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THE IMPACT OF ESTUARINE DEGRADATION AND CHRONIC POLLUTION ON POPULATIONS OF ANADROMOUS STRIPED BASS (*Morone saxatilis*) IN THE SAN FRANCISCO BAY-DELTA, CALIFORNIA.

A summary for managers and regulators .

by

Jeannette A. Whipple

ADMINISTRATIVE REPORT T-84-01

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A SUMMARY FOR MANAGERS AND REGULATORS

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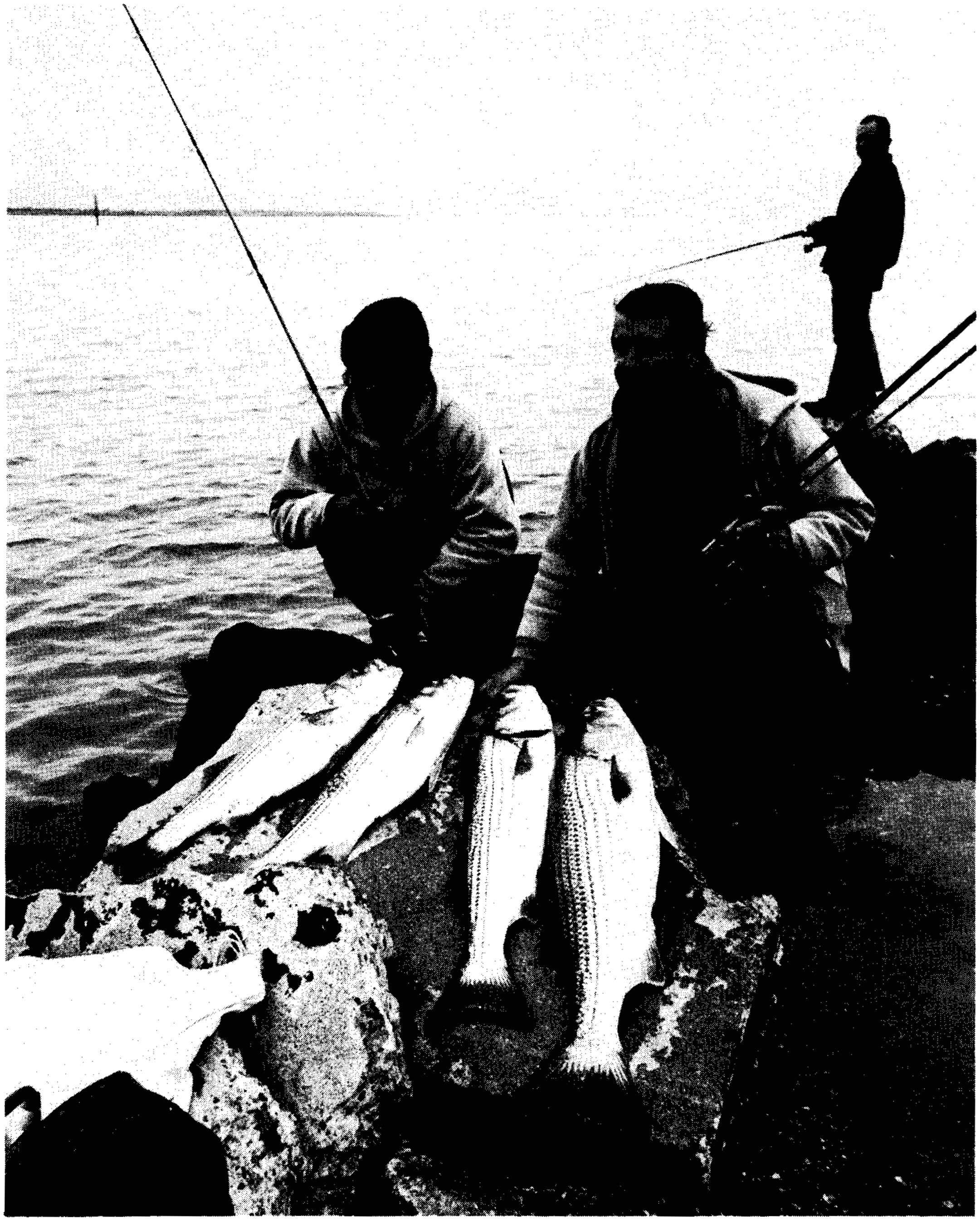

PLATE I. Sportswriters Larry Green and Abe Cuanang fishing for striped bass in San Francisco Bay. (Photo courtesy of Larry Green, San Francisco).

CONTENTS

SUMMARY OF RESEARCH

The goal of the Physiological Ecology Investigation has been to contribute to an understanding of the long-term ecological consequences of pollutant effects on aquatic resources. Specifically, we are concerned with developing knowledge of effects of chronic low-level pollutants on fisheries. Although the understanding of fate and effects of pollutants in the marine environment has increased in the past 10 years, this knowledge is still limited primarily to acute effects of single pollutants or pollutant classes. Little is known of chronic, interactive effects of pollutants within and between pollutant classes. Most effects studies are limited to the laboratory; little information exists on the quantitative effect of pollutants on a population level. Finally, few studies address the interactions of pollutants with inherent characteristics of the species or with other environmental factors.

Our initial work on pollutant effects in field and laboratory studies has shown us that considerable variability occurs, not explained by the circumstances of experimental design. We are attempting to approach our current studies on single-species populations by describing the major sources of variability in pollutant effects. We are measuring more variables and using multivariate analyses to refine data for use in the laboratory and for field prediction and monitoring. This approach concentrates on "easy to measure" characteristics of species which correlate with pollutant burdens--designated collectively as measures of body condition, liver condition and egg condition. The coefficients derived can be used for an overall assessment of the health of the fish. Some of the measures are also more sensitive, and thus more effective, in giving an earlier warning that a population is stressed. Ultimately, we hope to synthesize the results into a model of the impacts of long-term chronic pollution on "natural" mortality rates and resulting changes in the population of the affected fishery.

In our current study we simplified by selecting a "model species," the striped bass (*Morone saxatilis*), within a coastal, estuarine ecosystem-- the San Francisco Bay-Delta. This species appears to be on a long-term decline in this area.

We suggest that at least part of this decline may be due to the deleterious interactive effects of anthropogenic factors such as water diversion and pollution.

Initially, we were uncertain which classes of pollutants might be implicated. We now believe that certain petrochemicals, interacting with other pollutants such as PCBs and heavy metals, are involved. Our studies include measurements of petroleum hydrocarbons, chlorinated hydrocarbons and heavy metals in selected tissues (gonads, liver, muscle) of striped bass from the field, and laboratory studies of the effect of specific compounds from these classes. Compounds were selected for lab studies based on their occurrence in striped bass in the San Francisco Bay-Delta and include benzene(a petrochemical) and zinc (a heavy metal).

Field results indicate correlations of pollutants with parasite burdens, body condition, liver condition and, most significantly, egg and gonad condition. Fish chronically exposed to pollutant stressors may be susceptible to diseases and parasites; field data show that San Francisco Bay-Delta fish have relatively high parasite burdens. Fish from the San Francisco Bay-Delta appear to have higher and more damaging parasite loads than fish examined from other areas to date (Coos River, Oregon; Lake Mead, Nevada and the Hudson River, New York). Cestode-induced lesions, resulting in open wounds and secondary bacterial infections, are unique to fish from the San Francisco Bay area. It seems certain the lesions and subsequent infections cause mortality in younger fish. Even in older fish with healed lesions, there are associated deleterious conditions stemming from the earlier cestode infections. In field fish, the correlation between the burden of monocyclic aromatic hydrocarbons (MAH) and the presence of cestode lesions is significant.

Both field and laboratory results substantiate that fish exposed to chronic pollutant stress undergo significant reductions in reproductive capacity, fecundity and gametic viability. We estimated that the reduction in viable eggs, even before spawning, was at least 50% for the 1978 prespawning females. Pollutants most implicated in causing deleterious effects on reproduction and egg condition are MAH and zinc. DDT and PCBs were also associated with egg abnormalities in some fish.

At the beginning of these studies, we hypothesized that genetic population differences exist between areas (spatial isolation) and/or through time (temporal isolation). Preliminary results from field samples indicate genotypic variability in the population, most readily identified by color pattern and characteristics associated with color pattern. The variation may relate most significantly to temporal differences (annual and seasonal) in the population, possibly to different migratory stocks. Field and laboratory studies indicate genetic differences between solid-striped fish and those with stripe breakage. Preliminary data suggest fish of different color-pattern types may differ in migratory behavior, growth rates, reproduction and susceptibility to parasites and pollutant stress.

SUMMARY OF MANAGEMENT APPLICATIONS

Recommendations and Actions Taken
To Ameliorate Effects of Pollutants and Parasites
On the Striped Bass Fishery and to
Protect Public Health.

This work has benefited the general public and fishermen. It has also provided information to fisheries managers and regulators, and regulators of water quality. Our results have contributed useful information to solving problems revolving around several environmental issues, in particular the decline of the striped bass population in California. Some of these issues are:

FISHERIES MANAGEMENT (NMFS and State of California)
Declines in striped bass-California & all coasts
Declines in other commercial & recreational species

WATER QUALITY REGULATION (OMPA* and State of California)
Estuarine and marine pollution
Municipal and industrial discharges
Accidental gasoline and oil transport spills
Pesticide applications
Run-off from toxic waste dumps
Power plant effluents & diversion
Water diversion - agriculture, etc.
Dredging activity
Agricultural drain discharges

QUALITY & SAFETY OF FISHERIES PRODUCTS (NMFS and California)
Contaminant residues
Parasite loads

Initially, PEI research alerted the public and California management and regulatory agencies to a problem with the recreational striped bass fishery in the San Francisco Bay-Delta area. Our results showed significantly reduced egg condition, and high parasite and pollutant burdens which could significantly reduce the quality of the fishery and also contribute to a quantitative decline of the fishery. This prediction subsequently proved to be true, although factors other than pollution have also contributed to the decline of striped bass in the San Francisco Bay area.

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*Office reorganized as Oceans Assessment Division, Office of Oceanography and Marine Services, NOS. October, 1982.

As a result of our research showing the relationship between gasoline, oil and certain chlorinated hydrocarbon contamination with reduced reproduction and increased parasitic infections of striped bass, specific actions were taken by the California State Water Resources Control Board, the Regional Water Quality Control Board and California Department of Fish & Game.

These include:

1) warnings to the public on the potential health hazards associated with anasakid worm infections and pollutant residues in striped bass.
2) legislation introduced in the state legislature to increase significantly fines for gasoline spills in the bay.
3) recommendations to the Coast Guard to require greater safety precautions and more inspections of gas barges.
4) the banning of the pesticide toxaphene.
5) the implementation and funding of the study of chemicals used in rice fields.
6) the setting of limits on total monocyclic aromatic hydrocarbons in certain discharges.
7) requirements to accelerate the clean-up of PCBS remaining in the San Francisco Bay ecosystem.
8) implementation and funding of annual monitoring of the health of spawning striped bass, using our methods.
9) implementation and funding of further research on effects on striped bass larvae.
10) additional recommendations for further studies, not yet implemented, but planned for the future.

The information generated by this research has been used widely by managers and regulators involved in the problems listed above. We have provided further information to east coast researchers and fishermen concerned about the decline in the east coast striped bass fishery, in particular to the Hudson River Fisherman's Association. We have also provided information on the striped bass population in the Coos River, Oregon which has been useful to Oregon State managers.

I. INTRODUCTION

When most of us think of pollution effects on the marine environment, we are likely to think of dramatic events such as major tanker accidents and oil spills, or fish kills resulting from sewage effluents and toxic spills. These incidents are highly visible and receive considerable public attention. There is no doubt that such occurrences are damaging to the marine environment and warrant concern about the protection of that environment.

Unfortunately, we may be deluded into thinking that if we prevent or ameliorate damage from such catastrophic events, our pollution problems have been solved. If we do this, we overlook a potentially greater problem--that of continual or chronic input of pollutants at lower levels. For example, in the 1960's there was considerable activity leading to decreased sewage pollution of San Francisco Bay. This was certainly commendable, but also led to the impression that our pollution problems were over. Little attention was paid to the less visible and potentially more harmful effects of continually increasing pollution from "water-soluble" chemicals.

The long-range effects of chronic exposure to pollutants on our aquatic resources are still relatively unknown. Levels of pollutants, in this situation, are lower but more prevalent.

Effects, if they occur, are more subtle, yet the damage to our resources may be considerable and, in many cases, irreversible.

The recognition of the possible impact of pollution and other man-induced changes on our marine ecosystems led to the establishment of legislation to conduct research into these long-term effects. The Marine Protection, Research and Sanctuaries Act of 1972 (P.L. 92-532; Title II, Section 202) was one law that allocated funds for this type of research; the former Office of Marine Pollution and Assessment (OMPA) was authorized to manage the program. Our research on striped bass was primarily funded by this program and by the National Marine Fisheries Service (NMFS).

It is difficult to study effects of chronic pollution for a number of reasons. First, most marine ecosystems potentially impacted by pollutants are inherently complex and variable in space and time. Many ecosystems are described incompletely, either qualitatively or quantitatively, even under completely natural conditions. Natural perturbations may exceed those induced by man's influence (e.g. 1983 El Nino warm water conditions). This makes it very difficult to detect alterations in the environment ascribable to pollution, and even harder to predict them.

A second difficulty arises from the complex array of different pollutants occurring in the marine environment, sometimes thousands of compounds, particularly in estuarine ecosystems which are most affected by man.

Finally, sublethal effects of low pollutant concentrations on organisms are subtle and difficult to quantify on an individual or population level; their detection also may be obscured by inherent species variability such as age, sex, or genetic differences.

A solution to this intricate problem will require a long-term, cooperative effort.

In order to describe sources of variability in pollutant effects on striped bass more completely, we used techniques of multivariate analysis similar to those used in epidemiology. We were then able to refine the data to determine the best methods for measuring pollutant effects in both the field and in laboratory experiments.

Our approach concentrated on "easy to measure" and/or "sensitive" characteristics of the organism which appeared to correlate with pollutant burdens. The measurements were on several levels--from the biochemical to the subsample (population) level. Selected groups of variables (factors) were designated as measures of body condition, liver condition, and egg condition. These factor coefficients were then translated into an overall assessment of the health of the organism. The coefficients also can be used eventually to estimate quantitative effects on a population level, such as reductions in growth, reproduction and survival. Some of the measurements were also more sensitive and consequently more effective in giving us an early warning that individuals and/or the population were stressed.

A). Research Plan

The following questions were asked when formulating our research plans. In this summary, the questions are placed within the context of the OMPA Pollution Research Program Conceptual Organization (Figure 1).

<u>Anthropogenic Activities (SWRCB)</u>

1. Which pollutants are potentially impacting our marine resources, including fisheries?
2. What are the sources of these pollutants?

<u>Marine Ecosystem Processes (To Be Done)</u>

3. What are the interactive effects of the pollutants on fishes? How are they related to other ecosystem processes, such as variations in outflow and diversion?

<u>Consequences Attributable to Anthropogenic Activities (NMFS)</u>

4. Are there effects on fish attributable to chronic pollutant exposures?
5. If so, what are the effects and which measurements provide the most sensitive and specific assessment of them?
6. Are the effects reversible? Are there either short-term or long-term irreversible effects on individuals and populations?
7. What are the quantitative reductions in populations in growth, reproduction and survival attributable to pollutants?

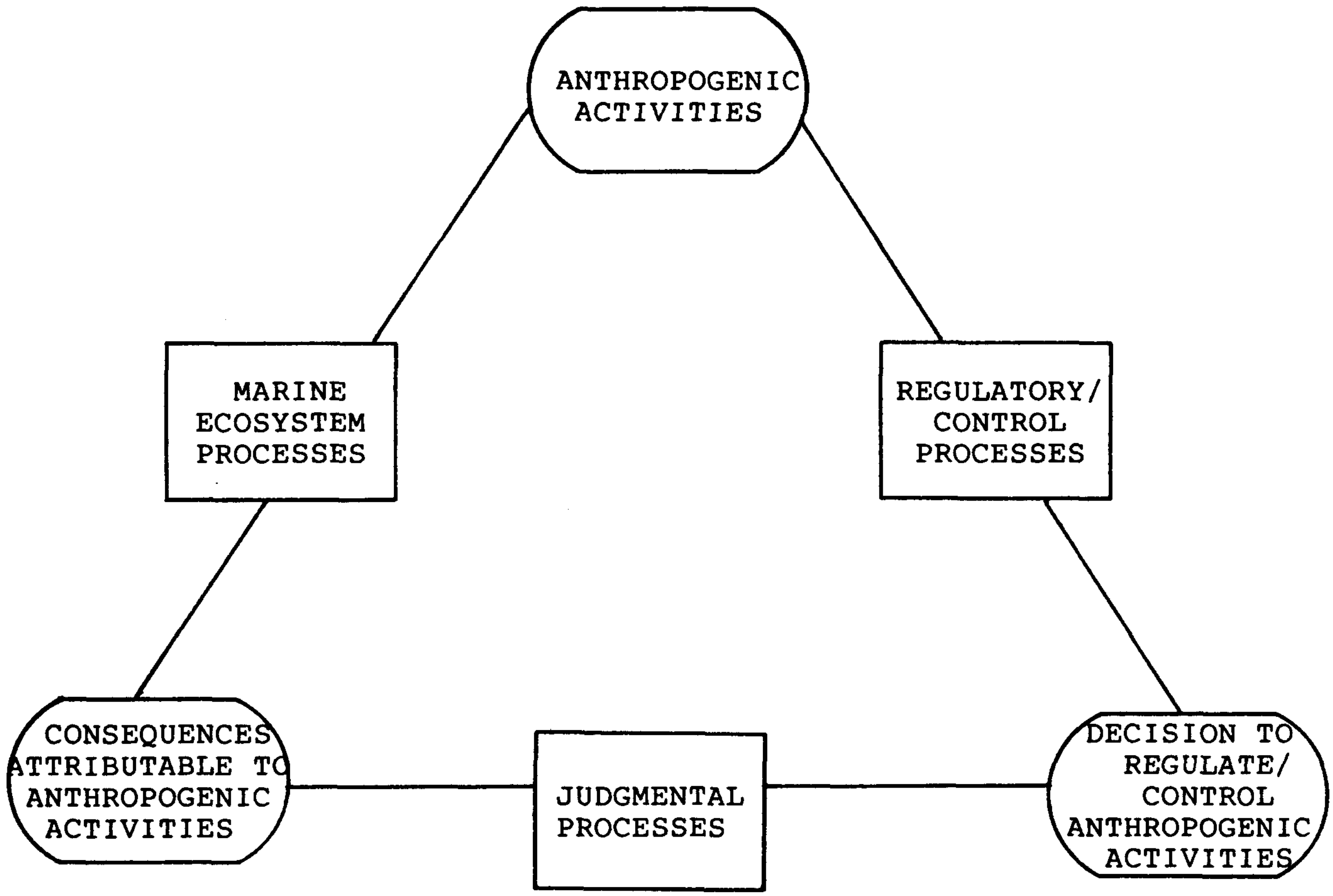

Figure 1. Conceptual representation of OMPA Marine Pollution Research Program. From R.E. Burns, January 29, 1982. "Office of Marine Pollution Assessment (OMPA) Financial Assistance for Marine Pollution Research."

Judgmental Processes (NMFS & SWRCB)

8. Can these effects be predicted?

9. What recommendations based on our results can be made to management and regulators for the decisions necessary to regulate anthropogenic activities deleteriously affecting fisheries?

Other (NOAA, NMFS, OMPA, SWRCB, CDF&G)

10. Other compartments in the conceptual representation in Figure 1 are in the purview of management.

In 1980, the Cooperative Striped Bass Study (COSBS) team was organized to examine different aspects of the above questions. (Whipple et al., in prep.; Whipple, Crosby and Jung, 1983; Whipple and Jung, 1981; Jung et al., 1981)

At the Tiburon Laboratory (NMFS), we concentrated on the effects of pollutants on striped bass populations (4 through 8, above). From this research, a number of recommendations have been made (9 above). The State Water Resources Control Board (SWRCB) stressed work on the anthropogenic sources of pollutants found in the striped bass and identification of the pollutants (1 and 2 above), funded additional studies on effects of pollutants and parasites, (4 through 8), and took a number of management actions (10 above).

We had hoped to continue our cooperation with the State of California through SWRCB and the Department of Fish and Game (CDF&G) by examining ecosystem processes in relationship to our findings with striped bass--for example, determining the relationship of pollutant concentrations to flow and diversion rates in the San Francisco Bay-Delta estuary (3 above). Although this work was not funded, we will continue to synthesize data available from existing studies.

Hoping that a broader program for the San Francisco Bay-Delta ecosystem can be implemented in the future, we are now concentrating on analysis of available data from a number of sources to complete our syntheses of pollutant effects on the striped bass population. No new research has been initiated by NMFS to date. Under the category of Judgmental Processes (8 and 9 above), we will be able to continue providing recommendations to management and regulatory agencies for only one more year.

II. BACKGROUND

There were a number of excellent reasons for selecting the striped bass as a model species in the San Francisco Bay-Delta ecosystem, but the major one was the long-term decline of this population in the area, as well as in most other estuaries of the United States. We suggest that at least part of the decline may be due to the interactive deleterious effects of anthropogenic factors, such as water diversion and pollution.

The striped bass also was a good choice for the study because it is a long-lived fish (approximately 20 years) and at all ages appears to accumulate relatively high levels of pollutants. It is a tertiary carnivore and may be expected to accumulate pollutants through the food chain. Striped bass are also very euryhaline, occurring in offshore marine areas, estuaries and in fresh water. They occur on all coasts of the United States and have been introduced into other countries. This fishery is also of great commercial and recreational value.

California Department of Fish and Game (CDF&G) biologists have studied the striped bass population in the San Francisco Bay-Delta estuary for about 40 years. Their work provided a framework for studies of this species, particularly in the field. The initial results of CDF&G studies revealed a high correlation between outflow from the Delta and survival of striped bass to "young-of-the-year" or juvenile stage. A correlation also existed between the percentage of water diverted south through the California aqueduct system and survival to juveniles. On the basis of these correlations, CDF&G was able for some years to predict survival to juveniles and recruitment to the fishery. These predictions became less reliable in later years, although outflow and diversion remain major controlling factors in survival.

The interaction of yearly temporal variation in net flow with spatial variation in spawning and nursery habitats appeared to be a major factor in the annual variation in survival of striped bass. We hypothesized that in critically low water years, or when certain pollutant "events", such as spills, occurred during spawning migration, this spatial-temporal equilibrium was disturbed. When this happened, the effects of pollutants and other environmental stress factors appeared to play a larger role in contributing to the mortality of striped bass. This system was thought of as a "model" for the interaction of the anthropogenic stressors of water diversion and pollutants.

The striped bass population within the San Francisco Bay-Delta ecosystem is also inherently variable. We believe there is both genetic and congenital variability in this population, possibly resulting from changes in the spatial-temporal environmental selection factors. We hypothesized that variability in the color pattern of the striped bass among different locations and times (days & years) related to variability in physiological adaptation to different environments. We hoped that assessment of the variability in color-pattern type could be used to predict population changes relevant to an understanding of population equilibrium.

III. GOALS

A). OMPA Goals*

Swanson (1982) outlined six major goals of OMPA arising from the Federal Plan for Ocean Pollution Research, Development and Monitoring, (Fiscal Years 1981-1985) and the NOAA Marine Pollution Program Goals.

Our research was designed to contribute specific information applicable to several of these goals, but in particular to goal 6 (Swanson, 1982; p. 5), stated as follows.

> "To document and evaluate the status and trends of source loadings, ambient levels and biological accumulations of critical pollutants and the probable effects of these pollutants on the ecosystem and on human welfare."

Our research examined effects of pollutants on fisheries, in general, using this study as a model species and ecosystem. To begin, we derived the following specific goals.

B). Specific Project Research Goals

1. To determine the consequences of chronic pollutants impacting a fishery's population.
2. To use striped bass, an apparently declining population in the San Francisco Bay ecosystem, as a "model species" for such a study.
3. To compare the San Francisco Bay-Delta striped bass population to other populations less impacted by pollutants.

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*Research under OMPA terminated in 1983.

4. To determine the condition or health of striped bass caught in the field, and, if in poor condition, to determine correlations with pollutant burdens in tissues.
5. To do laboratory studies to corroborate field-determined correlations between fish condition and pollutant burdens.
6. To formulate a quantitative model showing relationships between pollutants and the condition of the bass population in terms of reductions in growth, reproduction and survival.
7. To provide recommendations to appropriate agencies involved with management of fisheries, specifically the striped bass fishery, and to agencies responsible for the maintenance of water quality and the health of marine ecosystems.
8. To cooperate with other agencies in determining the main sources of pollutants deleteriously affecting striped bass.
9. To cooperate with other agencies in determining the pollutant burdens in striped bass potentially harmful to human health.
10. To cooperate with other agencies in determining the relationship of pollutant effects on striped bass to other ecosystem processes, e.g., water outflow and diversion and other species in the striped bass food chain.
11. To make field tests of predictive models.

Work on goals 1. through 9. above is primarily completed, with some data analyses and quantitative modeling still remaining. Work on 6. and 9. through 11. is continuing, but will require further support by the State of California, as well as reestablished involvement of NOAA.

IV. MAJOR ACCOMPLISHMENTS AND RESULTS

A). General Accomplishments to Date

We have examined approximately 500 fish captured in the field from the San Francisco Bay-Delta (400), the Coos River, Oregon (41), Lake Mead, Nevada (30) and from the Hudson River, New York (26). Techniques of histopathological examination and autopsy have been developed to assess the health of striped bass and to continue annual monitoring (Whipple and Jung, 1981, 1984; MacFarlane & Whipple, 1984). Approximately 350 characteristics of the fish were examined--from the biochemical level to organ system and individual organism levels--to determine the best measures of health. Subsamples were taken of liver, ovaries and muscle to determine burdens for the following major classes of pollutants: petrochemicals or petroleum hydrocarbons (monocyclic aromatics, polycyclic aromatics), chlorinated hydrocarbons (including PCBs, toxaphene, DDT and its metabolites and others), and heavy metals (copper, iron, zinc, cadmium, mercury, lead, nickel and others). Tissues were also scanned for EPA's priority pollutants.

Multivariate statistical techniques were applied to the field data to determine correlations between sets of variables describing condition and the pollutant burdens. Several laboratory experiments were performed to verify correlations seen in field fish. Unfortunately, all planned laboratory experiments were not finished due to termination of funding. Previous results are described in annual reports submitted to OMPA (May 15, 1982; July 15, 1982). A plan has been recommended for continued monitoring of prespawning striped bass (MacFarlane & Whipple, 1984). Data synthesis and work on a quantitative model of effects on sensitive life stages of the striped bass are still in progress.

B). Specific Results of Research

The following specific results apply to the goals above:

1. Location. There were differences among locations. The greatest proportion of the variability was attributable to different sampling locations. Thus, factor analyses were separated by location before assessing the other variability.

--Fish from the San Francisco Bay-Delta estuary were in poorer health or condition than fish from the Coos River, Oregon. A 1982 sample indicated that Hudson River fish were also in better health than those from the San Francisco Bay-Delta (Whipple, et al., in prep.).

--Comparisons with samples from Lake Mead, Nevada are incomplete. However, fish from Lake Mead were definitely less parasitized and had lower pollutant burdens than those from the San Francisco Bay-Delta system. Lake Mead fish, on the other hand, had poor body condition, indicating starvation and insufficient food.

--Fish from the San Francisco Bay Delta had higher tissue concentrations of petrochemicals than did those from the Coos River, Oregon of the Hudson River, N.Y., except for some xylenes, which were relatively high in all populations of fish sampled.
--Fish from the Coos River had the lowest concentrations of chlorinated hydrocarbons and heavy metals.
--Fish from the Hudson River had higher concentrations of PCBs in gonads and muscle, and higher concentrations of chlordane and dieldrin in gonads than did San Francisco Bay Delta fish.

--Fish from the San Francisco Bay-Delta had higher levels of DDT and metabolites than Hudson River fish.
--Fish from the San Francisco Bay-Delta had higher levels of copper, zinc, cadmium and nickel in gonads; higher levels of copper, zinc, mercury and nickel in liver; Hudson River fish had higher levels of mercury in gonads and muscle and higher cadmium in liver.

--Lesions caused by host reactions to cestode (tapeworm) larval parasites were found only in fish from the San Francisco Bay-Delta. The concentrations of several other types of parasites were also higher in fish from the San Francisco Bay-Delta area than in fish from any other area. Hudson River fish had a totally different parasite assemblage than fish from the West coast.

--Egg condition in fish from the San Francisco Bay-Delta was significantly poorer than in fish from any other area sampled to date.

--Fish from the San Joaquin River were in poorer condition than those from the Sacramento River, showing decreased body condition, higher levels of cestode larvae, and higher concentrations of zinc and other metals.

--Results show that it is difficult to find a "control population" for comparison with the California population because all examined so far have been impacted in some way by pollutants and/or have significant environmental differences. Nevertheless, of all populations examined, the San Francisco Bay-Delta fish appear in the worst health.

2. Sex. Although most fish sampled were females, both sexes were impacted. Males had higher levels of petrochemicals and PCBs in the liver and primarily toluene in testes. Females had higher levels of petrochemicals in ovaries, higher levels of metals in all tissues and higher levels of PCBs in ovaries than males had in testes. Body and liver condition was poorer in males than in females. Because sexes were sampled differently, and due to strong sexual differences, sexes were also separated in the factor analyses.

3. After location and sex, a large proportion of the variation (in the selected variable data base) was accounted for by the factors of age, color pattern, sexual maturity, pollutants, parasites, the time in the prespawning season, and year. An example of this is given for the San Joaquin River, major sampling area from 1978-1982 in Table 1.

--Year. Concentrations of petrochemicals varied with year (1978 to 1982) of sampling (Table 2 & Appendix). Highest levels were found in striped bass in 1978, a year of several petrochemical spills prior to collection. Some fish from all years, however, contained petrochemicals (except small sample of 7 fish in 1982). Cestode larvae and lesions appeared to increase from 1978 to 1982. Egg condition was poorest in 1978 and correlated highly with petrochemical concentrations in the liver and ovaries.

--Age. Older fish were in poorer condition, with reduced fecundity, higher parasite loads and greater concentrations of some pollutants, particularly PCBs and metals.

--Color pattern type (genetic?). There were different growth and reproduction rates, body proportions and pollutant and parasite burdens in fish of different color-pattern types (e.g. solid-striped, broken-striped, etc.).

--Sexual Maturity. Spent females were significantly different than maturing females in having higher concentrations of petrochemicals in the liver (particularly toluene) and higher parasite burdens. Young prespawning females exhibited more alterations of egg maturation rate and resorption associated with petrochemicals. Young prespawners were also more likely to have open or only partly healed cestode lesions.

--Parasites. A significant proportion of adults (approximately 33 percent) had scars from cestode lesions. These fish were in generally poorer condition than those without scars, and had higher levels of pollutants, particularly petrochemicals. Young adults and juveniles showed open lesions from these parasites (Plate II). Many of the older fish had relatively large numbers of Anasakid roundworm larvae, sometimes in muscle. This worm can impact the health of man.

TABLE 1.-- Factor analysis results for striped bass. Proportion of variance in data base attributable to different factors, or sets of variables. San Joaquin River prespawning females (n=141 fish); 1978-1982. The name of the factor indicates the major variable(s) hypothesized to control the variance of other variables in the factor set.

FACTOR NO.	FACTOR NAME	PROPORTION OF VARIANCE FACTOR%	ACCUMULATIVE%
1	AGE, WET WEIGHT	11	11
2	COLOR PATTERN-GENERAL	10	21
3	SEXUAL MATURITY	8	29
4	CHLORINATED HYDROCARBONS: Gonad & Liver-DDT	7	36
5	PETROLEUM HYDROCARBONS: Gonad-Ethylbenzene, m-Xylene	6	42
6	CHLORINATED HYDROCARBONS: Gonad & Muscle-PCBs	6	48
7	PARASITES-CESTODE LESIONS	5	53
8	TIME, TEMPERATURE	5	58
9	YEAR	4	62
10	PETROLEUM HYDROCARBONS: Gonad-Toluene	4	66
11	BODY CONDITION	3	69
12	PETROLEUM HYDROCARBONS: Liver-Toluene, Gonad-Xylenes	3	72
13	METALS:Liver-(LSI)	2	74
14	PETROLEUM HYDROCARBONS: Liver-Benzene, m-Xylene, 1,2-Dimethylcyclohexane	2	76
15	PETROLEUM HYDROCARBONS Liver-Ethylbenzene, 1,2-Dimethylcyclohexane	2	78

INHERENT FACTORS	ENVIRONMENTAL FACTORS	
	NATURAL FACTORS	POLLUTANT FACTORS
32%	14%	32%

TABLE 2.--Comparisons among years in environmental variables, pollutant residues, inherent characteristics and egg condition of striped bass (Morone saxatilis). Based on factor analyses of prespawning female striped bass collected from April to June; San Joaquin River. Variables listed in the table were grouped by factor analysis into a factor called YEAR. Each variable has a correlation or factor loading on YEAR $\geq$ 0.30. Variables also varied significantly among years ($P \leq 0.05$) when tested with correlation analyses. Here, the actual mean values of the variables are omitted for simplification and the years are compared by assigning ranks from highest (1) to lowest (6) mean values.

VARIABLE (N)	1978 (59)	1979 (42)	1980 (21)	1981 (12)	1982* (7)	1983* (16)
Outflow	2	5	3	4	1	1(?)
Diversion	3	2	3	1	4	(?)
Salinity	3	1	2	3	4	4
Temperature	3	1	4	2	4	5
Metals-Gonad						
Copper	1	NS	3	2	NM	NM
Zinc	2	NS	3	1	NM	NM
Iron	3	NS	2	1	NM	NM
Metals-Liver						
Copper	NS	NS	2	1	NM	NM
Zinc	NS	NS	2	1	NM	NM
Iron	NS	NS	2	1	NM	NM
Petroleum HC- Monocyclic Aromatics:**						
Gonad	1	2	4	3	0	5
Liver	1	2	3	4	4	2
Petroleum HC- Alicyclic hexanes						
Total	2	1	0	3	0	2
Color Pattern	6	3	1	4	5	2
Age	2	4	5	1	3	5
Total Parasite Severity***	5	2	4	3	1	4
Tapeworm Larvae	5	3	2	4	1	5
Tapeworm Lesions	5	1	3	2	6	4
+Egg Condition	5	4	2	3	1	2(?)

(Fewer resorbed eggs and ovaries and abnormalities, less delayed maturation).

TABLE 2.-- FOOTNOTES AND DEFINITIONS

(?) = Data analyses incomplete. NS = Not sampled. NM=Tissues sampled, but not measured; archived. 0=No residues detected.

*Sample sizes in 1982 and 1983 were small because of reduced population size of prespawning adults. Data from 1983 recently added, and incomplete.

**Ranks for monocyclics based on both mean concentrations and number of different monocyclics present. Polycyclic aromatics, thiophenes in particular, were found to be highest in fish from the San Joaquin-Sacramento River delta when compared to fish from the Chesapeake Bay (USFWS; 1982).

***All types of parasites and host reactions.

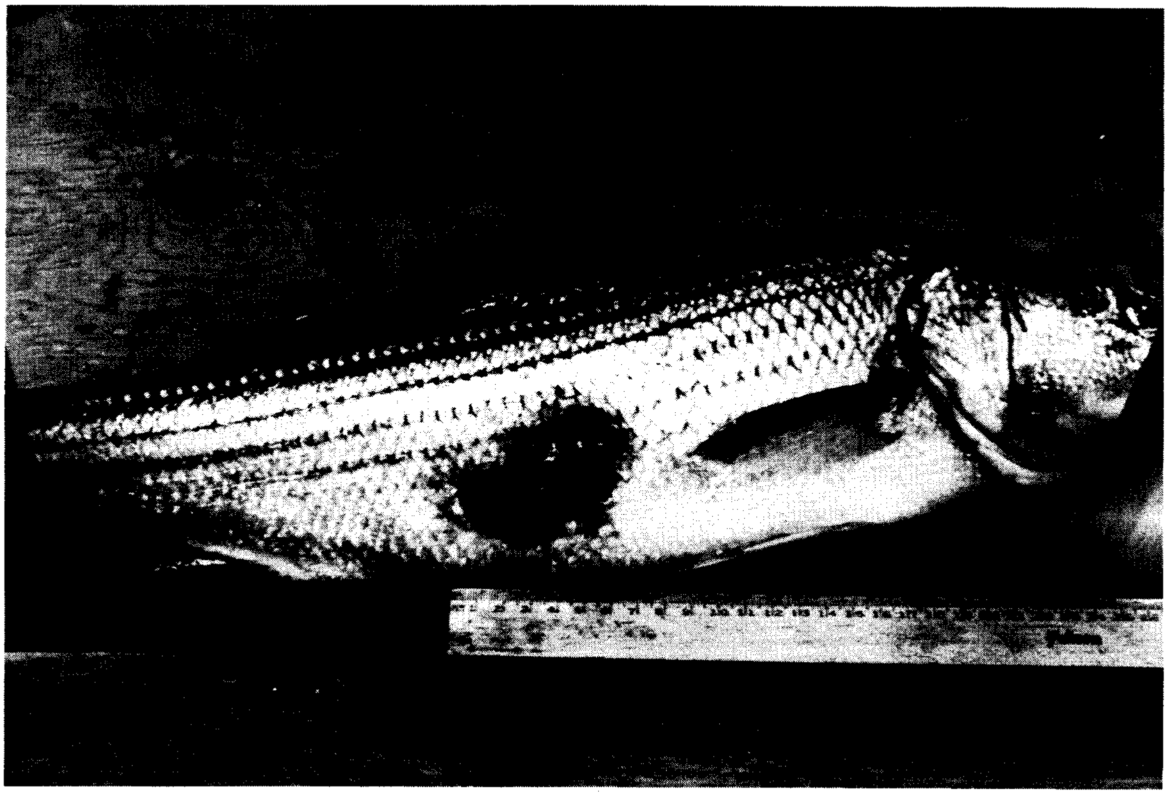


PLATE II. Lesioned striped bass. Open lesion a result of fish over-reacting to tapeworm larvae infection, followed by bacterial infection. In many striped bass, lesions may be healed with only scars showing on the surface.

4. Pollutants. Adult striped bass from the San Francisco Bay-Delta system contained relatively high levels of pollutants from several classes (Table 3, ranges; Whipple, et al., in prep. contains all means and standard deviations). Some of these pollutants showed strong correlations with poor health and condition, parasite burdens and impaired reproduction (Plates II and III).

--Petrochemicals. There were significant levels of monocyclic aromatic hydrocarbons, including benzene, toluene, ethylbenzene and three isomers of xylene, in tissues of striped bass. There were also significant levels of alicyclic hexanes. All these components are relatively toxic to fish (Benville, et al., in press). In addition to the effects on the fish associated with these compounds in liver and ovaries, the muscle tissue appeared to differentially accumulate toluene which has been shown previously to cause the "tainting" or bad flavor in other species. Other data (1982; U.S. Fish & Wildlife Service, unpublished data) show that there were also relatively high levels of polycyclic aromatics in adult striped bass. For example, levels of thiophenes in fish from the San Francisco Bay-Delta were higher than in fish from other areas. These compounds are carcinogenic.

High levels of petrochemicals in the fish correlated strongly with deleterious effects measured, including egg resorption and abnormal reproduction. An example of the proportion of egg resorption due to various factors, including, petrochemicals is shown in Figure 2. Reduced egg condition was particularly associated with high concentrations of ethylbenzene and 1,2-dimethylcyclohexane. These components are also among the more toxic and persistent of the low-boiling point petrochemicals.

High concentrations of benzene were associated with blood cell destruction, abnormal blood cell development and other blood parameters. There was also a correlation between the presence of lesion scars and petrochemical concentrations, particularly toluene and ethylbenzene. Concentrations of monocyclic aromatics in the tissues of field fish corresponded to levels reached in tissues of fish exposed in the laboratory to 50-100 ppb monocyclics (particularly benzene). The bioaccumulation was generally about one order of magnitude or 10X higher than the water concentrations (Whipple et al., 1981).

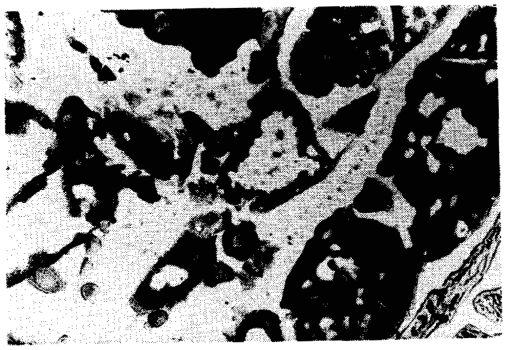
TABLE 3.--Concentration ranges of selected pollutant classes from San Francisco Bay-Delta estuary; data available to present. Tissue data from adult prespawning striped bass. Tissue concentrations in ug/g (ppm) wet weight for hydrocarbons, ug/g (ppm) dry weight for metals. Data modified from Whipple, et al, ms. in prep.

POLLUTANT CLASS	CONCENTRATION IN WATER (DISSOLVED) ug/L (ppb)	CONCENTRATION IN TISSUES (ppm) LIVER	GONADS	MUSCLE*
PETROLEUM HYDROCARBONS:				
Total Monocyclic Aromatics	1-200	0.01-10	0.01-10	0.01-7.5**
Total Alicyclic Hexanes	ND	0.02-5.0	0.02-10	0
Total Polycyclic Aromatics***	?	---Whole fish composite= approx. 2.0***		
CHLORINATED HYDROCARBONS:				
DDT	ND	0.09-0.12	0.10-0.68	?
DDD	ND	0.10-0.98	0.13-2.8	?
DDE	ND	0.03-3.1	0.10-12	?
Toxaphene	0.03-0.32	?	0.20-2.0	?
Total PCB's	ND	0.25-13	0.81-13	0.20-4.0
HEAVY METALS:				
Cadmium	0.08-0.20	0.29-9.4	0.08-0.71	0.18-1.3
Chromium	ND	0.61-3.3	0.51-2.2	0.31-2.2
Copper	1-4	1.0-220	1.0-35	0.10-12
Lead	.03-.12	0.09-0.37	0.06-0.89	0.11-0.62
Mercury	ND	0.49-13	0.03-0.96	0.06-1.6
Nickel	1-6	0.60-1.8	0.37-2.1	0.50-2.0
Zinc	2-6	7.0-250	3.0-310	1.0-66

* Muscle analyses with no skin attached.
** Mostly toluene in muscle.
*** Mostly thiophenes. Vassilaros, Preliminary Report, 3/11/1982; U.S. Fish & Wildlife Service.
ND = Not Detectable.

PLATE III. Eggs from ovaries of striped bass.

a. Normal egg in secondary to tertiary yolk stage.



b. Abnormal eggs, in varying stages of resorption. This condition is associated with petrochemicals.

c. Abnormal eggs, in late development stage, being resorbed. Note dark areas of melanin-containing melanomacrophages in intercellular areas. This condition associated with DDT.

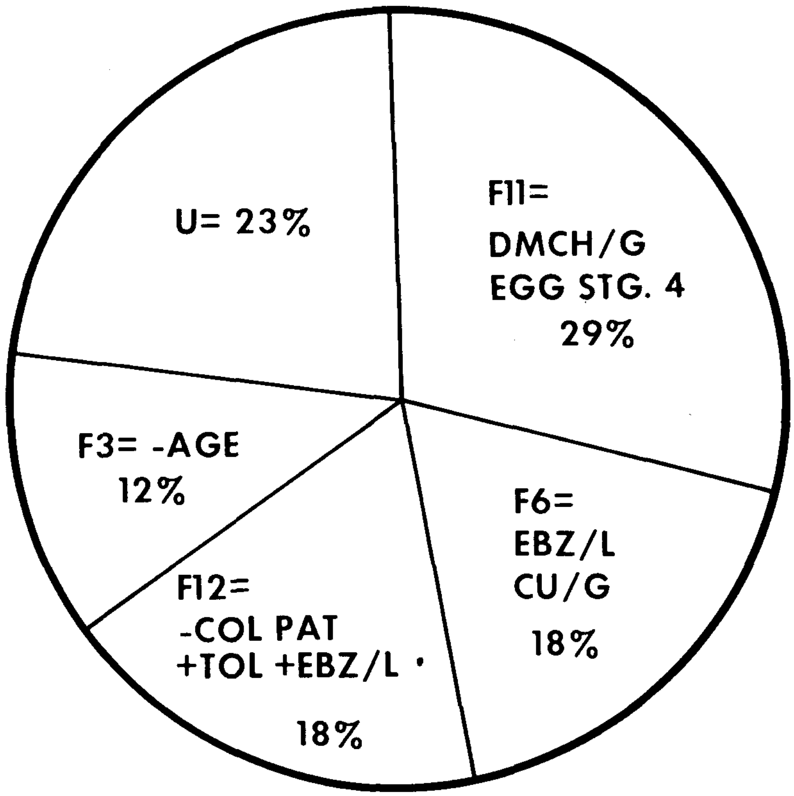


Figure 2. Proportion of total variance in egg condition (egg resorption) accounted for by different factors. Derived from factor equations in factor analysis. Most fish collected in this year had high levels of monocyclic aromatics in the liver and gonads.

EXAMPLE: San Joaquin River; 1978. N=59 females.

+EGG RESORPTION= .35F3 + .42F6 + .54F11 + .42F13 + U

U = Unidentified Variance; DMCH = 1,2-dimethylcyclohexane; EGG STG. = Egg Stage; EBZ = Ethylbenzene; CU = Copper; COL PAT = Color Pattern; TOL = Toluene.

--Chlorinated hydrocarbons. There were relatively high levels of PCBs, DDT and its metabolites, and other chlorinated hydrocarbons, including toxaphene, in liver and gonads of fish from the San Francisco Bay-Delta estuary (Table 3). Concentrations of some chlorinated hydrocarbons were at levels resulting in deleterious effects in other fish. The presence of DDT in liver and gonads (not metabolites DDD and DDE) was associated with abnormal egg development and necrosis of eggs. Delayed egg maturation rates (vitellogenesis) were associated with PCBs in ovaries .

--Heavy metals. There were relatively high levels of zinc and copper and other metals in adult striped bass livers and gonads (Table 3). The concentration of zinc and other metals correlated with decreased body and liver condition in some fish. Cadmium, nickel, zinc and copper also correlated with reductions in egg viability in the 1981 San Joaquin River sample. High levels of other metals were found, in particular mercury in some fish.

--Several pollutants, particularly chlorinated hydrocarbons, polycyclic aromatics, cadmium and mercury, were found at levels sufficiently high not only to affect the health of the fish but also to potentially affect human health.

--Pollutant interaction. Initial results show pollutant interactions were affecting the fish. This work is continuing with additional data from samples in 1981. Data show that hydrocarbons and metals interact to produce deleterious effects on egg and liver condition.

--Pollutants most implicated in deleterious effects on fish are, in order: ethylbenzene, 1,2-dimethylcyclohexane, benzene, toluene; DDT, copper, zinc, cadmium, nickel, mercury. Other pollutants may be involved, however, which we were unable to measure. The relevant fact is, there are strong associations of these pollutants with decreased condition, growth, reproduction and possibly survival of striped bass.

5. Laboratory experiments to determine the effects of representative pollutants (benzene and zinc) tended to corroborate the observations of effects in the field. Laboratory exposures equivalent to high chronic water levels in field resulted in tissue concentrations similar to those

in field fish (magnitude of concentration of benzene and/or other total MAH was approximately 10X). The effects on condition of tissues and organs, and other parameters were also similar. The following were some major results.

Adults:
--Benzene induced egg resorption in prespawning females similar to that in field fish. Fish with higher pollutant burdens when exposed to benzene were most seriously affected.

Juveniles:
--Uptake of benzene and zinc appeared to be antagonistic--high concentrations of benzene in the liver were related to low concentrations of zinc.

--Benzene appeared to accelerate and increase the inflammatory response to roundworm larvae.

--Benzene was associated with blood cell destruction followed by increased production of immature red and white blood cells.

--Zinc was associated with decreased liver condition (LSI).

--Zinc was associated with decreased levels of serum proteins hypothesized to be immunoglobulins.

--Fish exposed to benzene or zinc had higher levels of protozoan gill parasites than controls.

--The effects of benzene and zinc together resulted in greater effects on the fish than either pollutant alone, including the following.

- -Inflammatory response to parasitic worms was accelerated.
- -Blood cells and serum proteins were more deleteriously affected.
- -Liver tissue was more deleteriously affected.

6. Population Effects. On a population level, the following summarizes potential effects of chronic pollution, from our work to date. These effects indicated decreased growth, reproduction and survival of the striped bass population.

Although influences other than toxic chemicals and parasites (e.g., Delta outflow and diversion) are undoubtedly involved in the decline of the striped bass fishery, the following hypotheses were also supported by the study findings.

--There has been a reduction in numbers of larvae to young-of-the-year juveniles. Laboratory studies showed that larvae accumulate high levels of toxic pollutants (e.g., benzene) with deleterious effects. These studies should be corroborated in the field. We estimate that toxic pollutants and parasitic cestode lesions may also increase mortality of juveniles and subadults.

--There has been a reduction in the number of spawning adults. The poorer condition of older adults is at least partially due to the combined effects of parasitism and pollutants. It is also likely that increased mortality of adults has occurred, leading to fewer older fish which normally have the highest fecundity.

--There has been a reduction in the number of eggs (fecundity) per spawner. We estimate that the reduction in fecundity per spawner, due to the combined effects of pollutants and parasitism, was at least 50 percent in 1978. This reduction was assessed from measurements of:

- delayed rate of maturation (vitellogenesis)
- partial egg resorption
- complete egg resorption in maturing ovary
- no ovarian maturation in sexually mature fish
- egg death
- reduction in number of eggs (fecundity)

Additional mortality may have occurred in embryos and larvae after spawning, resulting in even further reduction in survival.

7. Ecosystem processes. The striped bass population is a major component of the San Francisco Bay-Delta ecosystem, particularly in past years prior to its decline. It would be of interest to do further work on the relationship of population dynamics of this species to the flow dynamics of the estuary. This would be of critical importance in making future management and water quality decisions. Preliminary to proposing further work in this area, we are gathering available data on hydrographic, climatological and water quality parameters, and on other species of fish and organisms in the striped bass food chain. Some preliminary analyses of relationships of these parameters to those we measured in the striped bass from 1978 to 1982 have been completed. We have proposed further synthesis work in this area in the future.

V. STATUS OF RESEARCH PROPOSED FOR FY83-85

(Research terminated under OMPA, 1983)

1. Complete all data analyses, including multivariate factor analyses and covariance analyses. Finish graphical representations of the data. (Continuing)
2. Continue data synthesis and publication of results from this project. (Continuing)
3. Perform more lab experiments on the interactive effects of pollutants. (No funding available for this in NMFS)
4. Refine data base, selecting appropriate variables to measure in monitoring the health of the striped bass (or other fishes). Determine a statistical method, using discriminant analysis, to distinguish healthy from sick fish or fish impacted by pollutants. (Continuing)
5. Recommend an annual monitoring regime to be adopted by the State of California for assessing the health of the striped bass population. Train them in collection, autopsy, synthesis and statistical analysis techniques. Assist in writing of monitoring manual. (Completed)
6. Develop a quantitative model of the striped bass population in cooperation with other agencies and universities involved in striped bass research. Add to the model a means of assessing and predicting the impact of pollutants. (Continuing)

7. Continue work with the State to accumulate additional data on outflow, diversion, climatological factors, pollutants and other water quality parameters which might correlate with our field and laboratory data for striped bass. (Continuing)

8. Recommend to OMPA the implementation of a cooperative study of the San Francisco Bay-Delta ecosystem as a representative ecosystem for studying the impact of anthropogenic activity. NMFS would cooperate with several other agencies and universities in this project. (Not funded or started)

9. Apply our research results to other areas, determining the health of the striped bass and suggesting problems which might be addressed in other populations, e.g., cooperative work with East Coast researchers on the Hudson River and Chesapeake Bay populations. (Hudson research completed, other not funded).

10. Apply the results of this research to other fish species. Suggest potential methods for assessment of shellfishes, keeping in mind habitat and behavioral variation in different species. (Not funded)

11. Participate in cooperative efforts of publication and reports to the public and fisherpeople. Make recommendations for fisheries management and water quality decisions as needed or required by OMPA, NMFS Habitat Protection, NMFS Southwest Fisheries Center, California SWRCB, CDF&G and others. (Continuing)

VI. SPECIFIC RECOMMENDATIONS (July 15, 1982)

A). To NOAA(OMPA and NMFS):

1. Low-boiling point petrochemicals at low chronic levels apparently can impact a fish population by affecting condition, reproduction and survival deleteriously. We recommend that further work be implemented on the sources, fates and ecosystem processes affecting these compounds. We believe the long-range effects of chronic concentrations of low-boiling point petrochemicals have been underestimated.
2. We recommend monitoring and regulating levels of low-boiling point aromatic hydrocarbons in both marine organisms and water, rather than continuation of the inadequate "total oil and grease" measurement, which does not include these compounds.
3. Utilize our results in assessing impacts of petrochemicals on fishes, particularly on reproduction.
4. Implement or support monitoring water for pollutants which were also found in striped bass tissues, including chlorinated hydrocarbons.
5. Continue to support the remainder of our synthesis work on striped bass in the San Francisco Bay area, and support comparisons with populations in other areas.

6. Take a lead role in implementing an ecosystem-level research program for the San Francisco Bay-Delta, involving all agencies cooperatively in this area. This ecosystem is already impacted by several anthropogenic activities of importance in determining long-range effects, e.g., petrochemicals, water diversion and reduced flows; it will be further impacted by proposed salt drain inputs and increased oil transport activities associated with OCS development of the California coast.

B). To California Department of Fish and Game:

1. Meet with COSBS, NMFS, and SWRCB personnel in November, 1982 to discuss and implement the following recommendations.
2. Continue annual monitoring of prespawning striped bass simultaneously with the sampling program now in existence. Use selected criteria for determining health of other stages of striped bass for existing sampling programs. We will provide recommendations of what and how to sample; we will also train personnel and provide a monitoring manual.
3. Take subsamples and analyze for selected pollutants.
4. Cooperate with NMFS and SWRCB in the formulation of a quantitative model of effects of pollutants on the striped bass population.

C). To California State Water Resources Control Board:

1. Work with Regional Boards to take appropriate measures to reduce the discharge of petroleum hydrocarbons (e.g., benzene, xylene) into San Francisco Bay-Delta receiving waters.
2. Cooperate with Regional Boards and the U.S. Coast Guard in development of improved oil and chemical spill control measures to minimize discharges to the San Francisco Bay.
3. Request the Department of Food and Agriculture to investigate the feasibility of reducing the amount of xylene and other petroleum hydrocarbons discharged into San Francisco Bay-Delta receiving waters. Five of the top ten pesticides used in Delta counties in 1981 were petroleum hydrocarbons. Over two million pounds of these substances were reportedly used as active pesticides exclusive of their use as carrier solvents.
4. Determine a). the relative input of zinc into San Francisco Bay-Delta waters from man-made and natural sources; and b) the technical and economic feasibility of further reduction of these discharges.
5. Request CDF&G to conduct an annual adult striped bass health-monitoring program using the health index method developed by COSBS.

6. Recommend to CDF&G that striped bass license fees support field studies to assess effects of toxic pollutants on striped bass egg and larval development. We have proposed the use of a floating laboratory at striped bass spawning areas for this work.

7. Request that CDF&G complete toxic chemical analyses of striped bass collected during 1981-1982. COSBS focused on 1978-1980 fish collections as a data base. Completion of these analyses would extend the documented data base on adult striped bass health from three years to five years.

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IX. APPENDIX

SUMMARY OF RESULTS FOR FIELD SAMPLING OF PRESPAWNING STRIPED BASS - 1983 SAN JOAQUIN RIVER

For several years, the Physiological Ecology Investigation, (PEI), has studied chronic pollutant effects on the parasitism and condition of striped bass in the San Francisco Bay-Delta estuary. During this study, techniques were developed and variables selected which showed an association of health of striped bass from the field with their parasite and pollutant burdens. In particular, low-boiling point petrochemicals occurring in tissues of prespawning striped bass are correlated with poor egg condition and reproduction and parasite lesions.

PEI staff have cooperated with the State of California (CDF&G, SWRCB) in portions of the study (Cooperative Striped Bass Study; COSBS), including the annual sampling of prespawning striped bass during their spawning migration through the San Joaquin-Sacramento Delta.

In 1983, the monitoring of the health and pollutant burden of striped bass was continued by members of the Stockton branch of CDF&G, after training by Dr. Jeannette Whipple, Brian Jarvis and Rahel Fischer of the Physiological Ecology Investigation. Most of the samples and data from the collection and autopsy of 36 prespawning striped bass from the San Joaquin River have now been analyzed.

Initial results show a number of differences between the current sample and those from previous years (Table A). The temperature and salinity of the water at time of collection was the lowest recorded since sampling began in 1978. The lower temperature and salinity are associated with a higher outflow than in previous years; the temperature during time of collection was approximately 14.5 deg C or 2 deg C lower than the mean of previous spawning seasons (April-June).

Only petrochemical pollutants have been measured for 1983 so far, although both muscle samples for mercury analysis and liver, gonad and muscle samples for chlorinated hydrocarbon analysis have been archived. Monocyclic aromatic and alicyclic hexane hydrocarbons in fish gonads were at lower levels than in most previous years (except for 1982), but higher in livers than in fish collected in other years (eg. all years except for 1978 and 1979). A lower percentage of fish contained petroleum hydrocarbons, however, than in previous years. The primary monocyclics found in the liver were toluene and o-xylene; the primary alicyclic hexanes were different isomers of dimethyl cyclohexane. The pattern of occurrence of these hydrocarbons is "typically" observed in the chronic petrochemical pollution of the San Francisco Bay-Delta estuary.

The effects of this pattern of petrochemical contamination appear to be less deleterious than when the pattern includes a higher proportion of the lower boiling point aromatics such as benzene, toluene, ethylbenzene, m-xylenes and p-xylenes together with 1,2-dimethyl cyclohexane. The latter pattern appears associated with gasoline spills, and has a higher correlation with deleterious effects such as reduced egg condition.

Fish had fewer parasitic roundworm larvae, but still exhibited relatively high numbers of cestode larvae and 50% of the fish sampled bore one or more lesions (open, healing & healed) resulting from the inflammatory response to cestode larvae. Other measures of the health of the fish and their organs indicated similar problems but, except for lesion damage, parasitic damage appeared less than in previous years.

The sample included 20 males and 16 females and fish were generally younger than those captured during most other years. The mean age of the fish sampled (4.92 yrs) was equivalent to those sampled in 1980 (4.95 yrs). Females captured in 1980 and 1983 were younger (mean = 5 yrs) than those captured in other years (mean greater than 5 yrs). This is probably part of the reason for their relatively good condition. Previous analyses show that overall condition in adults decreases in older females and males.

None of the females showed complete ovarian resorption from gross observations, one appeared delayed and two were immature. None were spent. Generally, females appeared somewhat delayed in egg maturation, probably due to the lower temperatures.

Resorbing eggs in ovaries of females were observed grossly. Slides of these ovaries, however, have not been completed and conclusions about the degree of egg resorption will not be made until completion of histological examination.

On the whole, autopsy data indicate that the fish were healthier than those collected in previous years, particularly in 1978 and 1981, but the low adult population size reflected by the difficulty in sampling fish, especially females, indicates a continued problem with the fishery. Few large adult females were captured during the 1983 sampling period and there still appears to be fewer large adult females spawning. It is possible that larger fish migrated from offshore into the delta to spawn later than mid-June and were missed by the sampling effort. We recommend that in the future, this possibility be examined in years of high outflow and lower temperatures, and that the sampling period be extended.

The continued existence of low-boiling point petrochemicals in the tissues of even the younger adults also indicates a continued problem with petrochemical pollution.

This monitoring program will continue in the future with CDF&G taking the lead in analyzing the health of bass in relation to pollutant burdens. The research will be funded by the SWRCB under the direction of the Aquatic Habitat Program. Dr. Bruce MacFarlane of PEI has presented our recommendations to the committee for continued monitoring of striped bass (MacFarlane and Whipple, 1984). Further recommendations for data analyses and assessment of the health in relation to the previous years are forthcoming.

The first draft of a manuscript on monitoring and autopsy techniques entitled "Histopathological Manual for Monitoring Striped Bass in Relation to Pollutant Burdens," by Jeannette Whipple, Marvin Jung, R. Bruce MacFarlane and Rahel Fischer has been completed and is slated for publication as a NOAA Technical Memorandum.

TABLE A. Comparisons among years in environmental variables, pollutant residues, inherent characteristics and egg condition of striped bass (*Morone saxatilis*). Based on factor analyses of prespawning female striped bass collected from April to June; San Joaquin River. Variables listed in the table were grouped by factor analysis into a factor called YEAR. Each variable has a correlation or factor loading on YEAR $\geq$ 0.30. Variables also varied significantly among years ($P \leq 0.05$) when tested with correlation analyses. Here, the actual mean values of the variables are omitted for simplification; the years are compared by assigning ranks from highest (1) to lowest (6) mean values.

VARIABLE (N)	1978 (59)	1979 (42)	1980 (21)	1981 (12)	1982* (7)	1983* (16)
Outflow	2	5	3	4	1	1(?)
Diversion	3	2	3	1	4	(?)
Salinity	3	1	2	3	4	4
Temperature	3	1	4	2	4	5
Metals-Gonad						
Copper	1	NS	3	2	NM	NM
Zinc	2	NS	3	1	NM	NM
Iron	3	NS	2	1	NM	NM
Metals-Liver						
Copper	NS	NS	2	1	NM	NM
Zinc	NS	NS	2	1	NM	NM
Iron	NS	NS	2	1	NM	NM
Petroleum HC- Monocyclic Aromatics:**						
Gonad	1	2	4	3	0	5
Liver	1	2	3	4	4	2
Petroleum HC- Alicyclic hexanes						
Total	2	1	0	3	0	2
Color Pattern	6	3	1	4	5	2
Age	2	4	5	1	3	5
Total Parasite Severity***	5	2	4	3	1	4
Tapeworm Larvae	5	3	2	4	1	5
Tapeworm Lesions	5	1	3	2	6	4
+Egg Condition (Fewer resorbed eggs and ovaries and abnormalities, less delayed maturation).	5	4	2	3	1	2(?)

TABLE A.-- FOOTNOTES AND DEFINITIONS

(?) = Data analyses incomplete. NS = Not sampled. NM=Tissues sampled, but not measured; archived. 0=No residues detected.

*Sample sizes in 1982 and 1983 were small because of reduced population size of prespawning adults. Data from 1983 recently added, and incomplete.

**Ranks for monocyclics based on both mean concentrations and number of different monocyclics present. Polycyclic aromatics, thiophenes in particular, were found to be highest in fish from the San Joaquin-Sacramento River Delta when compared to fish from the Chesapeake Bay (USFWS; 1982).

***All types of parasites and host reactions.