TOXICS AND YOUNG STRIPED BASS

By

Randall L. Brown

California Department of Water Resources

A working paper for the Interagency
Ecological Studies Program's Striped Bass
Report (DFG 25)

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PREFACE

This report has been prepared as a working paper for the Interagency Ecological Studies Program's Report on Striped Bass. Although the working paper has received limited review by members of the Interagency Fisheries/Water Technical Committee, the views may not reflect those of all committee members. Dr. Jeanette Whipple, National Marine Fisheries Service, did provide many useful comments on the original draft.

INTRODUCTION

This report presents information regarding the possible role of toxic materials in the observed decline in young striped bass in the Sacramento-San Joaquin estuary. The report has been prepared as a working paper in support of the interagency report on striped bass (DFG Exhibit No. 25). The material within this working paper is summarized in the main report. The analysis is based on data drawn from a variety of projects most of which were not specifically designed to determine the effects of environmental levels of toxics on the ability of young bass to survive in the estuary. Data from the east coast, where a similar decline in striped bass abundance has been observed, are also included.

If the toxics issue were to be addressed properly, researchers would initiate field studies for collection of a wide variety of samples to describe pollutant inputs, levels of suspected toxicants in water, sediment, and biota. Laboratory studies would then be conducted to assess the impact of specific toxic materials on the species of interest. Finally, the field and laboratory data would be analyzed to determine if effects observed in controlled studies actually occurred in the field. Such an approach was taken by the National Marine Fisheries Service (NMFS) beginning in the 1970s to assess, in particular, the effect of trace organic contaminants derived from petroleum-related activities on estuarine fish, including striped bass. The NMFS staff conducted numerous short-term laboratory studies of the effects of such compounds as benzene and hexane, but their program was terminated before many field studies of the effects of toxics on the eggs and larvae of striped bass could be conducted. Their program does, however, provide the most comprehensive data base available regarding toxics and bass in the Sacramento-San Joaquin estuary.

Loading

The Sacramento-San Joaquin estuary receives potential toxicants from a wide variety of sources such as industrial discharges, agricultural runoff, municipal treatment plants, spills, atmospheric fallout, and direct runoff from urban areas. Figure 1 is a map of the Bay-Delta system showing major point source waste water inputs. Actual measurement of pollutant loading to the system is complicated by the large number of sources, the often diffuse nature of the inputs and technical problems associated with the collection and analysis of compounds and elements that are often present in the part per billion or trillion range. Because of these complications, there has been no reliable estimate of trends in loading of toxic materials to the system. (Note: This working paper was prepared before the Aquatic Habitat Institute published its analysis of pollutant loading to the estuary and thus may not reflect the latest available information.) Citizens for a Better Environment (CBE 1983) did compile an estimate of pollutant loading to the Sacramento-San Joaquin estuary west of Chipps Island for 1982. The estimate was developed by using data from compliance self-monitoring reports submitted to the Regional

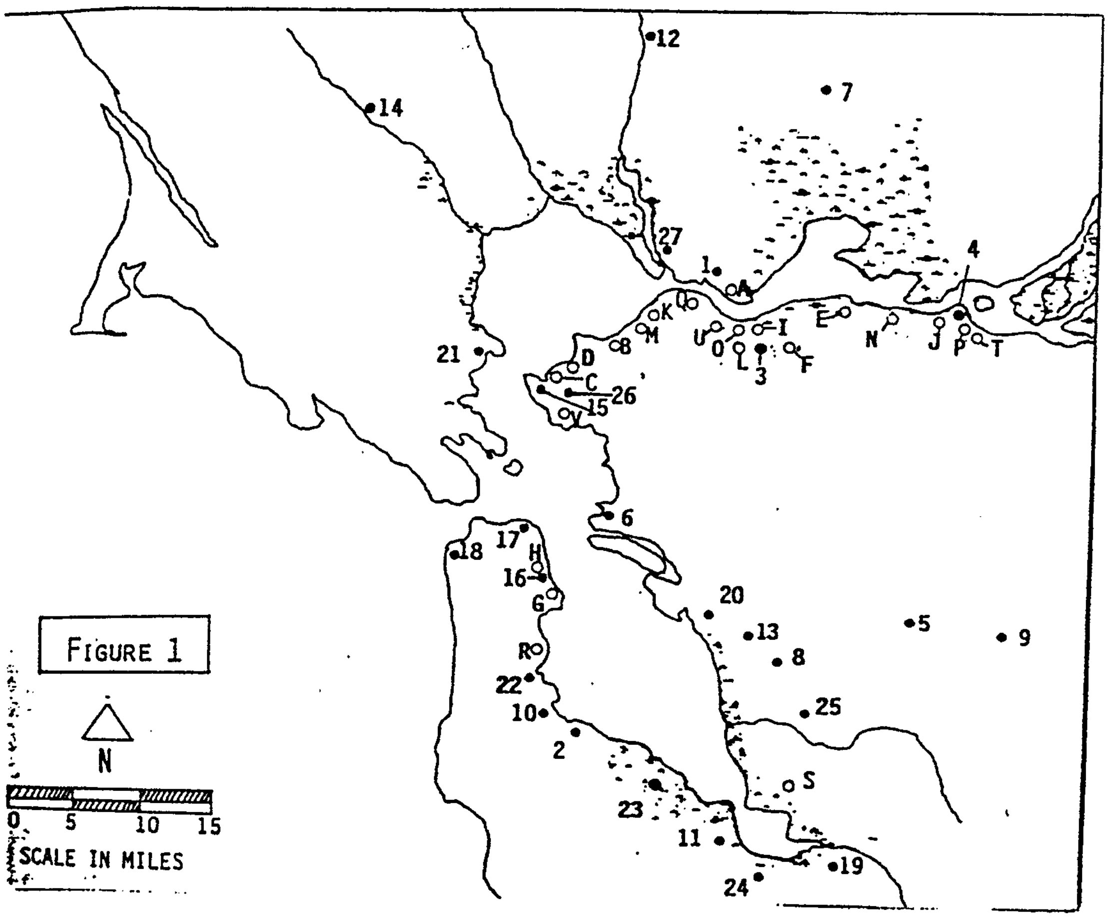

Figure 1. Point source discharges to the Bay-Delta system (From CBE, 1983) (numbers are publicly owned treatment works, letters are industrial discharges).

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Water Quality Control Board by the dischargers. Table 1 is a summary of the loading of several potential toxic materials to the Bay-Delta.

CBE (1983) also summarized earlier estimates showing trends in point source trace element loading to the system from the 1960s to 1982 (Table 2). As one might expect, better treatment has resulted in decreased loading from point sources, however, there are still several hundred thousand pounds of potentially toxic materials discharged annually. Such estimates are very rough and only provide an indication of trends in loading.

In addition to point source loading to the estuary, inflows from the Sacramento and San Joaquin Rivers contribute pollutants to the Bay-Delta. From a mass loading standpoint agricultural return flows are the largest contributor of potential pollutants to the rivers. During the period 1972-1981, agricultural return flows made up a substantial portion of the spring and early summer flows in the lower Sacramento River. The average monthly percentage that agricultural return flow contributed to total flows during this period were: April, 8 percent; May, 15 percent; June, 10 percent; and July, 8 percent. On the lower San Joaquin River surface and subsurface agricultural drainage and treated waste water make up most of the late spring, early summer flows during many years.

Pollutant loading to the estuary and striped bass nursery area by way of the San Joaquin and Sacramento rivers is not well documented. Ambient concentrations are often below detection by routine laboratory techniques and the sampling coverage is spotty. Concentrations of trace organics and persistent chlorinated hydrocarbons (DDT, for example) in fish tissue often can reveal the presence of compounds that are below detection in the water itself. Table 3 contains the results of residue analyses in catfish flesh at sites on the Sacramento and San Joaquin rivers (Hood and Vernalis respectively) just above the Delta. The data demonstrate the continued presence of chlorinated hydrocarbons in these rivers in spite of the regulations in place since the 1970s which limit the use of these compounds. In general, it appears that DDT and its metabolites and toxaphene are higher in the San Joaquin River while PCBs are higher in the Sacramento River. No particular downward trend in concentration is apparent. For comparison the geometric means of these compounds (ppb wet weight in flesh) in the National Pesticide Monitoring Programs (all United States stations) are shown below (from Schmitt et al).

Compound	Year 1976-77	Year 1978-79	Year 1980-81
Total DDT	370	350	290
Total PCB	880	850	530
Toxaphene	350	290	270

The San Joaquin River appears to be particularly high in comparison to the rest of the country with respect to DDT and toxaphene.

Table 4 contains a list of concentrations of trace elements in catfish livers at the Hood and Vernalis sites as reported by SWRCB. (Other elements were occasionally detected but the ones listed were found in all fish analyzed.) The data suggest that cadmium and mercury concentrations are higher in catfish

Table 1

REPORTED HEAVY METALS DISCHARGED TO THE SACRAMENTO-SAN JOAQUIN ESTUARY DOWNSTREAM OF CHIPPS ISLAND (10^6 LBS/YR) (Adaped from CBE, 1983)

Source of Estimate	Publically Owned Treatment Plants	Industry	Total
Pearson, et al (1970)	2.18	6.12	8.30
Risebrough, et al (1977)	0.99	0.13	1.12
Russell, et al (1978)	No data	No data	1.32
CBE (1983)	0.36	0.39	0.74

Table 2

DISCHARGES TO THE SACRAMENTO-SAN JOAQUIN ESTUARY DOWNSTREAM OF CHIPPS ISLAND IN 1982 - COMBINED MUNICIPAL AND INDUSTRIAL DISCHARGES (Adapted from CBE 1983)

Flow (mgd)	1,970[1]
Total Heavy Metals (lb/yr)	744,000
Total Oil and Grease (lb/yr)	11,300,000
Total Other Toxic Pollutants (lb/yr)	133,000
Total Selected Pollutants (lb/yr)	
Arsenic	11,000
Cadmium	24,000
Chromium	47,000
Copper	189,000
Lead	42,000
Mercury	800
Nickel	99,000
Silver	5,000
Zinc	111,000
Cyanide	50,000
Phenols	67,000
Thallium	81,000

1 Includes process waste water and cooling water from industrial sources.

Table 3

CONCENTRATIONS OF ORGANOCHLORINE CHEMICALS (PPB, WET WEIGHT) IN FLESH OF CATFISH COLLECTED AT HOOD (SACRAMENTO RIVER) AND VERNALIS (SAN JOAQUIN RIVER) DURING THE PERIOD 1978-1984 (Data from SWRCB, 1986)

		Compound		
Location	Year	DDT	PCB	Toxaphene
Hood	1978	132	ND*	ND
	1979	65	150	ND
	1980	103	90	ND
	1981	214	58	300
	1982	213	50	ND
	1983	240	182	ND
	1984	207	145	ND
Vernalis	1978	500	ND	430
	1979	2,420	ND	4,000
	1980	1,229	50	1,700
	1981	105	ND	2,900
	1982	611	50	850
	1983	1,094	ND	1,200
	1984	446	120	730

* ND = Not detected

Table 4

CONCENTRATIONS OF TRACE ELEMENTS (PPM, WET WEIGHT) IN LIVER OF CATFISH COLLECTED AT HOOD (SACRAMENTO RIVER) AND VERNALIS (SAN JOAQUIN RIVER) DURING PERIOD 1978-1984
(Data from SWRCB, 1986)

Location	Year	Cadmium	Copper	Zinc	Selenium	Mercury
Hood	1978	0.46	3.6	22		0.83
	1979	0.16	2.3	20		0.7
	1980	NA*	NA*	NA*	NA*	NA*
	1981	0.19	2.1	19		0.34
	1982	0.29	3.6	22		0.6
	1983	0.46	3.5	25		0.94
	1984	0.26	3.0	24	1.5	0.57
Vernalis	1978	0.08	4.7	23		0.3
	1979	0.06	1.7	21		0.4
	1980	0.05	2.1	16		0.26
	1981	0.04	1.4	20		0.17
	1982	0.12	1.6	25		0.32
	1983	0.07	1.6	22		0.44
	1984	0.09	3.6	22	1.2	0.40

* NA = not analyzed
** Mercury was analyzed in flesh, not the liver.

on the Sacramento side as compared to those on the San Joaquin and that copper and zinc are about the same in both populations. Too few data on selenium are available to draw a conclusion. (Additional data on selenium levels in striped bass are presented later in this section.)

The brief introduction on loading is intended to establish that there are numerous sources of toxics to the Bay-Delta. The National Oceanic and Space Administration and the Aquatic Habitat Institute are preparing detailed estimates of recent pollutant loading.

Effects on Young Striped Bass

Toxic materials can affect young striped bass in a variety of ways either directly or indirectly. Some materials may cause mortality at ambient concentrations with the young bass dying in a few days (acute toxicity) or a few weeks (chronic toxicity). In other instances the concentrations may be too low to cause direct mortality, but will produce an adverse effect during development (growth, skeletal formation) which limits the animals' chances for survival. Toxicants accumulated in the adults may lower the production of viable gametes (both eggs and sperm) with eggs being resorbed or the embryos not able to undergo normal development. Pollutants can also indirectly affect fish survival by reducing the available food supply.

The studies cited below address both direct and indirect effects of toxics with the overall objective of answering the question "In recent years have toxic pollutants in the Sacramento-San Joaquin system caused decreased abundance of young-of-the-year striped bass?"

The toxicological impact of many materials is affected by the ionic composition and strength of the water itself. For example, NMFS studies during the 1976-77 drought years demonstrated that the addition of salt or chelators (metal complexing materials) increased survival of striped bass eggs and larvae in natural San Joaquin and Sacramento River waters (Jeanette Whipple, personal communication). The overall impact of the interaction of ambient toxicant levels and ionic composition has not been well documented in the Sacramento-San Joaquin system.

Effects on Food Supply

The dynamics of the natural interrelation between factors controlling primary and secondary production which lead to adequate food for young striped bass is poorly understood; in fact we are not even certain what constitutes an adequate food supply. The superimposition of toxics onto the natural system provides an additional complicating factor. There have been few studies which even superficially address the affect of toxics on striped bass food supply. The following do provide some limited information on this topic.

Taberski (in draft) evaluated the role of two widely used rice field herbicides, Ordram and Bolero, on the growth rates of natural Delta algal populations, and two common Delta algae (Coscinodiscus and Melosira). The two herbicides were tested because their wide use in the Sacramento Valley has caused concerns about potential adverse environmental impacts in the river and estuary. Also, the use of herbicides in the Sacramento Valley increased considerably during the same period striped bass were experiencing a decline. Toxicity tests included evaluations of algal growth in samples spiked with high and low levels of both herbicides as well as testing the water draining from the rice fields. All tests indicated that Ordram and Bolero had no effects on algal growth at concentrations much higher than have been reported for the Delta.

In a separate study Taberski (Interagency Ecological Studies Program, 1987) attempted to determine if there had been an overall decrease in phytoplankton growth rates in the Delta between the early 1970s and 1984. Although the use of different methods to evaluate growth in the two periods caused some problems in comparing results from the studies, it did not appear that growth rates were significantly lower after the drought. Evidence from both of Taberski's studies supports the conclusion that the apparent decrease in number and changes in composition of Delta phytoplankton blooms since the 1976-1977 drought are not the result of toxics.

Fagella and Finlayson (1987) conducted a risk assessment of the effects of Bolero and Ordram on the opossum shrimp (Neomysis mercedis) in the Sacramento River. Using measured and projected concentrations of these herbicides in the river and toxicity data from a SWRCB study (Cornacchia et al 1984), the authors concluded that there was little risk of short-term (7-14 day) adverse effects on Neomysis populations. They did indicate that in the past there may have been a chronic (30-40 day exposure) adverse impacts and that proposed Department of Health Services' regulations regarding the use of these compounds may not provide adequate protection for opossum shrimp populations in the estuary. The authors proposed Ordram and Bolero levels which should provide an adequate margin of safety for Neomysis.

Another major source of agricultural drainage to the estuary is the San Joaquin Valley by way of the San Joaquin River. During the past 3 to 4 years considerable effort has been devoted to understanding the source, fate, and effect of pollutants in the San Joaquin River with much of the attention being devoted to selenium. Subsurface drainage, often high in selenium and other constituents leached from westside farms, reaches the San Joaquin River by way of Salt and Mud Sloughs as well as infiltration of shallow ground water moving towards the east. The State Water Resources Control Board (1987) has recently released a report describing the results of a technical committee established to assess the impact of drainage on the San Joaquin River and to recommend standards to protect the beneficial uses of the river. The report findings do not apply to beneficial uses in the Sacramento-San Joaquin estuary.

By the time it reaches Vernalis, the San Joaquin River rim inflow station to the Delta, agricultural drainage has been diluted considerably and selenium concentrations are generally below 1 ug/L. In the Delta and Bay selenium levels are in the 0.2-0.5 ug/L range (Cutter 1987). There do appear to be local inputs of selenium in the Carquinez Strait area and South San Francisco Bay (Cutter 1987). Waterfowl collected in South Bay and Suisun Bay have been found to have elevated selenium levels, although the sources and pathways of selenium from water to waterfowl have not been identified.

There have been no specific studies designed to evaluate the impacts of present loading of San Joaquin Valley drainage containing selenium and other elements to Bay-Delta organisms, however, there is limited information available. In 1983, Marine Bioassay Laboratories (MBL) conducted a series of bioassays of San Joaquin Valley drainage. The organisms tested ranged from algae through striped bass. Only the results of tests with phytoplankton, two common zooplanktons (Acartia clausii and Eurytemora hirunoides), Neomysis, and Palaemon (a small shrimp commonly found in the estuary) are reported in this section.

The algal species tested, Thalassiosira decipiens is usually abundant in the western Delta-Suisun Bay area and is an important component of the local food web. The results of MBL's studies indicated that the lowest drainage concentration tested (9.1 percent drainage water) caused reduced algal growth. Subsequent testing at U.C. Santa Cruz demonstrated a similar effect, with the ionic composition of the drainage water being the likely cause of the observed inhibition (M. Moser, personal communication). Since concentrations of subsurface drainage water in the Delta have never exceeded a small fraction of 1 percent, subsurface drainage should not present a problem to the Delta phytoplankton.

The results of 96-hour bioassays with the two copepods Acartia and Eurytemora did not show significant differences in mortalities at drainage concentrations ranging from 9.1 to 100 percent. There was, however, considerable variability in survival and there did appear to be changes in copepod behavior at the highest concentration tested. Attempts to complete a 28-day bioassay with these organisms were unsuccessful because there was excessive mortality in all concentrations including controls.

Acute toxicity tests (96-hour) with Neomysis mercedis showed significant increased mortality only at 100 percent drainage water, with mortality at 9.1 and 50 percent equal to controls cultured in Suisun Bay water. Life cycle testing with Neomysis was attempted, but without success. Stanford Research Institute (1985) continued the work the Neomysis and drainage and was able to run the tests through 16 days. Survival in artificial drainage was comparable with that actual drainage. (The only difference in test waters being that the artificial drainage did not contain trace element additions.) The results suggested that the toxicity to adult shrimp due to drainage water could be attributed to ionic composition (i.e. mortality in the drainage water containing no trace elements was statistically the same as that in natural drainage with these elements present). There were indications that at 9.1 percent drainage there was an adverse trace element effect on young Neomysis.

MBL's 96-hour bioassays with the oriental shrimp, Palaemon macrodactylus, did not demonstrate significant effects on survival at any concentration tested, including 100 percent drainage. In 28-day tests, shrimp survival was significantly less in 100 percent drainage than in controls, but was not reduced in 9.1 or 50 percent drainage.

Foe and Knight (1985) described the effects on selenium on the green alga Selenastrum capricornutum. Selenium-enriched algae were also fed to the water flea, Daphnia magna, to determine the impact of dietary sources of this element on survival of the test organisms. In the algal tests, selenium levels of above 70 ug/L caused adverse effects on growth of Selenastrum and small, but significant, increases in cellular selenium (as compared to controls) between 0 and 25 and 40 ug/L. Daphnia reproduced, and grew survived equally well for 10 days on diets containing either about 300 or 0.5 ppm selenium in the alga (Selenastrum).

During the past two years the Central Valley Regional Water Quality Control Board (CVRWQCB) has contracted with U.C. Davis to conduct EPA's standard acute toxicity bioassays using waters from various drains entering the Sacramento River watershed. Although the EPA protocol calls for three species, the assays conducted to date have usually included only algae (Selenastrum) and an invertebrate (Ceriodaphnia). The results indicate that water in agricultural drains entering the Sacramento River during the summer is often acutely toxic to both Selenastrum and Ceriodaphnia and the addition of this drain increases the toxicity of water in the mainstem Sacramento (personal communication from J. Bruns, CVRWQCB). Similar tests conducted during the winter did not demonstrate the presence of acute toxicity to the same organisms. Water from the American River (December 1986 samples) suppressed Selenastrum and Ceriodaphnia reproduction and caused an approximate 50 percent decrease in the reproduction of the invertebrate 3 to 15 miles downstream of the confluence of the American River with the Sacramento River. Algal production was decreased by about 50 percent (as compared to Sacramento River water above the American River) in water samples collected as far downstream as Freeport. Finally, American River water was acutely toxic to newly hatched fathead minnow larvae during a 1986 storm event with urban runoff the suspected source of the toxicity. Test conducted in 1987 indicated that such toxicity did not persist to the Delta (Chris Foe, CVRWQCB, personal communication).

Direct Toxicity To Young Striped Bass

Doroshov and Wang (1984) conducted 8-day bioassays of striped bass prolarvae in subsurface agricultural drainage alone and mixed with freshwater and Suisun Bay water (9 percent drain + 91 percent other), Suisun Bay water, freshwater, and a mixture of freshwater and Bodego Bay sea water (9 percent freshwater, 91 percent seawater). At 8 days mortalities were lowest (and statistically identical) in the drainage water, drainage water plus Suisun Bay water, and the freshwater/seawater mixture (Figure 2). The drainage water contained about 100 ug/L selenium in the selenate form. The mortalities in freshwater and Suisun Bay water (which had less than 1500 uS/cm specific conductance), appeared to be caused by the low salt content not by toxic constituents.

Marine Bioassay Laboratories (1984) conducted bioassays with several striped bass life stages and subsurface agricultural drainage. The results, by life stage and bioassay type, were:

1. Hatching success. Although no difference in hatching success was noted at any concentration tested (0, 9.1, 50, 100 percent drainage) experimental problems plagued this portion of the studies and the results are of questionable value.

2. 28-day tests with post-larvae (about 20 mm initial length). No significance difference in survival between any of the test concentrations (0-100 percent drainage water).

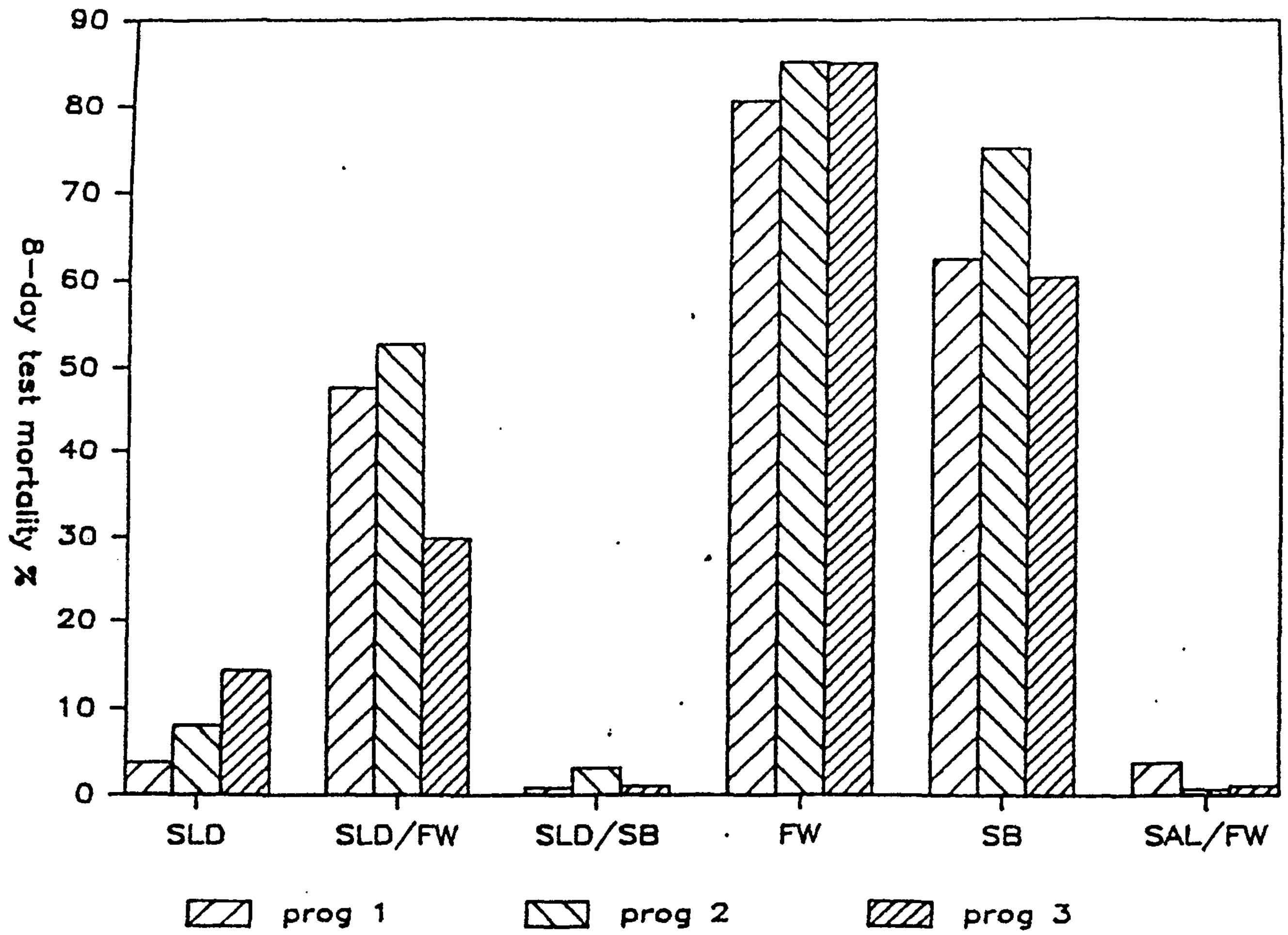

Figure 2. Mortalities of three striped bass progenies in experimental treatments observed at conclusion of 8-day test. (from Doroshov and Wang 1984)
SLD = San Luis Drain
FW = Freshwater
SB = Suisun Bay
SAL = Bodega Bay Ocean Water

3. 28-day tests with juveniles (about 130 mm initial length). No mortalities in any of the test concentrations (0-100 percent drainage).

4. 28-day bioconcentration tests with sub-adults (230-250 mm initial lengths). Five chemical elements had significantly increased concentrations in fish held in 9.1 percent drainage as compared to those in controls. These elements were arsenic, cadmium, lead, nickel, and selenium. Bioconcentration factors could be calculated for only two of the elements, cadmium and nickel, and in both cases the factors were very low.

The MBL results indicate that the drainage water they tested was relatively nontoxic to striped bass, however, these results must be viewed with some caution since the drainage water had less than 5 ug selenium per liter. Typical composite drainage from the San Joaquin Valley should probably contain closer to 100 ug/L. Monaco, et al (1979), did rear striped bass (initial size = 50 mm) for approximately 6 months in drainage containing about 100-150 ug selenium per liter with no apparent ill effects. These results are also of limited value because the tests were not standard toxicity studies.

Lemly (1986) in a review of selenium effects on fish and other aquatic life in impoundments stated that selenium concentrations in the range of 2-5 ug/L should have no effect on fish. This 2-5 ug/L level includes direct effects as well as effects through food chain accumulation. The State Water Resources Control Board (SWRCB 1987) staff recommended that a 2 ug/L standard be established for the San Joaquin River at Hills Ferry and the Grasslands to protect water related beneficial uses. An interim standard of 5 ug/L for the river was suggested to allow time for affected parties to implement measures needed to reach the 2 ug/L level. Although these SWRCB standards are under review, they represent the best efforts of staff to develop measures to protect aquatic biota. Cutter (1987) has reported Bay-Delta selenium levels to normally be less than 0.5 ug/L. At Vernalis selenium levels seldom exceed 1 ug/L.

Fagella and Finlayson (1987) conducted several bioassays with the rice field herbicides Ordram and Bolero using pro- and post-larval striped bass as the test organisms. The following is a summary of their results in terms of the no-observed-effect concentrations (NOEC) for the two compound and mixtures of the compounds.

Ordram		Bolero		Mixture	NOEC-mg/L	
Age(days)	NOEC-mg/L	Age(days)	NOEC - mg/L	Age(days)	Ordram	Bolero
6	<1.5	6	0.12	6	0.79	0.07
13	3.1	13	0.07	13	<0.88	<0.05
24	3.6	24	0.27	24	0.49	0.08
28	7.0	28	0.18	28	3.2	0.27
		45	0.40	45	3.5	0.35

From these data it appears that striped bass become more tolerant of the herbicide with age and that the compounds are more toxic at any age when mixed. Although no chronic eggs-to-fry tests were completed, a risk assessment based on worst case analyses was completed. Safety factors which

Table 5

MONOCYCLIC AROMATIC HYDROCARBONS (MAHS) IN LIVERS OF FEMALE STRIPED BASS, SACRAMENTO-SAN JOAQUIN ESTUARY, 1978-1985[1]
(Adapted from Knudsen and Kohlhorst 1987)

Year	Sample Size	Concentration-ppm Wet Weight Mean ± Standard Deviation	Percent of all Fish that Contained MAH
San Joaquin River			
1978	57	0.3 ± 0.5	81
1979	40	0.2 ± 1.5	3
1980	19	0.1 ± 0.1	37
1981	12	2 ± 1	100
1982	7	0.2 ± 0.6	29
1983	15	0.5 ± 1.7	13
1984	21	Not determined	
1985	23	0.4 ± 0.8	26
Sacramento River			
1979	37	0.1 ± 0.6	11
1980	19	0.2 ± 0.3	47
1984	19	0.1 ± 0.1	21
1985	20	0.1 ± 0.4	10

1 Data from 1978 through 1983 are from NMFS. 1984 and 1985 data are from CDF&G with technical assistance by NMFS.

compared measured and expected herbicide concentrations with estimated chronic eggs to fry no-observed-effect concentrations indicated that little or no toxicological hazard exists to young striped from exposure to Ordram or Bolero in the Sacramento River or in the Sacramento-San Joaquin estuary.

The NMFS staff at Tiburon has conducted numerous laboratory tests and bioassays to determine the energetics of the early life stages of the striped bass as well as the effects of organic pollutants. Although it is often difficult to apply the results of these tests to field situations, they do provide much useful information which can help develop an insight into the effects of pollutants on young bass. The following are a few examples of the type of information provided in these studies.

Eldridge, et al (1981) found that larval bass could survive as long as 18 days in the laboratory before first feeding and still have good survival. The oil globule provides part of the nutritional requirement during this period. They also found that maximum growth occurred at zooplankton populations much in excess of those found in the estuary. Speculation was that larvae which encountered dense patches of zooplankton in the wild would do well. Eldridge, et al (1981) found that initial egg size correlated positively with larval size and that egg size could be partially determined by pollutant body burden in the adult female. Taberski (1982) studied the effect of benzene on physiology and organ structure as well as fate in tissues in juvenile striped bass. Analysis of the data led her to conclude that field levels of benzene (near 100 ug/L) could reduce growth and fecundity, and cause increased susceptability to pathogens, predators, and other stresses.

Effect of Body Burdens of Toxicants In Adults On Young Bass

In 1979 the State Water Resources Control Board (SWRCB), the National Marine Fisheries Service (NMFS) and the California Department of Fish and Game initiated the Cooperative Striped Bass Study (COSBS). The study was an outgrowth of earlier work by NMFS which showed that adult striped in the Sacramento-San Joaquin may be in poor health compared to populations in other areas of the country. The study continued through 1983 and the results have been summarized by Jung, et al (1986). Beginning in 1984, Department of Fish and Game (with funding from SWRCB and technical assistance from NMFS) has continued an annual survey to assess the health of prespawning females. Both studies provided information regarding the effects of toxics on the reproductive potential of adult bass.

Whipple, et al (1983) reported that statistical analyses relating egg condition with various potential toxicants indicated a positive relationship between monocyclic aromatic hydrocarbons (MAHs) in the female and egg resorption and abnormal embryo development. MAHs include such widely used compounds as benzene, toluene, ethylbenzene, and xylene. Their analyses also indicated that prespawning females in the Sacramento-San Joaquin estuary had higher rates of egg resorption than females from other areas (Figure 3).

Table 5 contains data on the concentrations of MAHs found in the livers of prespawning females during the 1978-1984 period (from Knudson and Kohlhorst 1987). No trend is evident although it appears that fish collected in the Sacramento River had lower MAH levels than those from the San Joaquin River.

FIGURE 3 COMPARISON OF PERCENT EGGS RESORBED IN PRE SPAWNING STRIPED BASS FROM THE SAN JOAQUIN RIVER (1978 THROUGH 1985), THE COOS RIVER, OR (1980), AND THE HUDSON RIVER, NY (1982). (FROM WHIPPLE et al 1987)

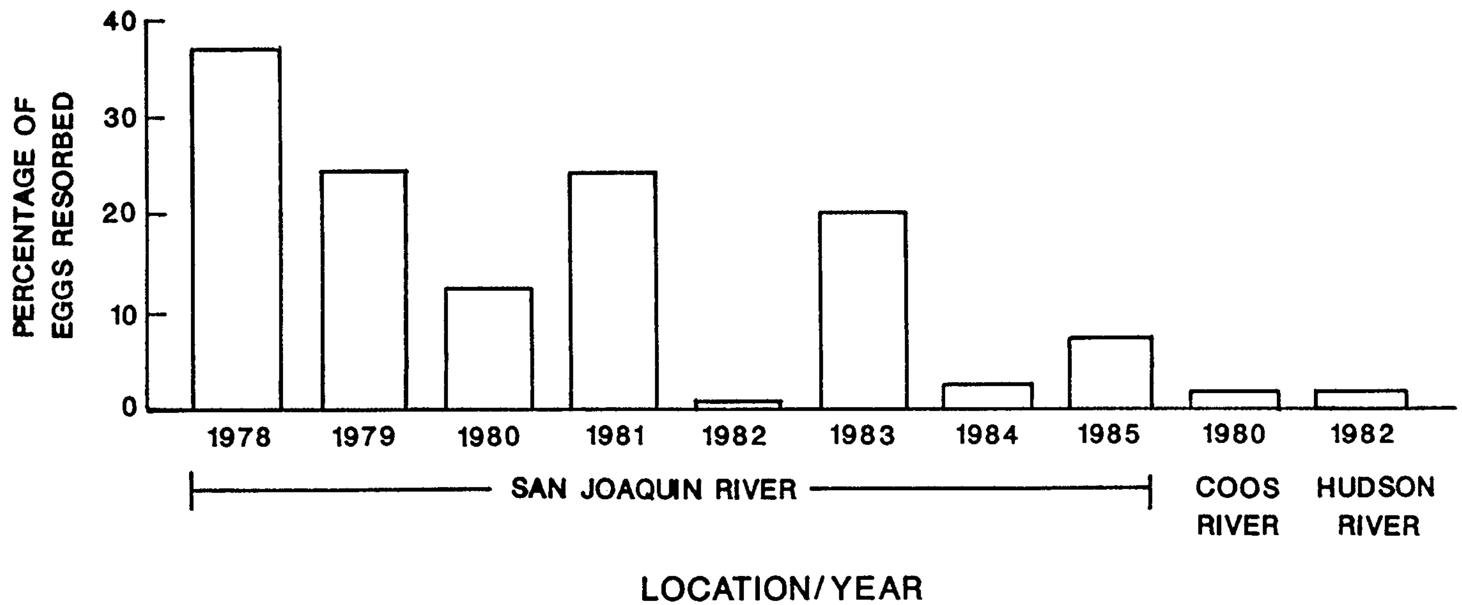

Table 6

PERCENT EGGS RESORBED BY FEMALE STRIPED BASS
IN THE SACRAMENTO-SAN JOAQUIN ESTUARY
(Adapted from Knudsen and Kohlhorst 1987)[1]

Year	Sample Size	Mean Percent Eggs Resorbed ± Standard Deviation	Percent of All Fish that Contained Resorbed Eggs
San Joaquin River			
1978	52	36 ± 42	83
1979	39	25 ± 39	69
1980	19	13 ± 27	63
1981	12	25 ± 36	81
1982	3	0	0
1983	15	19 ± 34	73
1984	20	2 ± 3[2]	44
1985	21	6 ± 15[2]	95
Sacramento River			
1979	36	30 ± 41	75
1980	19	4 ± 6	42
1984	18	3 ± 6	33
1985	20	4 ± 4	100

1 Same as on Table 5.
2 These estimates may be low. The ovarian sections are being reread.

Table 7

PERCENT FEMALE STRIPED BASS CAPTURED ON THE SACRAMENTO AND SAN JOAQUIN RIVERS RESORBING ALL EGGS, 1978-1985 (from Knudson and Kohlhorst 1987)

Location	Year	Sample Size	Percent
San Joaquin River	1978	52	29
	1979	39	21
	1980	19	5
	1981	12	17
	1982	3	0
	1983	15	13
	1984	20	0
	1985	21	0
Sacramento River	1979	36	25
	1980	19	0
	1984	18	0
	1985	20	0

Table 8

MEAN CONCENTRATION (PPM, WET WEIGHT) OF TOTAL ORGANOCHLORINE COMPOUNDS IN TISSUE EXTRACTS FROM FEMALE STRIPED BASS COLLECTED IN OREGON AND CALIFORNIA
(Data from Crosby et al 1984)

Source of Extract	Coos River, Oregon	Sacramento River, California
Lateral muscle	1.01	4.14
Ovary	1.82	5.77
Liver	0.75	3.38

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Table 9

CHLORINATED HYDROCARBONS IN THE OVERIES OF STRIPED BASS COLLECTED FROM THE SACRAMENTO RIVER IN 1981 (Data from Crosby et al 1984)

		Concentration, ppb Wet Weight		
Family		Total of Aroclor	Total DDT	Toxaphene
2		3,860	1,075	266
5		2,853	1,043	150
8		2,110	877	228
10		1,777	890	308
14		4,266	1,816	374
19		3,851	2,089	350
20		6,418	1,750	746
25		3,177	1,133	353
	Mean	3,539	1,334	347

Table 10

MEAN CONCENTRATIONS OF CHLORINATED HYDROCARBON (PPM, WET WEIGHT) IN TISSUE OF OVARIES, EGGS, LARVAE, AND FRY FROM FOUR FEMALES COLLECTED IN THE SACRAMENTO RIVER, 1981
(Data from Crosby et al 1984)

		Family			
Compound	Life Stage	8	10	14	19
Total PCB	Ovary	2.11	1.78	4.27	3.86
	Eggs	4.92	4.67	4.72	--
	Larvae	3.93	3.48	2.47	0.99
	Fry	0.70	0.86	0.83	3.66
Toxaphene	Ovary	0.23	0.31	0.37	0.35
	Eggs	0.26	0.21	0.35	--
	Larvae	0.25	0.42	0.35	0.19
	Fry	0.05	0.16	0.10	0.15
Total DDT	Ovary	0.88	0.89	1.82	2.09
	Eggs	0.95	1.32	1.50	--
	Larvae	0.44	1.03	0.70	0.37
	Fry	0.15	0.25	0.18	0.32
Total Organochlorines	Ovary	4.57	3.24	7.11	6.74
	Eggs	6.43	7.08	6.38	--
	Larvae	4.89	5.13	3.68	1.63
	Fry	0.94	1.33	1.16	4.29

In Tables 6 and 7 the resorption of eggs by these females for the same period is shown. Although there is no statistically significant trend in the data, it does appear in 1984 and 1985 percentage of fish with resorbed eggs declined. In 1984 and 1985 there were no females captured in either river that had resorbed all of their eggs. The 1985 ovarian sections are being reread to check on a possible analytical problem.

Jung, et al, 1986, in a summary of the COBS data, used statistical analyses to conclude that pollutants had possibly reduced the effective fecundity (egg production) of spawners using the San Joaquin River in 1978. This reduction was caused by: (1) delayed maturation; (2) partial egg resorption; (3) complete egg resorption in maturing ovary; (4) no ovary maturation in sexually mature fish; (5) egg death; and (6) actual reduction in the number of eggs. A worst-case analysis of the combined effect of these factors indicated that the number of viable eggs released might have been reduced by about 50 percent. Analyses such as this have not been made for other years, nor have analyses been made to determine the accuracy of the statistical relations used as a basis for the computations.

The COSBS investigators found that open lesions on striped bass were caused by a severe reaction by the host to an infestation of a larval parasitic tapeworm (Moser 1986). Although the parasite is ubiquitous such lesions were not found in striped bass from any other area of the country. A statistical relation between lesion formation and pollutant loading was found. It did appear that lesions in female striped bass could adversely affect reproduction potential by interfering with normal formation of the ovaries and by pressure induced egg deaths. There was no statistically significant trend in the numbers of lesions found in prespawning female bass during the period 1978-1984 (Knudson and Kohlhorst 1987).

As part of the Cooperative Striped Bass Study, Crosby, et al (1984) reported on experiments in which of the organochlorine content of ovaries of several females of striped bass were followed through the egg and larval stages. The investigators also collected adult females from Coos River, Oregon to compare organochlorine content, although they did not spawn the Oregon fish.

Table 8 contains data on the total organochlorine content in extracts from the muscle, ovaries, and livers of Coos River fish versus Sacramento River fish. In all cases the California fish had higher levels of organochlorines.

The data from eight prespawning females from the Sacramento River, Table 9, show that although there is some variability among individual fish, they all had significant body burdens of DDT, PCBs, and toxaphene. The ovary, eggs, and progeny from four of these females were analyzed for the same organochlorine compounds. The data, Table 10, demonstrate that these compounds are transferred from the ovary to the eggs and larvae. Without new sources of the materials, however, the concentrations generally show significant decreases in the later larval and early juvenile stages.

Although Crosby, et al, were not able to clearly establish the link between organochlorine body burdens in the adult and overall success of a particular brood, there were indications that mortalities and skeletal deformaties were related to high concentrations of total DDT and toxaphene, or perhaps DDT alone. Tables 11 and 12 show that DDT and PCBs were still present in Sacramento-San Joaquin fish in 1984 and 1985.

An attempt was made to determine if hatchery managers had detected trends in spawning success of their females and if the trend could be related to toxicants. Mike Cochrane (DFG's Central Valley Hatchery) and Ken Beer (a private firm, the Fishery) both indicated that they only collect spawners from the Colusa area and that there are so many variables involved in the capturing, holding, spawning, and rearing striped bass, that it is not possible to determine why one brood has good fertilization and survival and another does not. The NMFS staff did keep track of spawning success in their various attempts to obtain newly hatched embryos for laboratory testing. Eldridge, et al (1981) found that only 5 of 9 females attempted in 1977 produced embryos which proceeded through normal development. Higher concentrations of MAHs were found in the ovaries of females with poor hatching success, although the small sample size limits the general applicability of this finding (J. Whipple, NMFS, personal communication).

Table 13 summarizes the 1985 striped bass health index trace element data for adult female striped bass collected in the Sacramento and San Joaquin rivers. It appears from these data that metal concentrations are similar in fish collected from the two systems and that all fish contain these elements. Not much is known about the effects of these body burdens on health, although the COBS multivariate analyses did indicate that zinc and perhaps copper were possible contributors to poor health. In 1986, samples of striped bass and white sturgeon flesh were analyzed for selenium to assess the potential for public health concerns. The results showed an average of 1.9 $\pm$ 0.8 ppm selenium (wet weight) in sturgeon flesh and about 0.3 ppm ($\pm$ about 0.4) in striped bass (J. White, CDF&G, personal communication). Health concerns related to these concentrations either to humans or fish are not known.

East Coast Studies

On the east coast striped bass stocks have been maintained by periodic strong year classes (Figure 4). There has not been such a strong year class in most of the system since 1970. Although Hudson River production appears to be in relatively good shape, other adult stocks have declined to low levels. Spawning stock from the Hudson River has high PCB concentrations (see Table 14) and warnings have been posted regarding consumption of the fish. These warnings may have reduced fishing pressure, thus helping maintain stock size. The high PCB levels apparently do not interfere with egg production or larval development in that hatcheries report good spawning success in spite of the high PCB levels (B. Friedland, EA, Science and Engineering, personal communication).

Fishing restrictions, including spawning ground closures, have been imposed by most states to protect the remaining fish and numerous studies have been funded to determine the cause(s) of the decline. One of the studies being conducted by the USFWS National Fisheries Research Laboratory, has dealt specifically with the possible role of contaminants on the early life stages of striped bass. The overall study objective was to assess the relative importance of pollutants as a cause of poor year class strength during the past several years (CNFRL 1983).

Table 11

CONCENTRATIONS OF DDT AND ITS METABOLITIES IN THE LIVERS OF FEMALE STRIPED BASS FROM THE SACRAMENTO AND SAN JOAQUIN RIVERS IN 1984 AND 1985
(Data from Knudsen and Kohlhorst 1987)

Year	Sample Size	Mean Concentration ppm Wet Weight ± Standard Deviation	Percent of all Fish that Contained DDT and Metabites
San Joaquin River			
1984	20	0.3 ± 0.1	100
1984	23	0.5 ± 0.9	100
Sacramento River			
1984	19	0.4 ± 0.3	100
1985	20	1.5 ± 3.6	100

Table 12

CONCENTRATION OF AROCLOR-1260 (PCB) IN LIVERS OF FEMALE STRIPED BASS FROM THE SACRAMENTO AND SAN JOAQUIN RIVERS IN 1985 AND 1985 (Data from Knudsen and Kohlhorst 1987)

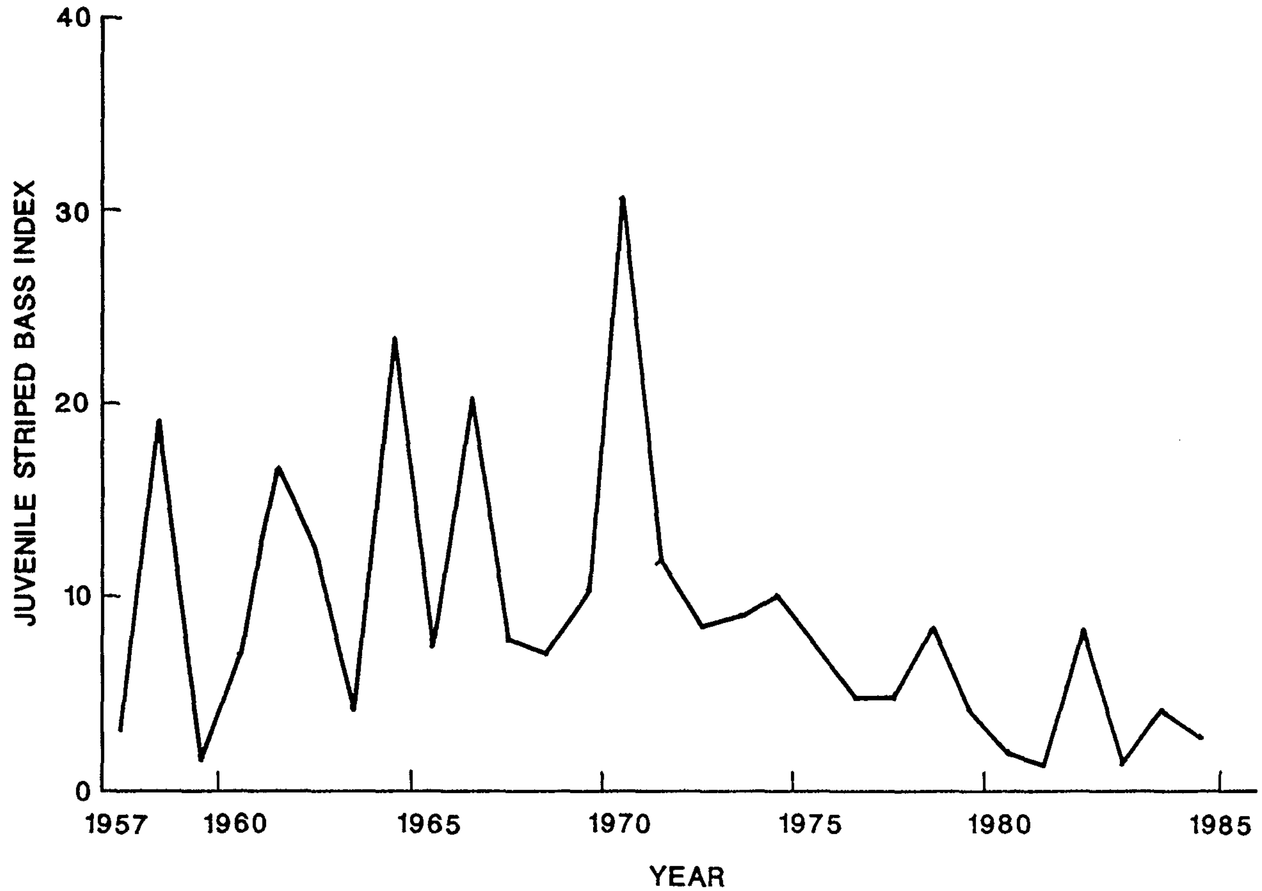
Year	Sample Size	Mean Wet Weight Concentration ppm ± Standard Deviation	Percent of all Fish that Contained Aroclor 1260
San Joaquin River			
1984	20	0.5 ± 0.2	100
1984	23	0.4 ± 0.3	100
Sacramento River			
1984	19	0.7 ± 0.4	100
1985	20	0.4 ± 0.4	95

Table 13

CONCENTRATIONS OF VARIOUS TRACE ELEMENTS (PPM DRY WEIGHT) IN LIVER OF FEMALE STRIPED BASS COLLECTED IN 1985 (Data collected from Knudson and Kohlhorst 1987)

Element	Concentration-ppm Wet Weight (all fish) Average ± SD		Percent of all Fish that Contained the Element
Copper	Sacramento River	67.5 + 45.2	100
	San Joaquin River	65.0 + 82.7	100
Zinc	Sacramento River	147.0 + 39.3	100
	San Joaquin River	155.0 + 35.1	100
Cadmium	Sacramento River	3.69 ± 2.34	100
	San Joaquin River	3.94 ± 3.03	100
Chromium	Sacramento River	0.08 ± 0.02	100
	San Joaquin River	0.07 ± 0.01	100
Mercury	Sacramento River	1.1 ± 0.74	100
	San Joaquin River	3.0 ± 4.37	100
Selenium	Sacramento River	7.2 ± 2.7	100
	San Joaquin River	8.6 ± 6.7	100

FIGURE 4 CHESAPEAKE BAY STRIPED BASS YEAR CLASS STRENGTH (MARYLAND INDEX) 1957 THROUGH 1985. (Data from Goodyear 1985 and Chesapeake Exec Council 1987)



The USFWS researchers conducted extensive field studies to determine environmental concentrations of potential contaminants in the water and in several striped bass life stages (CNFRL 1983). Tables 14 and 15 list organochlorine compounds and trace element concentrations in striped bass collected in 1980 from several east coast sources as well as the Sacramento River. The data demonstrate the presence of several potential toxic materials in striped bass and that Sacramento River fish are particularly high in organochlorine compounds as compared to most east coast sites. (Trace element concentrations, including selenium, were similar in samples from all areas.) Body burdens of contaminants in hatchery spawned female bass bore no relationship to the hatchability or survivability of their eggs, although there was an indication that high levels of DDT caused some decrease in survival.

Chronic toxicity bioassays used to test a mixture of pollutants at or near measured environmental concentrations generally showed that these concentrations did not affect survival of young striped bass for periods of up to 90 days. (Test organisms were 14 days post-hatch.) When concentrations were elevated to 2 or 4 times environmental concentrations some increased mortality was noted, especially in freshwater. Increased salinity, up to 5 ppt, appeared to decrease the toxicity of the mixtures. The investigators also tested the effects of contaminants on the young bass swimming ability, feeding, and ability to avoid predators. These laboratory studies demonstrated some adverse affects on these important behavioral traits depending on the concentration and salt content of the water.

In 1983, the overall conclusion reached from the first 3 years of studies was that no single contaminant, or combination of contaminants, could be identified as the cause of the decline in striped bass. The residue data and toxicity testing data did indicate pollutant might have played some role.

In a subsequent report (CNFRL 1986) the USFWS investigators published an update of their work through mid-1986. The effort focused on the interaction between low pH (as caused by acid rain or nitrogen fertilizers) and the toxicity of metals (aluminum in particular) to young striped bass. There was a pH-aluminum interaction (low pH increased Al toxicity), and there were instances when the ambient pH in spawning streams was low enough to be of concern. On-site testing of larval development in waters from 3 different rivers indicated there were times when ambient water quality was sufficiently poor to cause high larval mortality.

Summary and Conclusions

Striped bass in California contain appreciable amounts of several potential toxicants in various tissues, with chlorinated hydrocarbons and monocyclic aromatic hydrocarbons being particularly high. Compared to other populations, striped bass from the Sacramento-San Joaquin Rivers and estuary appear to be in poor health and often have open lesions because of reactions to parasite infection. Although data are fairly limited, enough information is available to document an extensive toxic loading to the estuary. Several studies have been conducted to determine the effects of particular pollutants, rice herbicides for example, on young striped bass and their food supply. Based on the available data a few generalized conclusions can be advanced. It should

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Table 14
ORGANOCHLORINE RESIDUES (PPM, WET WEIGHT) IN ADULT FEMALE STRIPED BASS AND UNFERTILIZED EGGS FROM EAST COAST AND SACRAMENTO RIVER, 1980
(Data from CNFRL, 1983)

Sample Source		Concentration in ppm Wet Weight		
	DDT	PCB	Toxaphene	Total
Adult Females				
Edenton Hatchery	0.45	0.5	0.4	1.35
Hudson River	0.76	9.1	0.1	9.96
Potomac River	0.40	2.2	0.5	2.65
Roanoke River	0.46	1.2	0.6	2.26
Elk River	0.48	1.1	ND*	1.58
Choptank River	0.47	2.8	0.2	3.47
Cooper River	0.64	1.7	1.36	3.70
Sacramento River	0.85	2.5	0.5	3.85
Unfertilized Eggs				
Edenton Hatchery	0.54	0.6	ND	0.60
Hudson River	0.84	26.4	ND	27.24
Potomac River	0.52	4.0	ND	4.52
Roanoke River	0.59	0.8	0.55	1.94
Elk River	0.99	3.91	0.24	5.14
Choptank River	1.64	6.19	0.55	8.33
Cooper River	0.36	0.9	ND	1.26
Sacramento River	6.80	10.74	1.44	18.98

* ND = nondetected.

Table 15

RESIDUES OF INORGANIC CONTAMINANTS FOUND IN WHOLE BODIES OF
ADULT STRIPED BASS (PPM) COLLECTED IN 1980
(Data from CNFRL, 1983)

Sample Location	Lead	Mercury	Arsenic	Trace Elements Selenium	Copper	Nickel	Chromium
Edenton Hatchery	0.25	0.08	0.17	0.19	1.36	0.13	0.65
Hudson River	0.61	0.14	0.78	0.34	1.39	0.13	0.61
Cooper River	0.27	0.11	1.21	0.54	3.28	0.12	0.90
Elk River	0.12	0.07	0.84	0.69	1.34	0.14	0.85
Potomac River	0.16	0.09	0.55	0.60	1.47	0.23	0.90
Roanoke River	0.29	0.17	0.43	0.55	1.15	0.23	0.79
Choptank River	0.16	0.09	0.94	0.34	1.67	0.25	0.78
Sacramento River	0.19	0.27	0.38	0.48	1.46	0.26	0.84

be emphasized that these conclusions are based on a limited amount of information and, as such, are preliminary.

Effect on food supply:

1. Toxics are probably not responsible for the changes in Delta phytoplankton populations noted since the drought.

2. The two rice field herbicides, Ordram and Bolero, used in the Sacramento Valley, may have adversely affected Neomysis and perhaps other zooplankton populations in the Delta. There are indications from the studies of agricultural drains and storm drains upstream of the Delta that these waters can be acutely toxic to zooplankton. These effects should be dissipated by the time the water reaches the Delta.

Direct toxicity on young:

1. Currently, there are no data which show that waters of the estuary or the upstream spawning areas are acutely or chronically toxic to young striped bass. There are laboratory bioassay data which demonstrated the toxicity of petrochemicals (MAHs) to young bass, although generally the levels tested are much higher than found in the field. The lack of demonstrated toxicity may be due more to lack of testing rather than actual lack of toxicity.

2. Selenium originating from the San Joaquin Valley and local inputs to the estuary does not appear to be adversely affecting survival of young striped bass in the Delta-Suisun Bay area, either through direct toxicity or food chain accumulation.

Effects transmitted through the spawning female:

1. Although pollutants such as organochlorine compounds are transferred from the female to the eggs, it has been difficult to quantify the effects of such levels. NMFS, U.C. Davis, and USFWS did find indications that DDT could cause significant abnormalities in striped bass eggs and developing larvae.

2. The COSBS demonstrated that females in the Sacramento-San Joaquin estuary have decreased effective fecundity compared to females from other systems and that this decrease appears to be related to the direct and indirect effects of pollutants, such as monocyclic aromatic hydrocarbons and DDT.

3. The most likely adverse impacts of toxics on the striped bass year class strength is through effects on fecundity and survival in the early larval stages. Although there is evidence of such adverse impacts, they have not been conclusively demonstrated.

General Conclusions

1. The analysis leading to the material contained in this working paper clearly pointed to the need for a more coordinated approach to evaluating toxic impacts on estuarine biota. Although there are scattered data

regarding body burdens of many chemicals, there are few studies which clearly show cause and effect relationships. The toxics issue is too important to be addressed in the present hit-or-miss fashion.

2. Given the prevalence and persistence of many of the potential toxicants found in this estuary, the apparent poor health of local striped bass as compared to other populations, and the laboratory data showing adverse physiological and developmental effects of some pollutants, it is probable that toxics act to reduce striped bass populations in the estuary. It is unlikely, however, that toxics alone are responsible for the reduction in population size that has occurred during the past 10 to 15 years.

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