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THE IMPACTS OF ESTUARINE DEGRADATION AND CHRONIC POLLUTION ON POPULATIONS OF ANADROMOUS STRIPED BASS (MORONE SAXATILIS) IN THE SAN FRANCISCO BAY-DELTA, CALIFORNIA: A SUMMARY

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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 warrent 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 is continual or chronic input of pollutants at lower levels. For example, in the 1960s, 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 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.

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, and even under completely natural conditions. Natural perturbations may exceed those induced by man's influence. For example, in 1983 the El Nino off the coast of California resulted in warm water conditions and significant alterations in distribution and survival of coastal fishes. 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, particularly in estuarine ecosystems such as San Francisco Bay-Delta, 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 requires a long-term, cooperative effort. The goal of the Physiological Ecology Investigation at Tiburon Laboratory has been to contribute to an understanding of the long-term ecological consequences of pollutant effect on aquatic resources. Specifically, we were 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 20 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.

In order to to describe source 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 organisms which appeared to correlate with pollutant burdens. Initially, the measurements were on several levels -- from the biochemical to the subsample (population) level. After preliminary studies, the most sensitive variables were delineated. Selected groups of variables (factors) were then designated as measures of body conditions, liver condition, and egg condition. Eventually, these factors coefficients were translated into an overall assessment of the health of the organism. The coefficients also can be used to estimate quantitative effects on a population level, such as reductions in growth, reproduction, and survival. Some of the measurements are also more sensitive and consequently more effective in giving us an early warning that individuals and/or the population are 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.

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

Anthropogenic Activities

1. Which pollutants are potentially impacting our marine resources, including fisheries?

2. What are the sources of these pollutants?

Marine Ecosystem Processes

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

Consequences Attribute to Anthropogenic Activities

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?

Judgemental Processes

7. What are the quantitative reductions in populations in growth, reproduction, and survival attributable to pollutants?

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 Compartments

10. Other compartments in the conceptual representation

Figure 1 are within the purview of management

*OMPA is now the Ocean Assessment Division of the National Oceanic and Atmospheric Administration (NOAA).

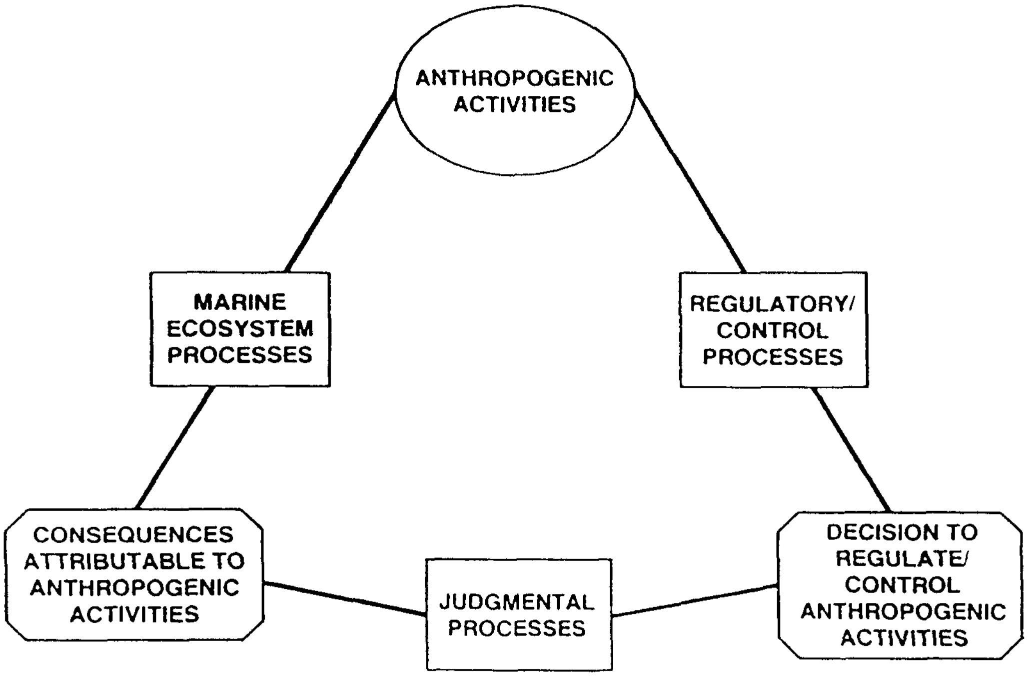

Figure 1. Conceptual representation of Office of Marine Pollution Assessment Research Program. From R.E. Burns, January 19, 1982. "Office of Marine Pollution Assessment (OMPA) Financial Assistance for Marine Pollution Research."

In June 1980, the Cooperative Striped Bass Study (COSBS) team was organized to examine different aspects of the above questions (Jung and Bowes, 1980; Jung et. al. 1981; Whipple, Crosby, and Jung, 1983; Whipple et. al. 1984; Jung, Whipple, and Moser, 1984).

At the Tiburon Laboratory, we concentrated on the affects 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 Resource 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). The California Department of Fish and Game (CDFG) also participated in management decisions (10 above).

There were a number of excellent reasons for selecting the striped bass as a model species in the San Francisco Bay-Delta ecosystem. The striped bass 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 accumulates pollutants throughout the food chain. Striped bass are also very euryhalone, occurring in offshore marine areas, estuaries, and in freshwater. They occur on all coasts of the United States and have been introduced in other countries. This fishery is also of great commercial and recreational value.

The major reason for studying striped bass, however, was the long-term decline on 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 because of the interactive deleterious effects of anthropogenic factors, such as water diversion and pollution.

California Department of Fish and Game (CDFG) biologists have studied the striped bass population in the San Francisco Bay-Delta estuary for about 40 years. Their work provided the framework for studies of this species, particularly in the field. The initial results of CDFG 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 of juveniles. On the basis of these correlations, CDFG was able for some years to predict survival of juveniles and recruitment to the fishery. These predictions became less reliable in later years (since approximately 1975), although outflow and diversion remain major controlling factors in survival. Figure 2A shows the decline in survival to juvenile striped bass in both the Suisun Bay and central Delta nursery areas; Figure 2B shows the decline in adult striped bass (from Stevens et. al. 1985).

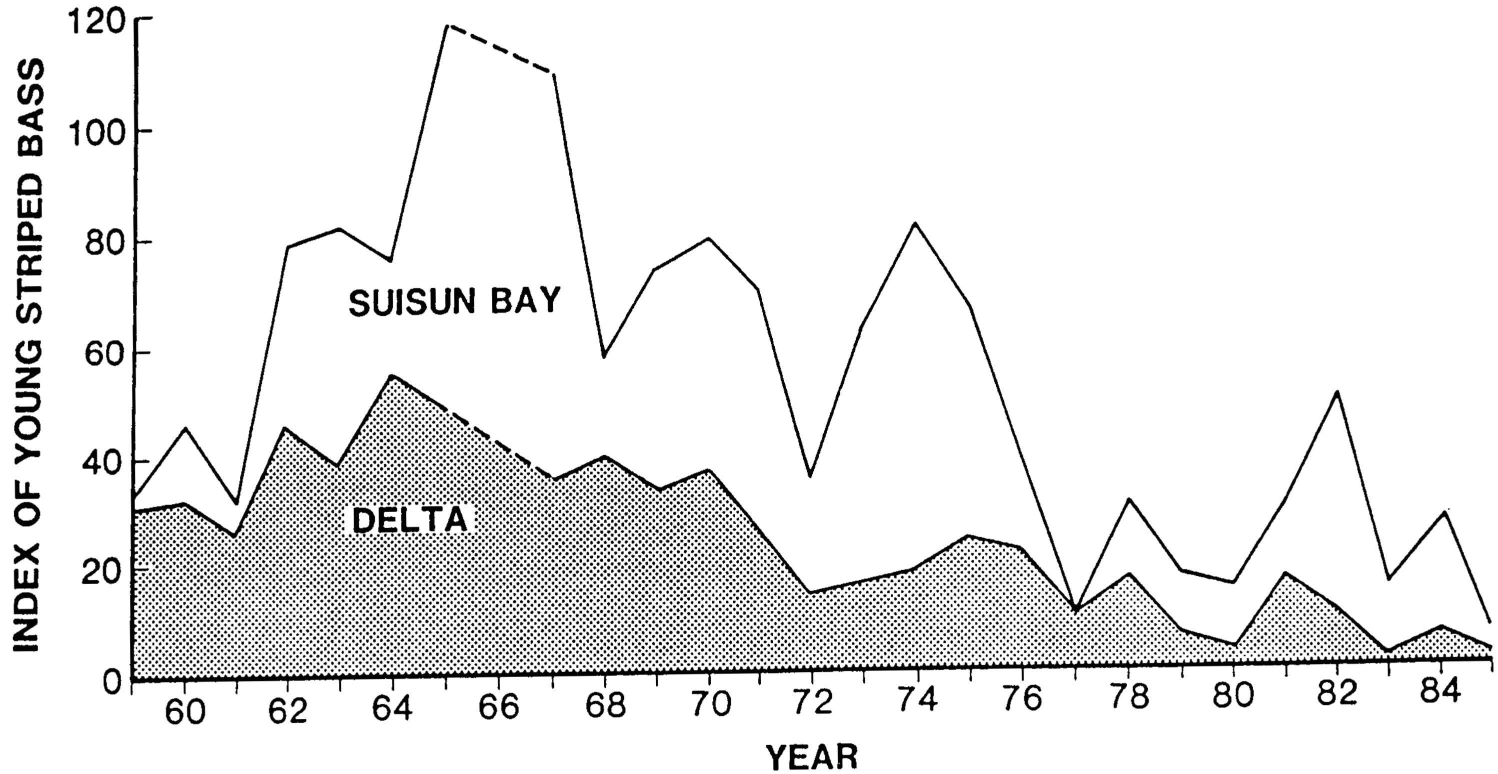

Figure 2A. Decline in the striped bass (*Morone saxatilis*) population in the San Francisco Bay-Delta area (Stevens *et al.*, 1985). Young-of-the-year striped bass (juveniles); change in the index with year. Decline pronounced since 1975.

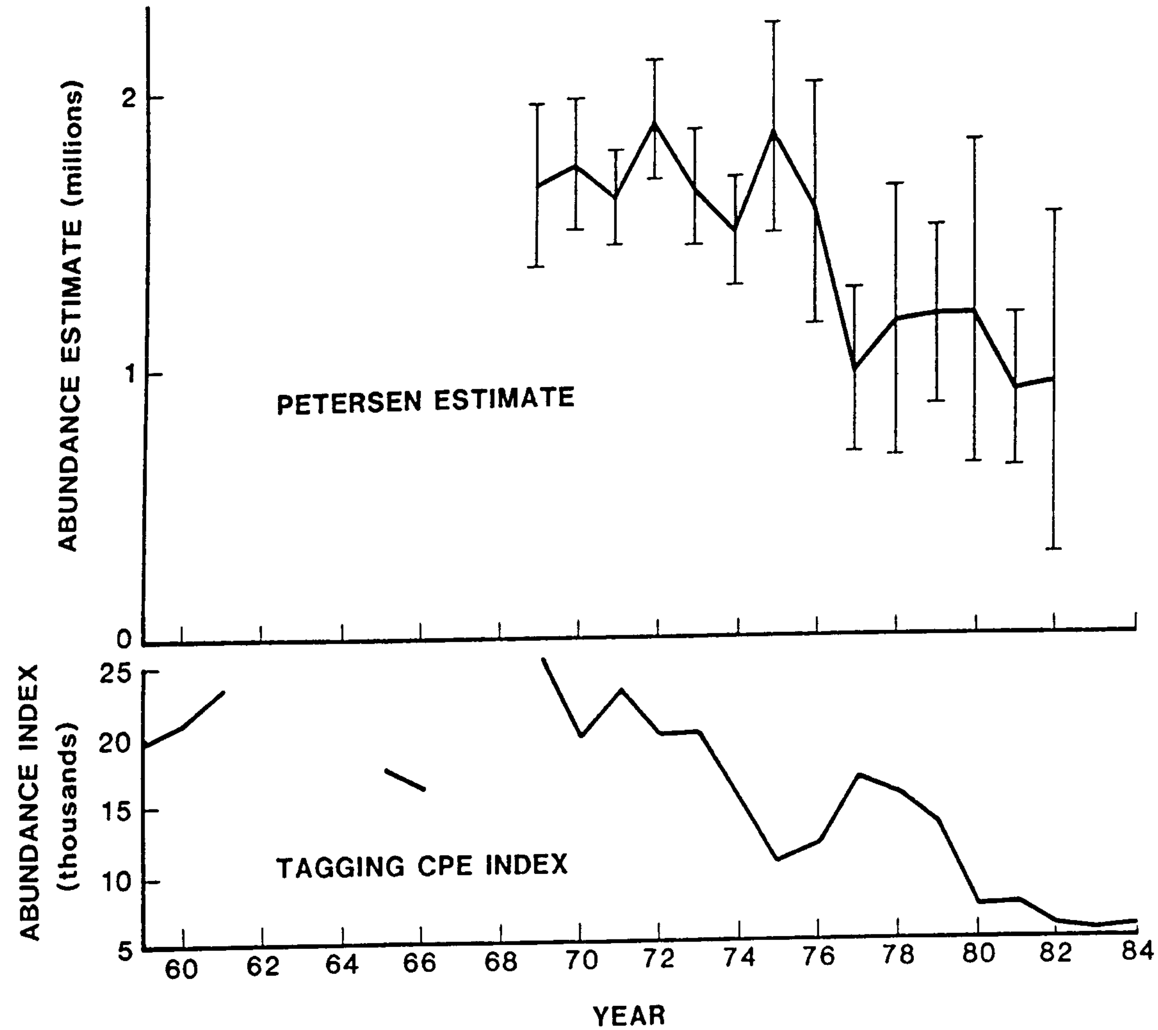

Figure 2B. Two measures of adult striped bass population size; change in Peterson and catch-per-unit effort estimates of adult bass with year. Decline obvious from 1975. (Stevens <u>et.al</u>., 1985)

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.

To begin research, we derived the following specific 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 and more impacted by pollutants.

4. To determine the condition or health of striped bass caught in the field, and if in poor condition, to determine correlation 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.

The results here are updated from a previous report (Whipple, 1984) and summarized from a manuscript in preparation: "A multivariate approach to studying the interactive effects of inherent and environmental factors, including pollutants, on striped bass in the San Francisco Bay-Delta, California" by Jeannette A. Whipple, R. Bruce MacFarlane, Maxwell B. Eldridge, and Pete E. Benville, Jr.

Methods

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, et. al. 1984). Approximately 350 characteristics of the fish were examined initially -- 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 muscles 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, including principal component factor analysis (Nie, 1975), were applied to the field data to determine correlations between sets of variables describing conditions and the pollutant burdens. The following summary of results includes correlations and regressions found significant in multiple regression analyses at the $P < .05$ level or less. Several laboratory experiments were performed to verify correlations seen in field fish (Jung, Whipple, and Moser, 1984).

Results and Discussion

The following summary of 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.

- Comparisons with samples from Lake Mead, Nevada showed that 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 and a greater number of separate petrochemical compounds than did those from the Coos River, Oregon or 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 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 or tapeworm larval parasites (<u>Lacistorhynchus tenuis</u>) were found only 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.

- Fish from 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.

- o 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. <u>Sex</u>. Although most fish sampled were females, both sexes were impacted. Because sexes were sampled differently, and because of strong sexual differences, sexes were also separated in the factor analysis.

   - o Males had higher levels of petrochemicals and PCBs in the liver and primarily toluene in testes.

   - o 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.

   - o Body and liver condition was poorer in males than in females.

3. <u>Other Factors</u>. 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, year, the time in the prespawning season, and parasites. An example of factor analysis results is given for the San Joaquin River from 1978-1983 Table 1.

   - o Year. Concentrations of petrochemicals varied with year (1978 to 1984) of sampling (Table 2). Most separate compounds and higher levels were found in striped bass in 1978, 1979, and 1981. Some fish from all years, however, contained petrochemicals (except small sample of 7 fish in 1982). Cestode larvae and lesions varied yearly and related to age and sexual maturity of adults. Egg condition was poorest in 1978, 1979, and 1981, correlating significantly with petrochemical concentrations in the liver and ovaries.

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

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

Table 1. -- Factor analysis results for prespawning striped bass. Proportion of variance in data base accounted for by different factors, or sets of variables. San Joaquin River prespawning females (n=157 fish); 1978-1983. The names of factors indicate the major controlling variables in factor sets.

FACTOR NO.	FACTOR NAME	PROPORTION OF VARIANCE FACTOR %	ACCUMULATIVE %
1	AGE, WET WEIGHT	10	10
2	COLOR PATTERN-GENERAL	9	19
3	SEXUAL MATURITY	8	27
4	PETROLEUM HYDROCARBONS: (Gonad & Liver-o-Xylene)	7	34
5	YEAR	6	40
6	CHLORINATED HYDROCARBONS: (Gonad & Liver-PCB's)	5	45
7	CHLORINATED HYDROCARBONS: (Gonad & Liver-DDT)	5	50
8	TIME, TEMPERTURE	4	54
9	PARASITES-CESTODE LESIONS	4	58
10	YEAR	3	61
11	METALS:Liver-(LSI)	3	64
12	PETROLEUM HYDROCARBONS: (Gonad-Ethylbenzene, m-Xylene)	3	67
13	SEXUAL MATURITY	3	70
14	PETROLEUM HYDROCARBONS: (Liver-Ethylbenzene, 1,2-Dimethylcyclohexane)	2	72
15	BODY CONDITION	2	74
16	PETROLEUM HYDROCARBONS: (Liver-Benzene, m-Xylene, 1,2-Dimylcyclohexane)	2	76

INHERENT FACTORS	ENVIRONMENTAL FACTORS: NATURAL FACTORS	ENVIRONMENTAL FACTORS: POLLUTANT FACTORS	UNIDENTIFIED
32%	17%	27%	24%

Table 2.-- Year factor; ranked differences among years in inherent characteristics, environmental variables and condition of striped bass. Based on factor analyses of prespawning female striped bass collected from April to June; San Joaquin River. Loadings on factors greater than or equal to 0.30. Ranked from highest (1) to lowest (7) total mean values. NS = not sampled; NM = sampled, but not measured.

YEAR1 (N) VARIABLE	1978 (59)	1979 (42)	1980 (21)	1981 (12)	1982 (7)	1983 (16)	19842 (21)
Inherent Factors							
Age	2	4	7	1	3	6	5
Color Pattern	6	3	1	5	4	2	2
(Stripe Breakage)	(8.5)	(9.9)	(10.5)	(9.0)	(9.1)	(10.1)	(10.1)
Environmental Factors							
Outflow	4	5	3	5	2	1	?
Diversion	2	1	2	1	3	4	?
Petroleum HC- Monocyclic Aromatics:							
Gonad	4	2	5	1	6	3	NM
Liver	3	5	6	1	4	2	6
Petroleum HC- Alicyclic hexanes							
Gonad	3	2	5	3	5	1	5
Liver	3	2	5	4	5	1	5
Metals-Gonad							
Copper	1	NS	3	2	NM	NM	NM
Zinc	2	NS	3	1	NM	NM	NM
Metals-Liver							
Copper	NS	NS	3	2	NM	NM	1
Zinc	NS	NS	3	2	NM	NM	1
Cadmium	NS	NS	NS	2	NM	NM	1
Chromium	NS	NS	NS	1	NM	NM	2
Mercury	NS	NS	NS	1	NM	NM	2
Selenium	NS	NS	NS	2	NM	NM	1
Parasites							
Tapeworm Larvae	6	5	2	6	1	4	3
Tapeworm Lesions	4	1	3	2	5	1	4
Tapeworm Rafts	6	1	4	5	6	3	2
Total Parasite3 Severity	2	2	5	4	1	4	3
Condition Factors							
+Egg Resorption	1	2	4	2	6	3	5

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

1 Sample sizes in 1981 and 1982 were small because of reduced population size of prespawning adults.

2 Some outflow and diversion data not available.

3 All types of parasites and host reactions.

- o 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.

- o Parasites. A significant proportion of adults (approximately 33 percent had scars from cestodes-induced 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 (Figure 3). Many of the older fish had relatively large numbers of Anasakid roundworm larvae, sometimes in muscle. This worm can impact the health of man.

4. <u>Pollutants</u>. Adult striped bass from the San Francisco Bay-Delta system contained relatively high levels of pollutants from several classes (Table 3. ranges; Whipple, <u>et. al</u>. 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.

   - o 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 and Korn, 1977; Benville <u>et. al</u>. 1985). 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 (Vassilvos, <u>et. al</u>. 1982) 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 (Figure 4) and abnormal reproduction. The mean egg resorption by year, comparing locations, is shown in Figure 5. In 1982, sample size (7) was

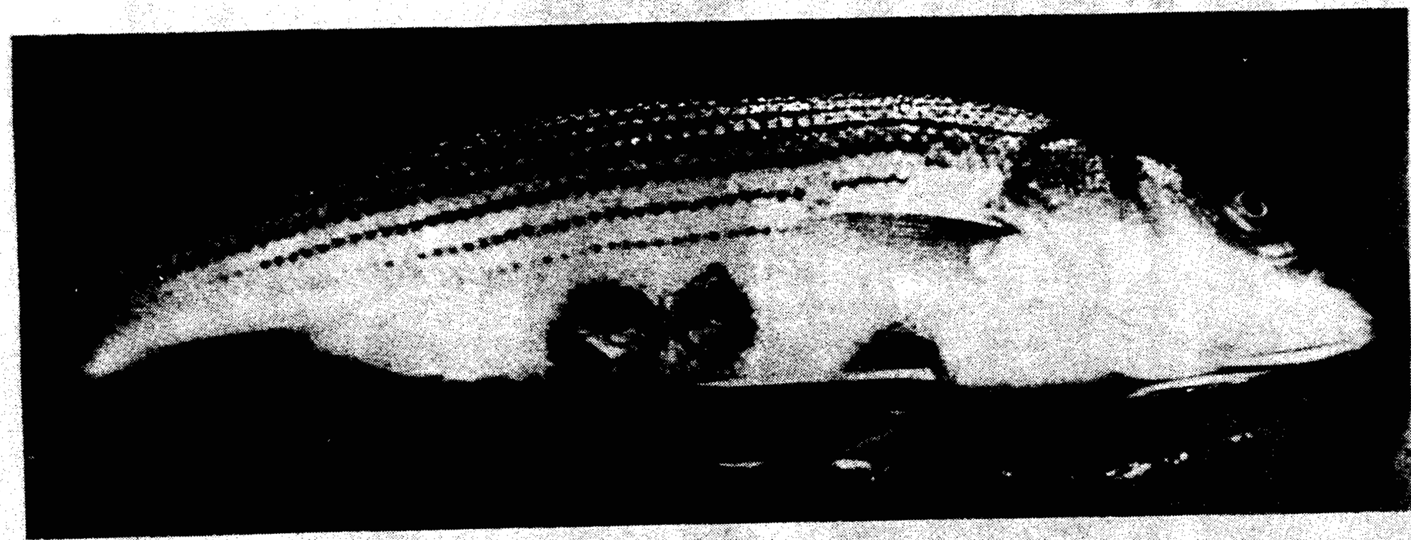

Figure 3. Lesioned striped bass. Open lesion is a result of fish over-reacting to tapeworm larvae infection, followed by bacterial infection. In older bass, lesions may be healed with only scars showing on the surface.

Figure 4A. Eggs from ovaries of striped bass.
Normal eggs in secondary to tertiary yolk stage.

Figure 4B. Abnormal eggs, in varying stages of resorption. This condition is associated with petrochemicals.

Figure 4C. Abnormal eggs, in late development stage, being resorbed. Note dark areas of melanin-containing melanomacrophages in intercellular areas. This condition is associated with DDT.

REPRODUCTION: PERCENT EGG RESORPTION

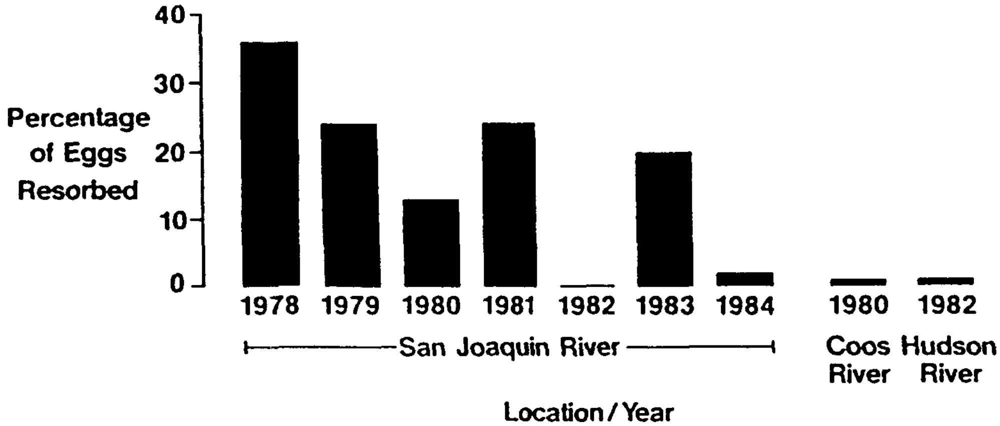

Figure 5. Mean egg resorption in striped bass prespawning females by year (1978-1984) and at different locations.

too small for a representative assessment. An example of the proportion of egg resorption because of various factors, including petrochemicals, is shown in Figure 6. Reduced egg condition was particularly associated with high concentrations of ethylbenzene and 1, 2-dimethylchyclohexane. These components are also among the more toxic and persistent in tissues 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 concentration, particularly toluene and ethylbenzene.

Concentrations of monocyclic aromatics in the tissues of field fish correspond to levels reached in tissues of fish exposed in the laboratory to 50-100 ppb monocyclics (particularly benzene). The bioaccumulation was generally about ten times higher than the water concentrations (Whipple, et. al. 1981).

- Chlorinated hydrocarbons. There were relatively high levels of PCBs, DDT, and its metabolites, and other chlorinated hydrocarbons, including toxaphene, in liver and gonads and 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 (Jung, Moser, and Whipple, 1984). The presence of DDT in liver and gonads (not metabolites DDD and DDE) was associated with abnormal egg development and necrosis of eggs (Figure 4C). 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, particularly mercury, in some fish.

- Pollutant interaction. Initial results show pollutants interacted in affecting the fish. In particular, high levels of petroleum hydrocarbons interacted with chlorinated hydrocarbons to produce effects on reproduction. Data also show that hydrocarbons and metals interact to produce deleterious effects on egg and liver condition.

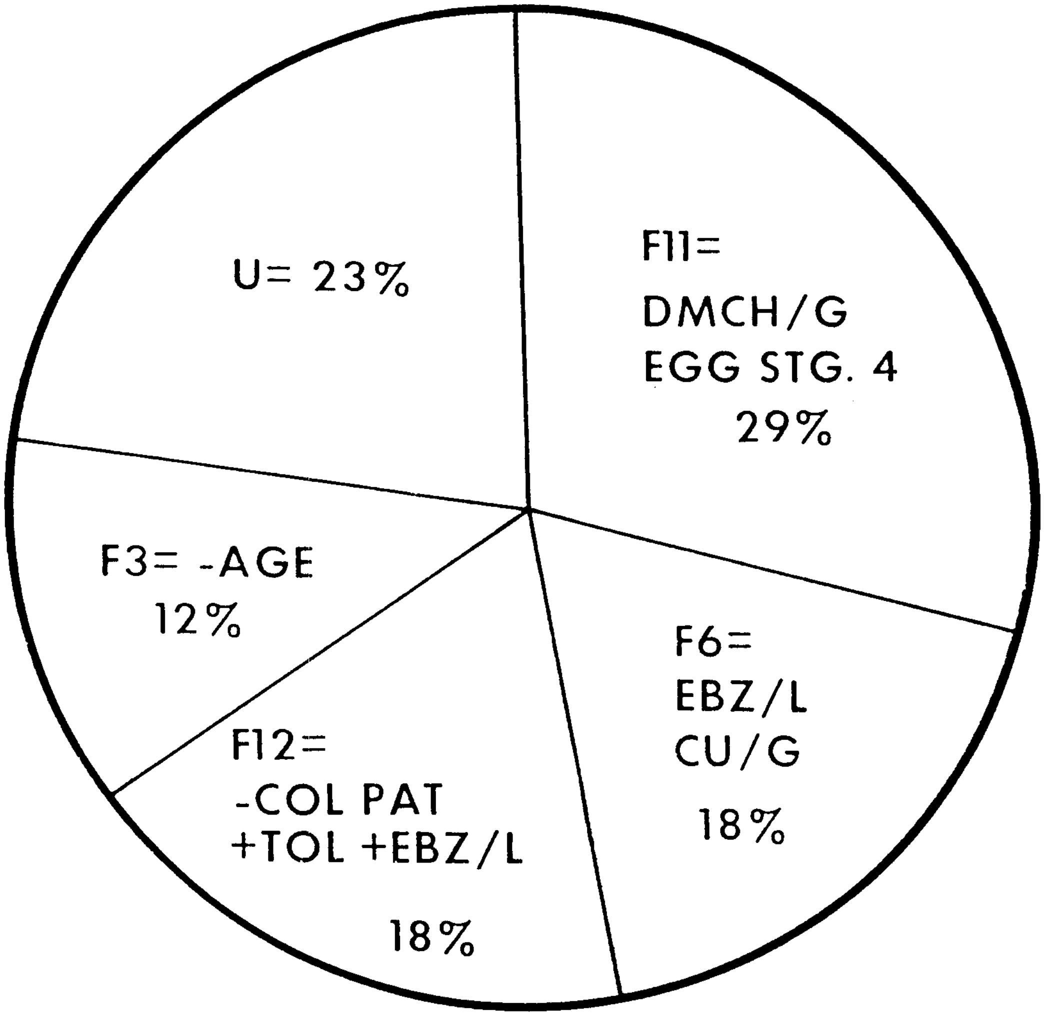

Figure 6. Proportion of total variance in egg condition (egg resorption) accounted for by different factors. Derived from factor equations in factor analysis. Most fish collected in this year had high levels of monocyclic aromatics in the liver and gonads.

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.

Table 3.--Concentration ranges of selected pollutant classes from the San Francisco Bay-Delta estuary; data available to present. Tissue data from adult prespawning striped bass (Morone saxatilis). Tissue concentrations in ug/g (ppm) wet weight hydrocarbons ug/g (ppm) dry weight for metals. Data from this study and Vasillaros et al. (1982), Eaton (1975), and Girvin et al. (1978). ND = not detectable; NM = not measured.

Pollutant class	Concentration in water (dissolved) ug/L (ppb)	Concentration in tissues (ppm) Liver	Gonads	Muscle[1]
Petroleum hydrocarbons				
Total monocyclic aromatics	1-200	0.01-10	0.01-10	0.01-7.52
Total alicyclic hexanes	ND	0.02-5.0	0.02-10	0
Total polycyclic aromatics (All components)	?	--Whole fish composite 10.0----		
Total naphthalenes (Dicyclics)	?	--Whole fish composite 0.009---		
Total sulfated thiophenes	?	--Whole fish composite 6.0----		
Chlorinated hydrocarbons				
DDT	ND	0.09-0.12	0.10-0.68	NM
DDD	ND	0.10-0.98	0.13-2.8	NM
DDE	ND	0.03-3.1	0.10-12	NM
Toxaphene	0.03-0.32	?	0.20-2.0	NM
Total PCB's	ND	0.25-13	0.81-13	0.20-4.0
Trace 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	0.03-0.12	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
Selenium	?	3.2-21	NM	NM
Zinc	2-6	7.0-250	3.0-310	1.0-66

[1]Muscle analyses with no skin attached. Mostly toluene in muscle.

Pollutants most implicated in deleterious effects on fish are, in order: ethylbenzene, 1, 2-dimethylcyclohexane, benzene toluene; DDT, copper, zinc, cadmium, nickel, and mercury. However, other pollutants may be involved that we were unable to measure. For example, recent measurements show that there are relatively high levels of selenium in liver and gonads of striped bass. 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.

The relevant fact is that there are strong associations of these pollutants with decreased condition, growth, reproduction, and possibly survival of striped bass.

5. <u>Laboratory experiments</u>. Experiments performed in the laboratory showed that representative pollutants (benzene and zinc) produced effects similar to those observed in the field (Jung, Whipple, Moser, 1984; Whipple, <u>et. al</u>. ms in prep.). Laboratory exposures equivalent to high chronic water levels in the 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 correlated with low concentrations of zinc.
- Benzene appeared to accelerate and increase the inflammatory response to roundworm larvae.
- Benzene was correlated with blood cell destruction followed by increased production of immature red and white blood cells.
- Zinc was correlated with decreased liver condition (LSI).

Zinc was correlated 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. Although influences other than toxic chemicals (e.g, Delta outflow, larval food supply and entrainment; Stevens et. al. 1985) also are 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 (Eldridge et. al. 1981). These studies should be corroborated in the field. We suggest 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 that normally have the highest fecundity. Ultimately, this will lead to decreased egg production by the population and decreased abundance of juveniles. According to Stevens et. al. (1985), this is probably an important cause of the decline in the striped bass population.

   - The reduction in the number of eggs (fecundity) per spawner, due to the combined effects of pollutants and parasitism, was at least 36-50 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)

Pollutants, therefore, can lead to additional decreases in the egg production of the population. Additional delayed mortality may have occurred in embryos and larvae after spawning, resulting in even further reduction in survival.

o Multiple regression analyses were done with data collected for the years 1978 to 1984 (7 years) from San Joaquin and Sacramento Rivers. Results showed that survival to young-of-the-year related to age distribution of spawning adults, outflow and diversion, petrochemicals and egg resorption. The best correlation was with egg resorption (Figure 7). The hierarchy of relationships is probably as follows (Figure 8): Environmental factors such as lower outflow are associated with higher petrochemical contmination; higher residues of petrochemicals interact with inherent factors in prespawning adults to affect condition and reproduction. Greater egg resorption occurs and subsequently there is higher larval mortality. Higher mortality of eggs and larvae results in lower abundance of juvenile striped bass. The important result, in terms of fisheries management, is that recruitment to the fishery is reduced. If successful, this method can lead to the forecasting of recruitment several years in advance. Our results so far, however, are for a short period (7 years) and need to be validated by continued monitoring before conclusions can be drawn.

Conclusions

The San Francisco Bay-Delta estuary has been modified in several ways since humans settled this area (Nichols et. al. 1986). Among the most significant of these is the elimination of habitat for fish and other biota through human activities such as filling of wetlands and diversion of water for agriculture. Further degradation of this estuary due to increased diversion of water and increased disposal of toxic wastes is predicted.

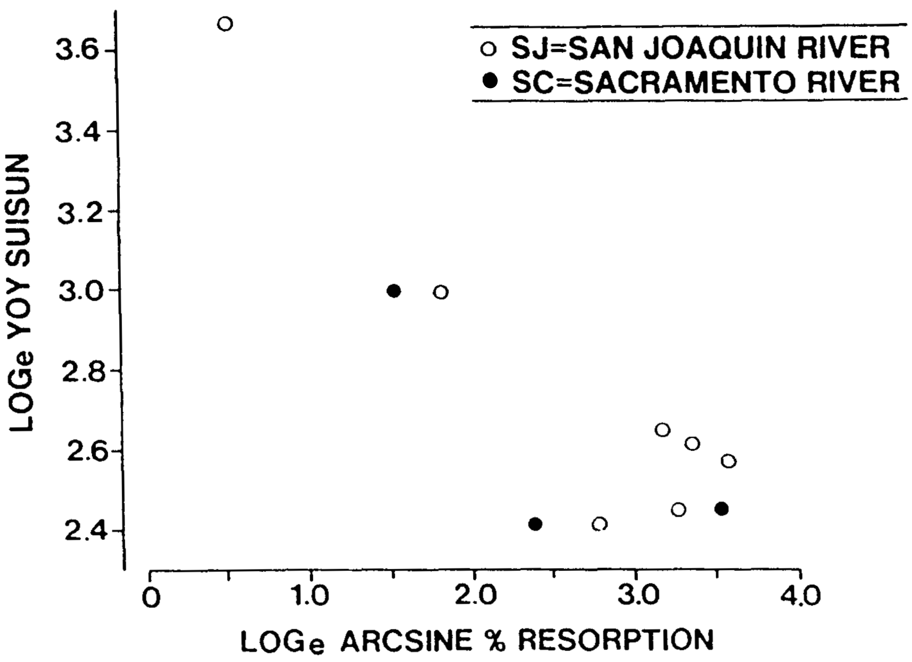

Figure 7. Correlation of yearly mean survival to young-of-the-year juveniles (YOY) with mean egg resorption in adult females of that spawning season. Data on YOY striped bass index from David Kohlhorst

ln YOY Suisun = 3.60 - .341 ln Egg Resorption

$r = -.869$; $P < .001$

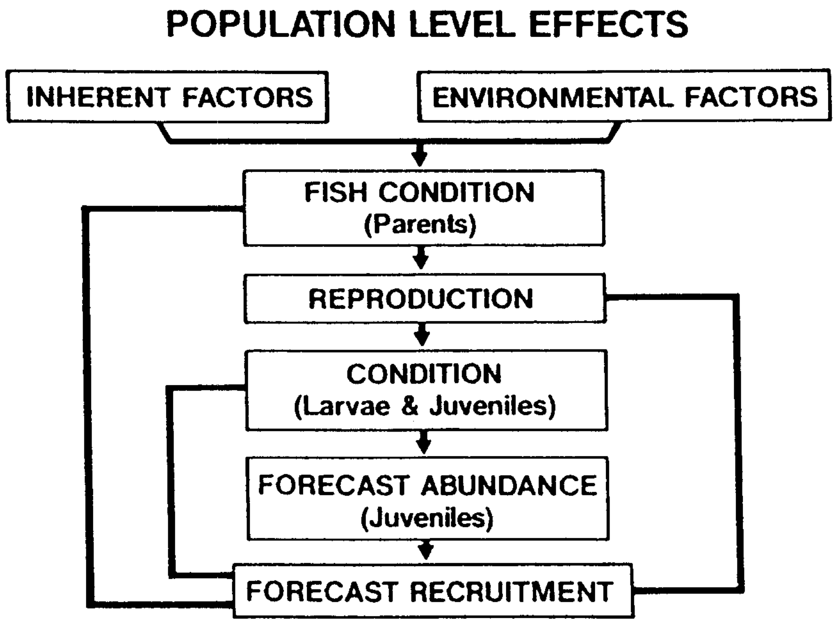

Figure 8. Population level effects. Determining the relationship of environmental factors (e.g. pollutants) on fish condition, reproduction and recruitment to the fishery.

The striped bass population is a major component of the San Francisco Bay-Delta estuary, particularly in past years prior to its decline. It would be of interest to do more research on the relationship of the population dynamics of this species to the flow dynamics of the estuary, and to examine the striped bass in an ecosystem context. This would be of critical importance in making future decisions on water quality and the management of fisheries in the San Francisco Bay-Delta system.

In conclusion, we believe that further investigation of sources and effects of pollutants on striped bass and other biota in the San Francisco Bay-Delta is warranted. We believe also that enough is known for managers and regulators to act now and that any activity reducing the input of these toxic pollutants into the estuary will be beneficial to the health and abundance of the striped bass population.

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