE	FREQ	EURYTEM	SINOCAL	OTHER FOOD	BOSMINA	CYCLOPS	CHLA	TOTAL ZOO
1	72	72	1	1	4	1021.22	0.00	18801.4	5586.67	3008.89	0.0000	46702.6
2	73	73	1	1	4	837.05	0.00	667.8	1189.60	167.15	0.0000	29233.6
3	74	74	1	1	4	2613.58	0.00	3616.8	3322.88	289.46	0.0000	40559.5
4	75	75	1	1	4	1002.04	0.00	989.0	1156.50	185.25	0.0000	21914.2
5	76	76	1	1	4	452.75	0.00	7649.3	5782.13	727.13	10.0000	19707.3
*6	78	78	1	1	4	1582.00	0.00	419.9	1623.38	211.52	6.2857	23685.0
7	79	79	1	1	4	404.11	3230.53	113.5	417.42	58.68	6.7895	15067.7
8	80	80	1	1	4	318.46	1738.50	2502.7	712.71	530.50	7.5000	20381.5
9	81	81	1	1	3	25.18	913.27	745.3	306.45	266.64	13.4545	15506.1
10	82	82	1	1	4	1144.75	618.73	339.9	1181.03	156.40	28.2444	21,589.7
11	83	83	1	1	4	1216.88	103.99	635.8	1272.95	184.65	4.3375	12797.9
12	84	84	1	1	4	179.94	1603.15	149.9	207.34	53.67	8.0750	9842.9
13	85	85	1	1	4	27.74	973.80	264.5	164.44	58.36	10.3556	8482.4
14	86	86	1	1	4	590.50	2659.26	356.5	653.38	129.13	13.6190	17146.5
15	87	87	1	1	4	122.25	4537.93	439.7	446.37	29.44	4.4800	15761.1
16	88	88	1	1	4	115.71	783.14	285.3	297.10	29.83	0.0000	8818.6
17	72	72	1	1	4	342.75	0.00	11960.4	923.40	1578.15	0.0000	46169.3
18	73	73	1	1	4	669.71	0.00	1983.6	983.13	281.33	0.0000	31658.1
19	74	74	1	1	4	2603.79	0.00	4058.5	3458.38	289.17	0.0000	41855.9
20	75	75	1	1	4	1002.04	0.00	989.0	1156.50	185.25	0.0000	21914.2
21	76	76	1	1	4	331.94	0.00	18832.9	5622.53	701.29	12.9412	36109.9
22	77	77	1	1	4	370.17	0.00	2586.2	961.50	821.58	2.5833	28206.5
23	78	78	1	1	4	1414.92	0.00	458.7	1444.33	182.88	5.7917	18533.8
24	79	79	1	1	4	290.17	2412.67	329.0	439.75	11.38	7.1292	13280.7
25	80	80	1	1	4	324.04	1972.29	2722.2	795.75	517.38	6.8750	20549.6
26	81	81	1	1	4	470.17	524.25	7705.17	3901.17	489.167	20.3750	23499.5
27	82	82	1	1	3	1143.77	2351.54	539.10	1222.68	304.714	28.1611	23318.4
28	83	83	1	1	4	1216.78	103.50	708.69	1274.80	175.585	4.2875	12371.8
29	84	84	1	1	4	125.89	1382.74	1784.64	753.99	80.363	16.6208	11726.9
30	85	85	1	1	4	70.98	644.65	2597.91	851.54	114.606	21.8375	9344.5
31	86	86	1	1	4	518.46	5512.32	792.68	557.18	194.232	19.4208	22727.1
32	87	87	1	1	3	232.00	2164.88	7251.89	3287.33	70.896	7.9882	22255.7
33	88	88	1	1	4	101.67	217.65	1760.84	583.95	71.546	0.0000	10703.0

OBS	YEAR	EC SURF	LOG EURYTEM	LOG SINOCAL	LOG OTHER	LOG BOSMINA	LOG CYCLOPS	LOG TOTAL	NUMBER STAT	TOTAL STAT	RIVER
1	72	413.111	2.40471	0.00000	3.86969	3.29182	3.27188	4.56490	9	9	Sacramento
2	73	405.300	2.09266	0.00000	2.32660	1.29255	1.80575	4.31479	20	20	Sacramento
3	74	358.667	3.01370	0.00000	2.87802	1.28496	2.27384	4.53205	24	24	Sacramento
4	75	222.500	2.10778	0.00000	2.31008	1.61864	1.82478	3.55999	24	24	Sacramento
5	76	478.625	2.50107	0.00000	3.22415	2.05004	2.60728	4.21113	8	8	Sacramento
*6	78	299.095	2.68415	0.00000	2.33584	0.73223	1.86966	4.28732	21	21	Sacramento
7	79	456.158	2.06382	3.35682	1.48767	0.84735	0.96911	4.11259	19	19	Sacramento
8	80	339.417	1.90902	3.15127	3.07944	2.20144	2.55778	4.28478	24	24	Sacramento
9	81	292.091	0.75041	2.62615	2.54896	1.53235	1.82495	4.04595	11	11	Sacramento
10	82	264.889	2.09733	2.56156	2.45967	1.45184	2.13730	4.23198	11	11	Sacramento
11	83	175.333	0.93580	1.47869	2.55965	2.18370	1.98308	3.79278	24	24	Sacramento
12	84	385.563	1.60787	2.96099	1.89148	0.97820	1.46716	3.96014	16	16	Sacramento
13	85	400.000	1.00455	2.64327	2.26218	1.49619	1.41039	3.89245	9	9	Sacramento
14	86	497.381	2.42900	3.14283	2.20849	0.69127	1.80163	4.18915	21	21	Sacramento
15	87	347.000	2.01893	3.59100	2.03251	1.79715	1.23125	4.17411	5	5	Sacramento
16	88	511.778	1.87042	2.74004	2.21206	1.96796	1.12674	3.91857	9	9	Sacramento
17	72	448.700	1.92437	0.00000	3.87430	3.37357	2.93097	4.62664	20	20	SanJoaquin
18	73	401.833	2.43153	0.00000	2.50183	1.81878	1.68122	4.21395	24	24	SanJoaquin
19	74	362.583	2.96005	0.00000	2.96665	1.57103	2.28236	4.57109	24	24	SanJoaquin
20	75	222.500	2.10778	0.00000	2.31008	1.61864	1.82478	3.55999	24	24	SanJoaquin
21	76	460.353	2.00985	0.00000	3.67636	2.87754	2.66151	4.37521	17	17	SanJoaquin
22	77	624.000	2.44838	0.00000	3.28704	2.86852	2.66417	4.40968	12	12	SanJoaquin
23	78	318.458	2.60522	0.00000	2.44365	0.88420	1.88824	4.14119	24	24	SanJoaquin
24	79	387.042	2.03616	3.21982	1.78625	1.36379	0.53492	4.06551	24	24	SanJoaquin
25	80	342.875	2.00969	3.20981	3.11622	2.24907	2.56832	4.27804	24	24	SanJoaquin
26	81	385.792	0.85200	2.38633	3.19676	2.80261	1.85131	4.19037	24	24	SanJoaquin
27	82	265.056	2.02670	2.65528	2.49955	1.47609	2.18902	4.25642	18	18	SanJoaquin
28	83	176.792	0.95883	1.46868	2.59735	2.23730	1.99990	3.78572	24	24	SanJoaquin
29	84	429.500	1.38362	3.06361	2.77573	2.34631	1.50239	4.04984	24	24	SanJoaquin
30	85	440.167	1.24281	2.54462	3.06800	2.95755	1.38379	3.92421	24	24	SanJoaquin
31	86	487.625	2.42206	3.26605	2.45590	0.93012	2.01544	4.24164	24	24	SanJoaquin
32	87	466.059	1.61726	3.24998	3.53163	3.45856	1.14886	4.25518	17	17	SanJoaquin
33	88	470.474	1.60715	2.25266	2.77923	2.70051	1.38436	3.90587	19	19	SanJoaquin

*Note that there are no data for 1977 between Observations 5 and 6.

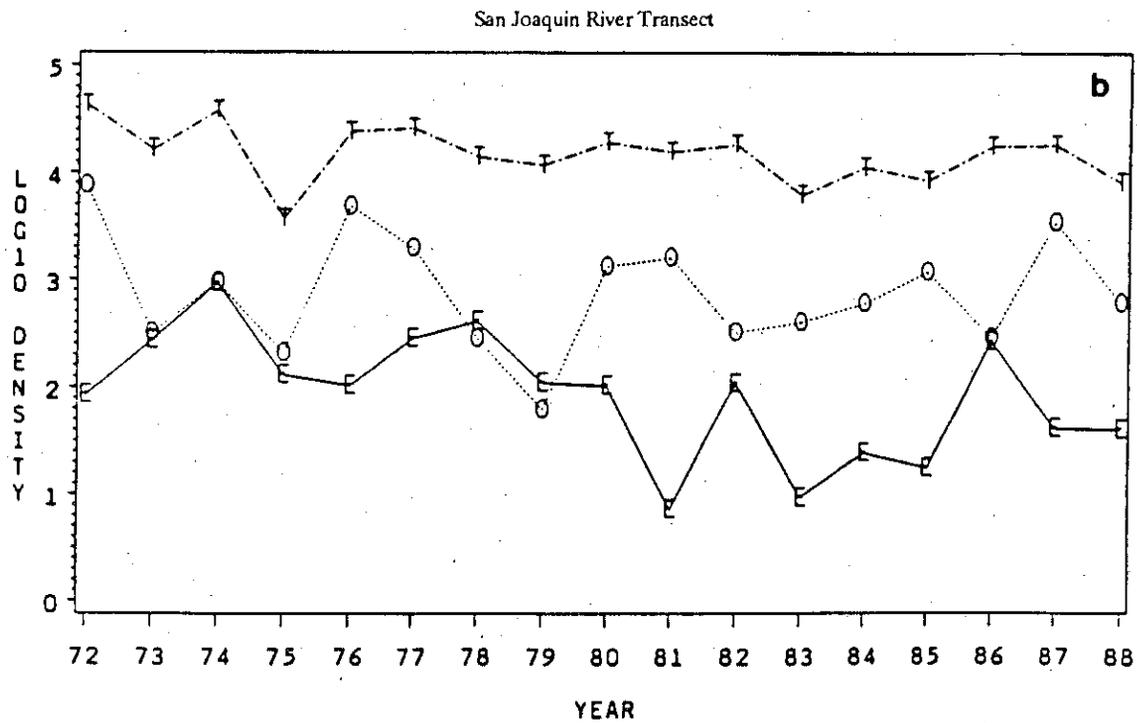
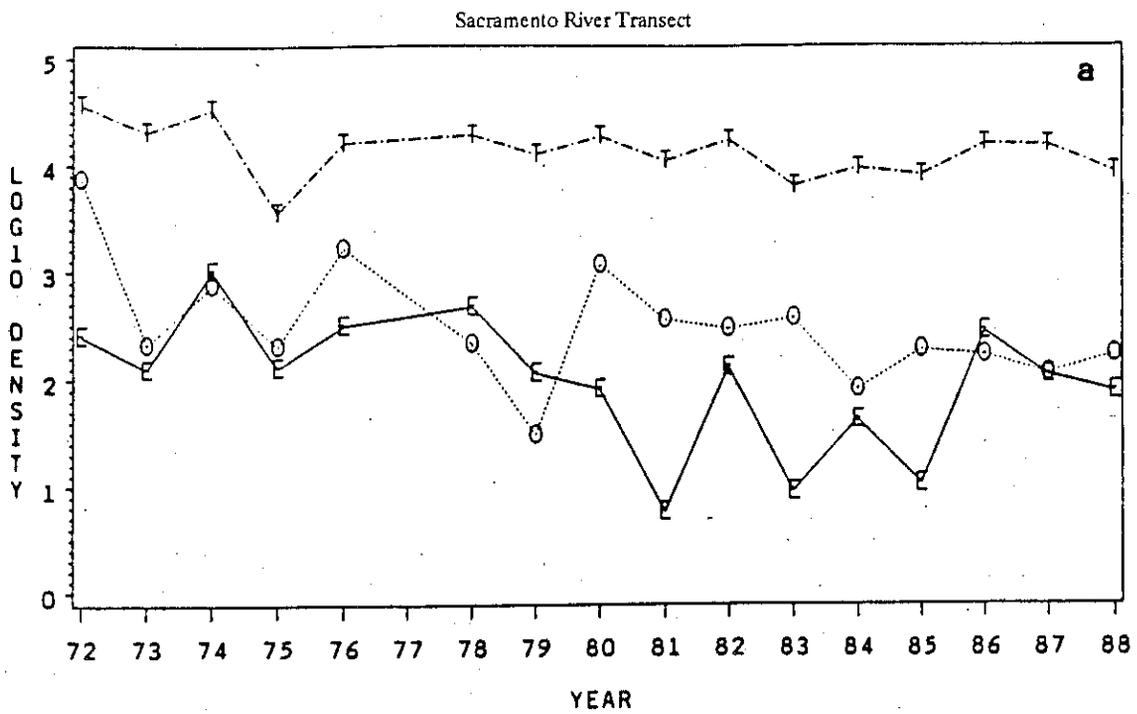


Figure 8
 TIME SERIES FOR MEAN MAY/JUNE LOG₁₀ CONCENTRATION OF *EURYTEMORA* (E),
 OTHER ZOOPLANKTON FOOD (O), AND TOTAL ZOOPLANKTON (T) (EXCLUSIVE OF ROTIFERS),
 FOR THE 6-STATION REACH UPSTREAM OF WHERE SPECIFIC CONDUCTANCE IS 1,000 μ S/cm

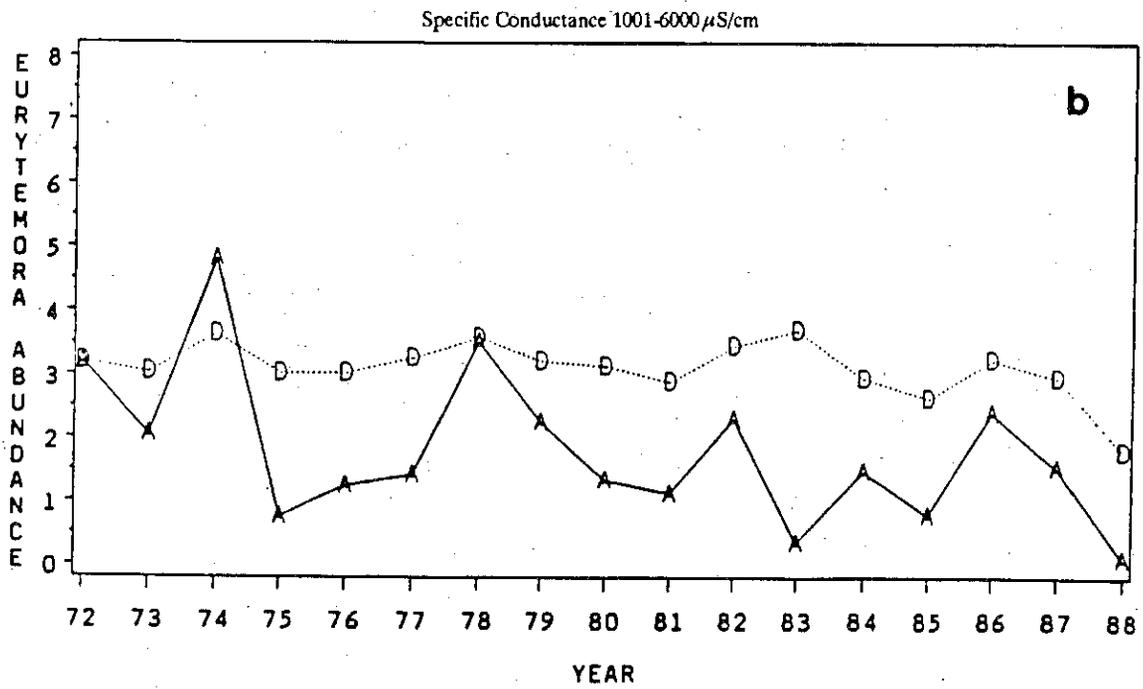
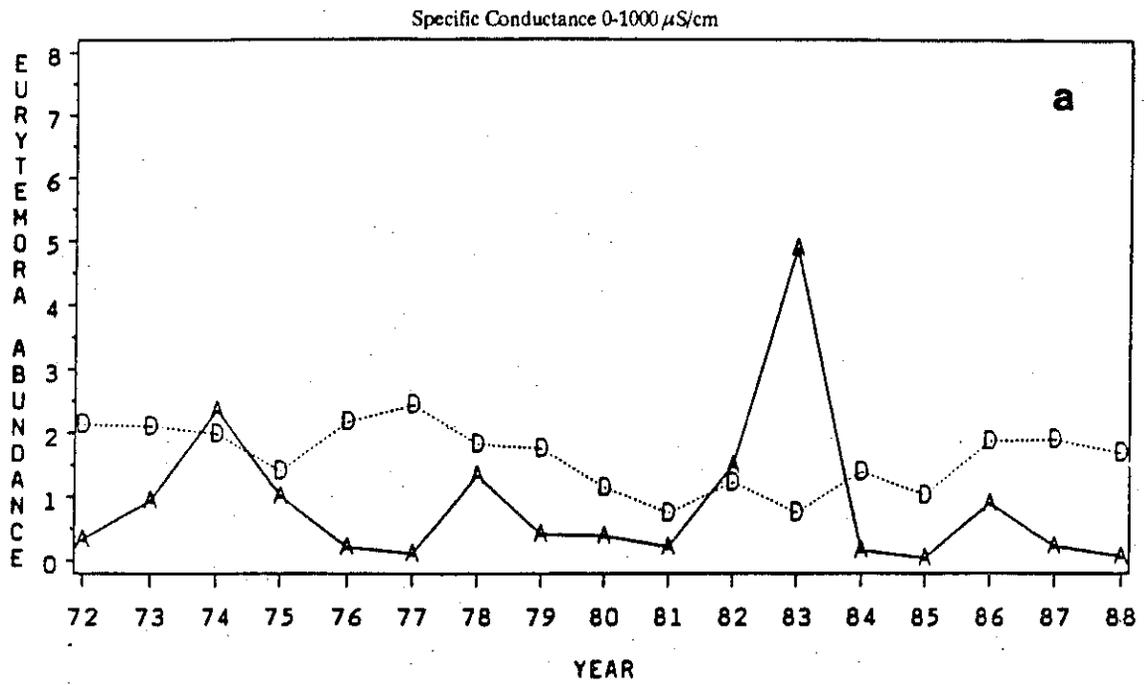


Figure 9
 TOTAL MAY/JUNE ABUNDANCE (A) OF *EURYTEMORA* (in billions)
 COMPARED TO LOG₁₀ CONCENTRATION (D)

Recommendations

- Investigations into zooplankton trends should employ the $\log_{10}(\text{concentration} + 1)$ transformation of the data until some better transformation is validated and recommended. Wim Kimmerer has suggested that adding a number other than one is a valid means of scaling the values. The use of log transformations makes possible statistical comparisons and testing of hypotheses using these zooplankton data.
- More rigorous testing of both the *Neomysis* and zooplankton data should be pursued using analysis of variance (*ANOVA*) or other appropriate tests to determine which years are significantly lower.
- Hypotheses need to be listed and tested to explain the variations and trends in *Eurytemora* or other zooplankton.
- We should try to improve analyses by developing relationships between (or ratio of) bottom specific conductance and surface specific conductance and Delta outflow. Data with which to do this are available from the zooplankton surveys for 1982-1989. If a workable model could be developed between flow and intensity of stratification, bottom specific conductance values for the past could be estimated based on flows, making it possible to summarize the data by bottom specific conductance.
- It would be desirable to develop an analysis that would describe whether habitat for zooplankton or other species expands and contracts related to flow conditions, stratification, or the upstream and downstream movement of the entrapment zone.

Comments of the Food Chain Group

Lee Miller's and Jim Orsi's presentations of historical zooplankton estimates to several meetings of the Food Chain Group generated much controversy about what we could and could not conclude from this huge database. Sampling has been done regularly since 1972 and with major effort and expense. With such a database, one might think population changes would be easy to detect, but they are not. Collecting plankton by towing a net diagonally for about a quarter of a mile from bottom to top and identifying and counting it is usually easy enough, but interpreting just what those counts mean is not. Variation in concentrations from one sample to the next is great enough to make comparing one with another or with others far from a straightforward process.

Miller's paper introduces readers to this problem, which is being pursued by a major analysis of historical data by Jim Orsi of the California Department of Fish and Game, Wim Kimmerer of BioSystems Analysis, and Steve Obrebski of the Tiberon Research Center.

D. W. Kelley, Chairman
Food Chain Group

Observations on Relationships Between Striped Bass Young-of-the-Year Indexes and Flow Conditions in the Sacramento-San Joaquin Estuary

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December 1990

Abstract: The annual measure of young striped bass abundance from 1978 to 1989 was compared with flow estimates at selected locations in the Sacramento-San Joaquin estuary during 10-day periods prior to the young bass population averaging 38-mm long. The most significant relationship ($R^2 = 0.78$) was between young bass abundance and flow in the lower San Joaquin River during the 41- to 50-day period. Other significant relationships at the 1 percent level of significance were with flows in the lower San Joaquin River for the 31- to 40-day period and flows in the upper San Joaquin River from 21 to 30 days, 31 to 40 days, and 41 to 50 days before the 38-mm index.

Introduction

Turner (1990) recently examined various factors in an attempt to explain the differences between the annual abundance of young striped bass (YOY index) in 1984, 1985, 1986, and 1988. The number of 6-mm larvae transported into Suisun Bay agreed quite closely with the YOY indexes for those four years. Turner's analysis suggested that transport of striped bass eggs and larvae by streamflow, especially in the lower San Joaquin River, had a major effect on the YOY index in 1986. Higher flows moved more larvae down into Suisun Bay, resulting in a larger YOY index for that year. This paper examines the relationship between the YOY index and flow conditions at various locations in the estuary from 1978 to 1989, the period of major decline in the YOY index.

Results

The YOY index of young bass is calculated when measures of bass caught in tow-nets indicate the population averages 38 mm in length. This time varies from year to year (Table 1), probably due to annual variations in water temperature. Because of this, I compared the indexes with flows in a particular year over a series of 10-day periods from the time the YOY index is determined until 70

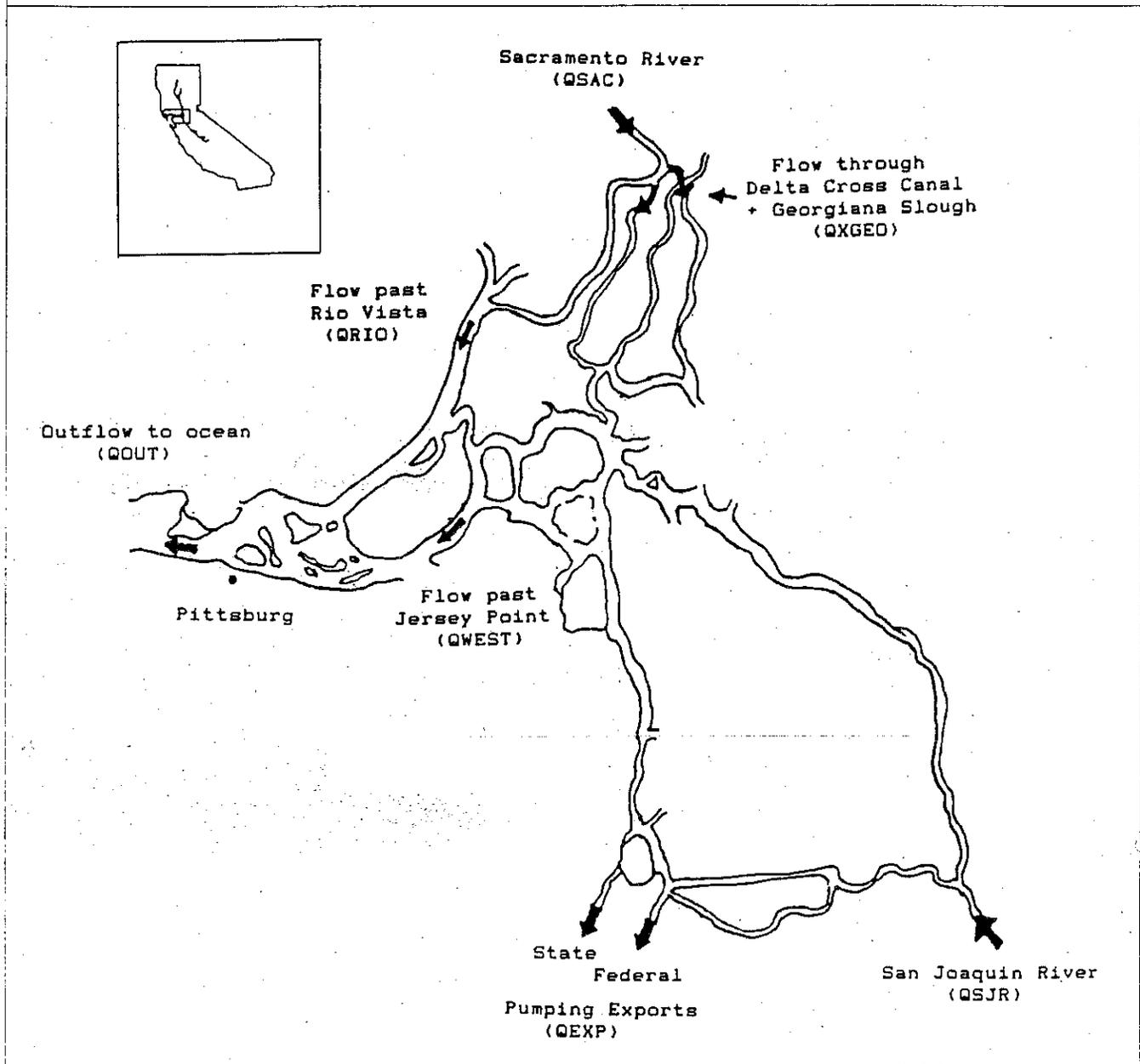
days before. Figure 1 shows locations at which average flows were calculated. Flow is estimated from the *DAYFLOW* program of the California Department of Water Resources and was calculated for me by programmers at the U.S. Bureau of Reclamation.

I used the data for all years except 1983, a very high flow year. The YOY index for 1983 is believed to be biased low because the fish were swept out of the sampling area by the high flows (DFG, 1987).

Table 1
ESTIMATED ANNUAL DAY OF YEAR
WHEN THE
STRIPED BASS YOY INDEX AVERAGES 38 MM

Year	Day of Year
1978	203
1979	200
1980	209
1981	183
1982	211
1983	---
1984	195
1985	197
1986	191
1987	173
1988	206
1989	192

Figure 1
 LOCATIONS OF FLOW MEASUREMENTS IN THE SACRAMENTO-SAN JOAQUIN ESTUARY



Several significant relationships at the 1 percent level were found between the YOY index and mean 10-day flows (Table 2). The highest relationship ($R^2 = 0.779$) was between the YOY indexes from 1978 to 1989 and outflow in the lower San Joaquin River (*QWEST*) during the 41- to 50-day period before the 38-mm length. *QWEST* flows were also significant for the 31- to 40-day period. Other highly significant flows were in the upper San Joaquin River (*QSJR*) for periods from 21 to

30 days, 31 to 40 days, and 41 to 50 days before the 38-mm index.

Significant relationships at the 5 percent level were found between the YOY index and outflow past Chippis Island for four periods from day 31 through day 70. Flow in the Delta Cross Channel and Georgiana Slough (*QXGEO*), exports at the Federal and State pumping plants (*QEXP*), flow in the lower Sacramento River (*QRIO*), and flow in the

Table 2
RELATIONSHIP (R^2) BETWEEN
THE STRIPED BASS YOY INDEX IN MIDSUMMER FROM 1978 TO 1989
AND
FLOW ESTIMATES AT VARIOUS LOCATIONS IN THE ESTUARY DURING
10-DAY PERIODS PRIOR TO THE YOUNG BASS POPULATION AVERAGING 38 mm

Period (Days)	Location in Estuary						
	QXGEO	QEXP	QOUT	QWEST	QRIO	QSJR	QSAC
0-10	0.023	0.057	0.183	0.244	0.024	0.405	0.023
11-20	0.004	0.183	0.227	0.405	0.005	0.459	0.004
21-30	0.016	0.030	0.200	0.350	0.001	0.638*	0.002
31-40	0.152	0.020	0.363	0.644*	0.056	0.743*	0.099
41-50	0.212	0.295	0.467	0.779*	0.095	0.518*	0.133
51-60	0.131	0.119	0.429	0.368	0.273	0.473	0.150
61-70	0.015	0.001	0.381	0.336	0.281	0.441	0.214

*Significant at 1% level.

Significance at 1% $R^2 = 0.501$

Significance at 5% $R^2 = 0.331$

QXGEO = Flow in the Delta Cross Channel and Georgiana Slough

QEXP = Flow exported at the State and Federal pumping plants

QOUT = Flow downstream of Chipps Island

QWEST = Flow in lower San Joaquin River

QRIO = Flow in lower Sacramento River

QSJR = Flow in upper San Joaquin River

QSAC = Flow in upper Sacramento River

upper Sacramento River (QSAC) were not significant for any period.

There were significant relationships between the three flow variables QWEST, QSJR, and QOUT. The R^2 relationship between QWEST and QSJR is 0.640 for the 31- to 40-day period and 0.786 for the 41- to 50-day period. The relationship between QWEST and QOUT is 0.887 and 0.774 for the same two time periods.

Figure 2 shows a plot of the highest relationship between the YOY index and QWEST during the 41- to 50-day period. The years 1985, 1988, and 1989 all have an index below 10 when QWEST has an average negative flow in the San Joaquin River.

Discussion

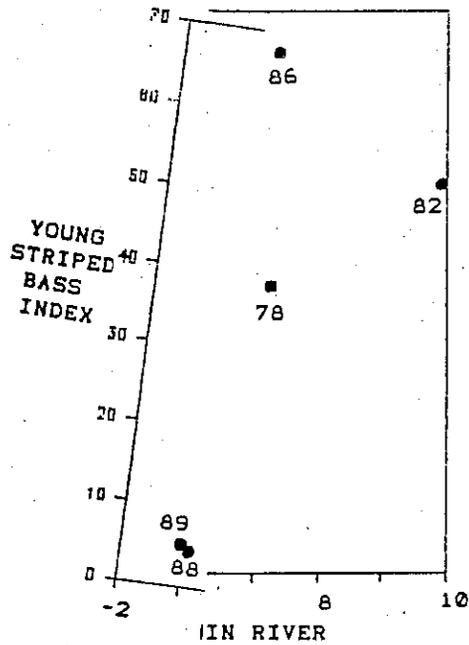
The abundance of young striped bass from 1959 to 1971 was closely related to the amount of fresh-

water outflow from the Delta and the percent of water diverted from the Delta by the pumping plants in the southern Delta (Turner and Chadwick, 1972). High outflows and low percent diversions resulted in high indexes of young striped bass.

In the early 1970s, abundance of young bass was lower than expected because of a decline in the Delta portion of the index. This decline coincided with higher diversion rates at the export pumps. The combination of lower freshwater outflow and higher diversion rates could account for the decline in the Delta index (Chadwick *et al.*, 1977). The bass index in Suisun Bay was still best explained by the freshwater outflow, as it had been since 1959.

Since 1977, young striped bass abundance has been much lower than that predicted from the earlier relationships between outflow and diversions (DFG, 1987).

Figure 2
 RELATIONSHIP BETWEEN MEAN FLOW DOWN THE LOWER SAN JOAQUIN RIVER (QWEST) FROM 41 TO 50 DAYS BEFORE THE YOY INDEX IS DETERMINED AND SIZE OF THE YOY INDEX, 1978 TO 1988



NOTE: Numbers on figure designate years.

This paper suggests that the present abundance of young-of-the-year striped bass is most closely related to flows down the lower San Joaquin River (*QWEST*) and the upper San Joaquin River (*QSJR*) and less so with total outflow (*QOUT*) from the system. The interrelationship between the three flows makes it difficult to determine which is important, but the high R^2 between the

YOY index and *QWEST* occurring early in the season suggests that it is probably the most important and that it is important during the early stages of larval development.

Results of this analysis suggest we should explore ways to move pre-feeding and early-feeding larval striped bass down into Suisun Bay, particularly those spawned in the lower San Joaquin River.

Literature Cited

- Chadwick, H.K., D.E. Stevens, and L.W. Miller. 1977. "Some Factors Regulating the Striped Bass Population in the Sacramento-San Joaquin Estuary, California", *Proceedings of the Conference on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations*. W. Van Winkle, editor. Pergamon Press, New York. pp. 18-35.
- Department of Fish and Game. 1987. *Factors Affecting Striped Bass Abundance in the Sacramento-San Joaquin River System*. Exhibit 25, State Water Resources Control Board Water Quality/Water Right Proceedings on the San Francisco Bay and Sacramento-San Joaquin Delta. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Technical Report 20. 149 p.
- Turner, J.L. 1990. *Observations on Factors Affecting the Young Striped Bass Index in the Sacramento-San Joaquin Estuary*. Food Chain Group Working Paper FCG-90-3.
- 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." *Trans. Amer. Fish. Soc.* 101:442-452.

convincing if flows were calculated by using a model designed to provide better estimates. The lack of such flow information is, in our opinion, a serious handicap to analysis of the biological data.

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Food Chain Group

Comments of the Food Chain Group

Mr. Turner's analysis adds information to his earlier assessment of factors influencing the Striped Bass Index (see Food Chain Group working paper 3). He examines flows in various parts of the estuary (as calculated by DAYFLOW) during 10-day periods prior to the date when the average length of young-of-the-year striped bass reached 38 mm in all years from 1978 to 1988 except for 1983. These periods are different from year to year because the fish spawn at different times.

Turner finds the correlation between these flows and the following 38-mm Striped Bass Index is best using estimates of San Joaquin River flow as it enters the Delta 21-30 and 31-40 days before the bass reached 38 mm and in the lower San Joaquin River of the western Delta 31-40 days and 41-50 days before that date. Correlations with Delta outflow are not so good, and correlations of other flows are not at all significant.

In this paper, Mr. Turner does not speculate on causes or mechanisms, but in the Food Chain Group meetings, we have speculated a lot about them. The most logical and compelling idea is that higher flows in the San Joaquin River washed bass down into the "entrapment zone", where they had more food and were less subject to entrainment by the CVP and SWP pumps in the southern Delta.

Jim Orsi, Wim Kimmerer, and Steve Obrebski of our group are analyzing the zooplankton data to determine whether there really was more food down there and, if so, why. We are examining the information on this and other entrapment zones to understand how they work. Lee Miller and his staff in Stockton are examining the massive amount of data gathered on distribution and abundance of bass larvae and are reading otoliths to see what affects growth and survival. Mohammad Rayej of DWR has done enough preliminary work on a model of how eggs would be transported from spawning sites to their feeding ground to convince us that development of such a model is very important to the solution of this problem. Finally, Jim Arthur and Doug Ball of USBR have designed several devices to continuously sample bass eggs and larvae at any given point so as to tell when they are and are not abundant so flows might be adjusted accordingly.

The crash in 1988 of the staple bass food of the entrapment zone, *Eurytemora affinis*, and its failure to recover during the long drought has, of course, complicated the idea. The relationship described by Mr. Turner may no longer apply. Whether it does or not, the idea of moving bass larvae to some part of the estuary where there is a good food supply and where they are less exposed to diversion losses is still a good one. Better understanding of Delta hydrodynamics is essential.

Mr. Turner's use of DAYFLOW estimates for 10-day periods has again raised the issue that DAYFLOW does not include any influence of the tides. Its purpose was to generate monthly volumes of flow for water project operation studies, not to provide daily or short-term estimates of flow to compare with short-term biological conditions. Turner has used 10-day averages (which somewhat mitigate the errors of calculation), but the analysis would be more

