San Francisco Bay

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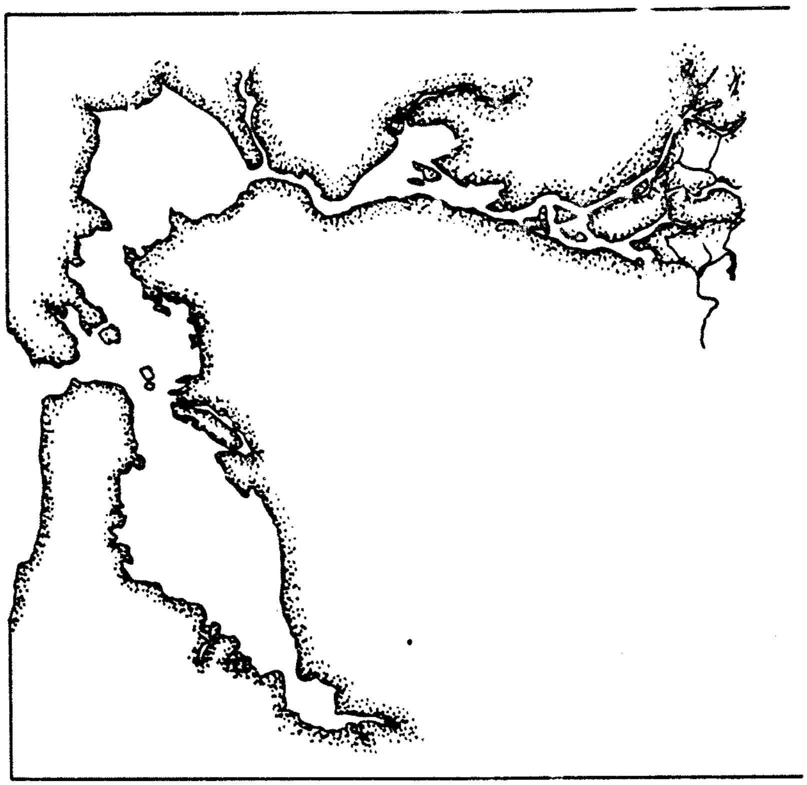

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This report contains papers presented at a seminar on San Francisco Bay held on November 22, 1985 with the objective to bring to the public attention the important research and management issues in the Bay. An overview of the Bay is given by senior scientific investigators that includes explanations of contaminants, nutrients, and water diversion on the Bay; followed by an examination of management issues by leaders of planning and regulatory agencies involved in the Bay.

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Seminar Series No. 6

San Francisco Bay: Issues, Resources, Status, and Management

Edited by David M. Goodrich

Proceedings of a Seminar
Held November 22, 1985
Washington, D.C.

U.S. DEPARTMENT OF COMMERCE
Clarence J. Brown, Acting Secretary

National Oceanic and Atmospheric Administration
J. Curtis Mack II, Acting Under Secretary

NOAA Estuarine Programs Office
Virginia K. Tippie, Director

San Francisco Bay

Environmental Status and Management of Living Resources

an
ESTUARY-OF-THE-MONTH
SEMINAR

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November 22, 1985

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EDITOR'S PREFACE

The following are the proceedings of a seminar on San Francisco Bay held on November 22, 1985, at the Herbert C. Hoover Building of the U.S. Department of Commerce in Washington, D.C. It was one of a continuing series of "Estuary-of-the-Month" seminars sponsored by the NOAA Estuarine Programs Office (EPO), held with the objective of bringing to public attention the important research and management issues in our Nation's estuaries. To this end, the seminar first presented an overview of the Bay by senior scientific investigators, followed by an examination of management issues by leaders of planning and regulatory agencies involved in the Bay.

We would like to acknowledge the assistance of Dr. Michael Josselyn of the Tiburon Center for Environmental Studies, San Francisco State University, who had principal responsibility for assembling the speakers. Dr. Josselyn's cooperation in producing these proceedings and his experience with the Bay and its people have been invaluable to us. The seminar series was organized by Dr. James P. Thomas of the EPO, with the assistance of other members of the EPO staff. Word processing for these proceedings was done by Janet Davis.

David M. Goodrich
NOAA Estuarine Programs Office
Washington, D.C.

SAN FRANCISCO BAY
ISSUES, RESOURCES, STATUS, AND MANAGEMENT

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CONGRESSIONAL VIEWS: STATEMENT OF CONGRESSWOMAN BARBARA BOXER

During my career as an elected official, I have always served constituents who live on and around San Francisco Bay and for whom the Bay is a symbol of environment values. During these years, I have watched with alarm as Bay fill, pollution, and water diversions contributed to the gradual decline of the largest estuary on the West Coast, one of this country's most valuable national resources.

Since coming to Congress two and one-half years ago, I have sponsored legislation which would protect the Bay and adjacent coastal waters, and I have fought to retain the National Marine Fisheries Service Tiburon Laboratory and its critical research on the effects of pollutants on striped bass and other fish. I am a strong supporter of the Clean Water Act, especially the amendment which would provide much needed funds for improved information gathering and management of the Bay.

I am delighted the San Francisco Bay is the Estuary-of-the-Month because such designation is an acknowledgement of concern over the status of our Bay. NOAA's Estuarine Programs Office and the EPA are performing an important public service by bringing this excellent group of Bay researchers and managers here to talk about the Bay's problems and by soliciting input on solutions from Congress and other estuarine experts.

I look forward to an informative and productive day and I am prepared to offer my support to assist in implementing any suggestions which are designed to enhance San Francisco Bay.

CONGRESSIONAL VIEWS: STATEMENT OF CONGRESSMAN NORMAN D. SHUMWAY

I thought this morning I would like to focus my remarks on three topics that are related to San Francisco Bay. One, of course, is the coastal zone mechanism which California and the Bay Area have developed to conquer problems in the San Francisco Bay and ensure the success of that program. Secondly, is how these programs begin to relate to activities outside of the Bay's legal coastal zone. Thirdly, how the general experience of the San Francisco Bay management can be used as an example for other estuaries of national significance and more specifically, what Congress has done recently.

Recognizing generally that there is a national interest in the effective management, the beneficial use and protection, and development of a coastal zone, Congress, in 1972, passed the Coastal Zone Management Act (CZMA). The Federal program was set up to encourage coastal states to develop their own individual coastal management programs which accounted for national interest and policies and to have these programs approved by the Federal Government.

As you all may know, there are two basic incentives for a coastal state to participate. These are, Federal funds to coastal states to help develop and implement management programs, and the consistency program which is a Federal assurance that Federal activities directly effecting the coastal zone will be provided to the maximum extent practicable and consistent with approved state management programs. These two incentives have been successful in getting 28 of the 35 coastal states and territories to obtain Federally-approved management programs. As a result of this achievement, the House of Representatives, in June of this year, passed HR-2121 to authorize Federal programs through the year 1990.

California has adopted a coastal zone management program and incorporated a San Francisco Bay Plan into this program. Also, as part of this program, an independent state agency was created, the San Francisco Bay Conservation and Development Commission, which we will refer to as BCDC. It is an agency which is dedicated to the implementation of the Bay plan. All of this, of course, is to achieve comprehensive bay management, very fitting for the uniqueness of that resource.

In my mind, there are three significant advantages which the CZMA lends to such an estuary management effort which guarantees the success of the Bay plan's comprehensive approach, the emphasis on state and regional responsibilities as the principal managers, and the consultation ability which CZMA's consistency

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provision provides. With regard to the first advantage, water quality, recreational uses, air quality, shoreline growth, and landslide activities are all related and should be managed as such.

I think one of the aspects of the overall management of the estuary would ensure a certain degree of inefficiency. For example, as you probably know, early Federal efforts to manage the Chesapeake Bay were largely ineffective because they isolated only one aspect of estuarine management; in this case, the Chesapeake Bay's water quality. Now, to combat that approach, the EPA and the surrounding states are looking at the factors involved in Chesapeake Bay water quality degradation. They are looking at agricultural runoff, urban runoff, and other landslide activities and not just at industrial sources. As a result, we have a comprehensive approach which, I think all will agree, is more effective than the initial approach.

With regard to the second advantage, it is most appropriate that state, regional, and local officials be the principal authors of any specific estuary management plan. The appropriate rule under the CZMA is to provide limited grants to assist in that effort, provide guidelines and technical assistance relative to national interests, and to approve a plan on development and implementation.

With regard to the third advantage, Federal consistency, in the San Francisco Bay Plan has been implemented through a consistency procedure and jurisdiction granted to the BCDC. The relevant California state law, that is McAteer-Petris Act, has been approved by NOAA pursuant to the CZMA, as part of California's Federally-approved Coastal Management Program.

BCDC has authority over all areas of the Bay, extending landward 100 feet, including Suisun Marsh and the surrounding wetlands. Permits are required for practically all work involving fill from the driving of a single pile to the development of larger scale projects. Permits are issued only if the proposed work is consistent with the McAteer-Petris Act and the Bay Plan.

Let me give to you an example of what I think is good co-operation in the implementation of the Bay Plan. That is the relationship of the U.S. Army Corps of Engineers and the BCDC. Obviously, there are competing uses for the Bay and the shore-line. Probably the most critical has to be resolved in managing the Bay. Since the Corps has permitting authority for all proposals and the CZMA requires consistency certification for such a Corps permit where activities are within the legal coast-al zone, the Corps simply recognizes a BCDC permit as a consistency certification. With regard to jurisdiction, BCDC uses its consistency authority to work with the appropriate local, state, and Federal agencies conducting activities that could effect the Bay.

For example, with regard to water quality matters, BCDC has used this consistency provision as a comment authority on the regional water quality award. Through their permitting process, BCDC can actually enforce state water quality regulations. It has been critical that BCDC and other effected agencies recognize the legal limitation of the consistency provision. Consistency should not be misconstrued as a state or local veto over Federal matters, but rather as a mechanism designed to promote state/Federal consultation and resolutions wherever practicable on matters of mutual or conflicting issues.

In Congressional activities relating to estuary management in general, both the House and the Senate have passed legislation to reauthorize the Clean Water Act. Included in both of these bills are proposals for a National Estuary Program. These proposals allow for a state governor to nominate estuaries which are deemed to be of national significance to be included in this program. If the EPA administrator concurs with that nomination, a Congressional Committee is convened comprised of Federal, state, and local officials to develop a water quality regulatory program for those estuaries which have national significance.

Certain members of the Merchant Marine and Fisheries Committee leadership, including Chairman Jones, are interested in broadening the scope of these programs and shifting their focus to develop an overall management program as opposed to programs specifically limited to water quality. These broad regulatory programs will then be forwarded to the state CZMA plan.

I believe there is some merit in this Merchant Marine and Fisheries Committee approach. Certainly, the more comprehensive the management framework and more of the state and local role in estuarine programming is increased, the more appropriate and effective, I believe, the management will be.

However, as we have seen in the case of the San Francisco Bay, the Federal mechanism in the form of CZMA is already in place. I believe it promotes a comprehensive estuary management regime.

We are seeking ways to cut Federal spending. Reduction mechanisms are being seriously considered by Congress. I think it is going to be hard to justify a new program for management of estuaries, even those that have national significance. I believe that maybe a more appropriate method of encouraging states to use the CZMA will be simply to amend the 1977 Act to outline national interests for specific management plans for estuaries of national significance as part of the Federally approved coastal management programs, as San Francisco, I believe, has already done.

The San Francisco Bay has provided examples. Example 1 is that CZMA worked. Example 2 is that it has influence, which certainly effected its own strength and legal confines and is felt in surrounding areas as well. I think it also provides comprehensive and overall management to a resource which is valuable to all of us as Americans and certainly to those of us who are Californians.

Obviously, Congress does not yet have answers to all the challenges that we face. I think we are going to be looking to people such as you to provide recommendations and guidance for our actions and activities in the future. I look forward to that kind of product coming from you and from this conference and I look forward to working with you in the months and years ahead. Thank you.

CONGRESSIONAL VIEWS: STATEMENT OF CONGRESSWOMAN SALA BURTON

Estuaries in the surrounding California marshes and life carrying tributaries are unique ecosystems of great value to man and nature. Yet, for too long, estuaries have been regarded as useless resevoirs for municipal and industrial waste.

More than 100 acres of estuarine habitat have been lost nationwide since 1960 and estuaries around the country have been considered ecologically. One of those estuaries is of great concern to me and happens to be the largest estuary on the West Coast, San Francisco Bay, and it's in serious trouble. The striped bass population has plummeted 80 percent in the past two decades. Salmon, trout, shad, and crab populations have also seriously declined. High concentrations of toxics have been found in the Bay and is the highest ever recorded in scientific literature. Ninety-five percent of the Bay's original wetlands have been converted to non-wetland use depriving the Bay of required pollution filtration and wildlife habitat functions. In fact, this is a matter I have addressed with the Army Corps of Engineers in hope that greater attention will be given to these concerns that are so important to the continued health of the Bay.

As you may be aware, I have offered an amendment to the Clean Water Act legislation, HR-8, which authorizes development of the San Francisco Bay estuarine programming. Since San Francisco Bay estuarine watershed is the coastal line to the State of California, the Bay system does not currently qualify under the interstate provision of the national program. The intent of this amendment is to develop a management plan for the Bay's estuaries which would be similar to the national plan indicated under the EPA's estuary program authorized by Section 320 of the Clean Water Act. HR-8 has passed the House with this amendment in tact but the Senate has not included this language in its Clean Water Act. A conference between the House and the Senate is expected to convene after the Thanksgiving recess to rectify the differences in these bills. We are working very hard to make sure that San Francisco Bay is included in the final version.

I am very pleased that this seminar is being held to discuss San Francisco Bay and I want to thank you for permitting me to speak on this most important issue for San Francisco. Thank you.

INTRODUCTION TO THE SAN FRANCISCO BAY ESTUARY

Michael Josselyn
Paul F. Romberg Tiburon Center for Environmental Studies
San Francisco State University

It is a pleasure to welcome our audience to a day-long presentation on San Francisco Bay, our Nation's second largest estuary and perhaps also its youngest in terms of scientific research and understanding. As we shall hear today, San Francisco Bay is a key region in the management of California's water, and we greatly appreciate the Congressional interest given to this important national resource. Currently, the House of Representatives has passed an amendment to the Clean Water Act which designates a greater role for the U.S. Environmental Protection Agency in managing our Nation's estuaries, and we look forward to working with Congress to ensure the San Francisco Bay estuary is included in that effort.

Before I begin my introduction to the San Francisco Bay estuary, I would like to acknowledge the support and assistance provided by Dr. James Thomas, Acting Director, and the staff of the Estuarine Programs Office. We are pleased to be the sixth in what is an excellent series of seminars on the Nation's estuaries. In addition, I wish to acknowledge the support of the agencies of the individual speakers, especially the U.S. Geological Survey, the National Marine Fisheries Service, and the Environmental Protection Agency, Region 9.

My role is to set the stage for the following speakers. Many of the audience may have seen the San Francisco Bay region previously; others may have only limited knowledge of its history, geomorphology, and the problems. We, as estuarine scientists, are not as fortunate as our colleagues along the eastern and Gulf coasts of the United States in that large estuaries are a rare phenomena along the precipitous coastline of the western United States. More typical are small coastal rivers and streams entering the ocean over sand bars with narrow coastals marshes behind the dunes. Larger rivers such as the Columbia support more extensive estuarine habitats within the confines of the river valley. However, only in a few areas have the coastal mountains opened to a broad semi-enclosed basin which supports typical habitats associated with the estuaries environment: tidal marshes, mudflats, and protected open water. Coupled with the freshwater inflow from the Sacramento and San Joaquin Rivers, the San Francisco Bay basin provides a unique physical environment which supports a great number of organisms tolerant of fluctuating salinities, temperature, and turbidity. Some of the geophysical facts about San Francisco Bay and its comparisons with other estuaries are given in Tables 1 and 2.

Although estuaries have many qualities and functions in common, the San Francisco Bay estuary has many distinctive attributes compared to other estuaries in the United States. The estuary is actually a continuum of basins, deltas, and rivers -- as my fellow scientists at the Romberg Tiburon Center, Dr. Michael Rosengurt, refers to as the River-Delta-Estuary-Sea system. Two major rivers flow into the basin: the Sacramento and the San Joaquin. Together, they drain over 40 percent of the State of California (approximately 153,000 km^2). Before reaching the estuarine portion of the basin (where salt and freshwater mix), the two major rivers mix with other tributaries with a vast interconnecting maze of channels called the Sacramento-San Joaquin Delta (Figure 1). The Delta, once the largest (over 1,400 km^2), is now largely used for farming and recreation. As our speakers will relate, the Delta also represents the single most important element in the vast "pipe-work" of water conveyance facilities in the state as well as providing important spawning and nursery areas for the state's recreational fisheries.

Although many estuaries have variable inflow rates associated with storms and snowmelt, the annual inflow pattern to the San Francisco Bay estuary fluctuates in response to the Mediterranean-type climate: frequent and heavy winter storms followed by dry summers. Winter rains result in both immediate local runoff and accumulation of water in the snow pack, which later melts and results in heavy discharges in April and May. With an approximate annual river discharge of 20.9 x 10^2 m^3, 80-90 percent enters the estuary from December to April (Figure 2). The climate also affects net water budgets due to the greater amounts of evaporation occurring in the region evolution of a unique marsh ecosystem, sometimes referred to in creation of a major business for salt production in large evaporation ponds. For those of you who have flown into San Francisco Bay, these large multi-hued basins are often the most distinctive landform on the approach path.

Another unique characteristic of the San Francisco Bay estuary is the separation of the basin into two major circulatory systems. The "North Bay", consisting of Suisan, San Pablo, and the northern portion of San Francisco Bay (sometimes referred to as the "Central Bay") is dominated by a typical estuarine gravitational circulation pattern. Freshwater inflow meets the bottom-flowing oceanic water in the region between Chipps Island in the western Delta and San Pablo Bay depending upon the amount of inflow. During the summer, the usual location of this interface region is within Suisun Bay, where it is

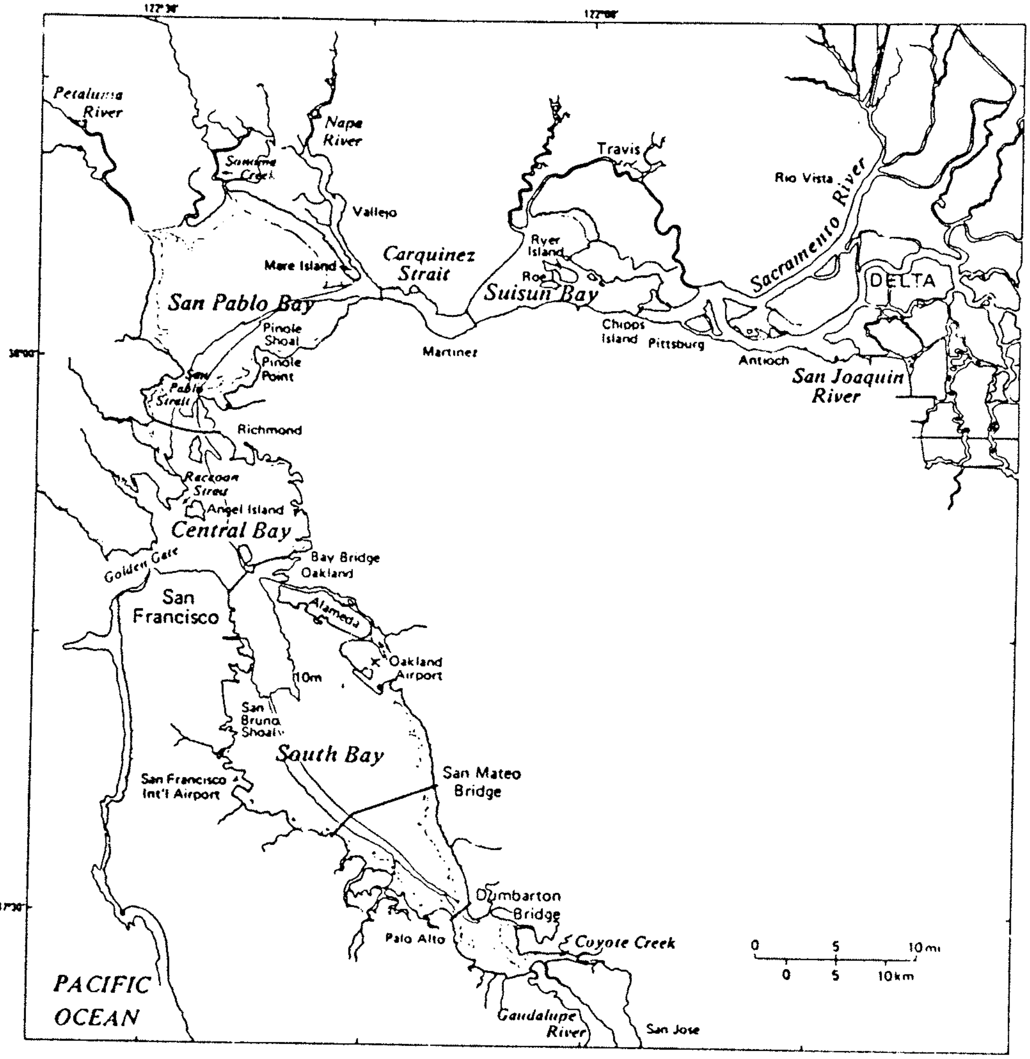
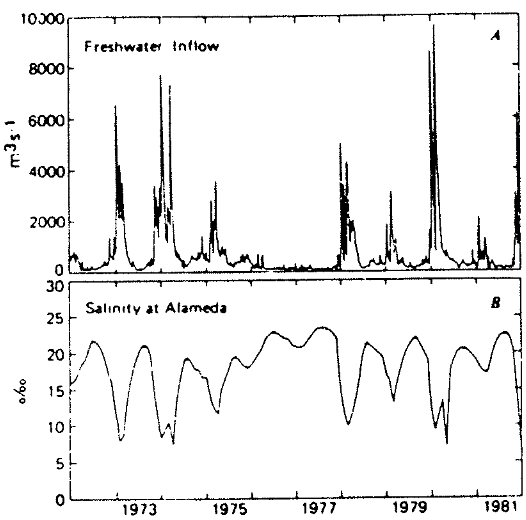


Figure 1. Map of San Francisco Bay showing the Delta region, the North Bay and the South Bay.



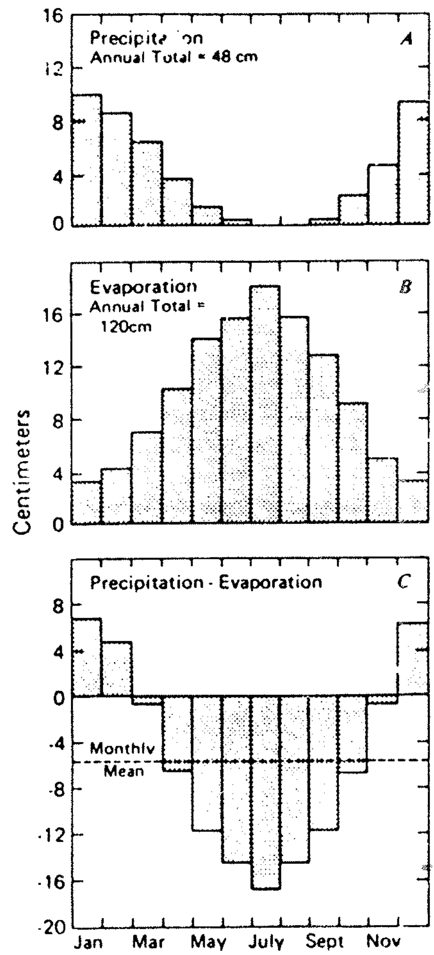


Figure 2. Interannual variation in freshwater inflow to San Francisco Bay estuary.

A. Regulated freshwater inflow as measured in the Delta

B. Salinity change as measured in the Central Bay. From Conomos et al. (1985)

Figure 3. Annual water budget for the San Francisco Bay region. The region exhibits a net evaporative loss over the year with rainfall confined to the winter months. From Conomos et al. (1985)

Table 1
Comparisons of San Francisco Bay with Other North American Estuaries

	Basin Area (1000 km^2)	Surface Area (km^2)	Inflow (m^3/s)
San Francisco Bay	153	1240	500
Columbia River	671	380	5500
Fraser River	203	-	2700
Delaware Bay	33	303	550
Chesapeake Bay	166	11400	1600

From Conomos et al. (1985)

Table 2
Geostatistics of San Francisco Bay

Statistic	Value(x 10^9)
Area (mean lower low water)	1.04 m^2
Including mud flats	1.24 m^2
Volume	6.66 m^3
Tidal Prism	1.59 m^3
Average Depth	6.1 m
Median Depth	2.0 m
Regulated River discharge (annual)	
Delta outflow	19.0 m^3
All other streams	1.9 m^3

Modified From Conomos et al. (1985)

referred to as the null zone and has been shown to support a significant phytoplankton-zooplankton food web. On the other hand, the "South Bay", the portion stretching from the industrial city of South San Francisco to the Silicon Valley of San Jose, has little freshwater inflow and functions more like a large lagoon. Occasional freshwater cells may move into the basin from the North Bay during the winter. In the summer, the major freshwater source is treated domestic effluent.

The Urbanized Estuary

Flying into San Francisco or viewing the region from space, one is impressed with the urban development surrounding the Bay. Certainly, the land-use along the edge of the Bay has undergone a significant change over the past 170 years; these changes undoubtedly have had an influence on the physical, chemical, and biological functioning of the estuary. Nichols et al. (1986) have written an excellent summary of the changes that have occurred in San Francisco Bay since 1850 and I want to briefly summarized their remarks.

One of the major activities was the diking of "swamp and overflowed lands" and subsequent draining of the wetlands for agricultural purposes. The greatest loss occurred in the Delta, where the entire wetland system was lost due to the construction of levees. Small portions of the wetland system can be observed today as islets within the river channels and along levee banks. However, the increasing trend toward placing a rip-rap on levees and removing vegetation is eliminating even these small riparian areas. The tidal salt marshes of the Bay have faired only slightly better, with over 85 percent having been diked or filled for agricultural, salt ponds, or urbanization. The largest remaining wetland system in the estuary is located around Suisun Bay. These wetlands are also diked; however, water flow is managed to support habitat to attract waterfowl for hunting by the over 150 private duck clubs in the region.

At the time that wetlands were being diked, another anthropogenic process was imperceptibly building more shallow water habitat. To retrieve gold from the foothills, miners used large water monitors to wash the overburden and gold-containing sediment through sluiceways and into rivers, the Delta and, after several decades, the Bay. Hydraulic mining was halted in 1884, but the redistribution of sediment from rivers to the Bay went on for the following half century. In several locations in Suisun and San Pablo Bays, new marshlands were created by the sediment, and many former deep harbors were silted in.

The gold of California transplanted many Easterners to the Bay region, who brought with them the cultural and culinary tastes of their Atlantic upbringing. With the completion of the transcontinental railroad, the means to transport entire estuarine communities (with the purpose of introducing the eastern oyster) became available. Oyster culture in San Francisco Bay was a major industry, and with it came other mudflat organisms. Some were edible, some innocuous, several destructive (e.g. Teredo, the shipworm). All were aggressive and quickly became dominant members of the Bay's fauna. Today, over 100 species of introduced benthic and intertidal invertebrates are found in the Bay as well as fish, plants, and zooplankton. One of the most popular introduced species is the striped bass which, as will be described by Dr. Whipple later this morning, has also become the Bay's "miner canary" in that its recent decline may be a warning of a system pushed beyond its natural resilience.

While the marshes were being filled and new species introduced, another activity began in the Central Valley and southern California which would have an impact on the Bay -- irrigated agriculture. The demand for water for the arid south brought political and economic pressures for state and Federal water projects to redirect water from the Bay to other uses. Although water flow varies considerably from year-to-year, the loss of freshwater inflows is evident, amounting to 40-60 percent of the natural flows in recent years (see Rozengurt, this proceedings). Much of the diverted water is taken from the spring flows, an important period for some spawning fish. Furthermore, the water from Sacramento Valley (which receives 70 percent of the state's runoff) must pass through the strategically located Delta before reaching the pumping facilities at Tracy. The Delta is not only an important fish habitat, it also affects downstream salinity intrusion, sedimentation, and flooding. Yet this "sieve", through which freshwater must pass, is itself weakening as increasingly, frequent levee failures during floods and winter storms occur.

The discussion of water needs and natural resource requirements is always bound to create an argument among farmers, biologists, and public interest groups. Even the Federal and state authorities responsible for separate water storage and conveyance facilities had no joint operating agreements until 1986. The State Water Quality Control Board issued a policy (referred to as Decision 1485) to provide for water flows necessary to protect the beneficial uses of the Delta; the decision is up for renewal in 1988. We can expect a great deal of data, interpretation, and emotion at these hearings given the impact such a decision can have on the competing demands for water use for economic and natural resource protection purposes.

The reduction in water quantity has been accompanied by a reduction in water quality. Fortunately, San Francisco Bay recovered from the anoxic events of the 1950s and 1960s as a result of improved wastewater treatment and the movement of discharge locations to regions of greater flushing. Yet population growth has expanded the amount of effluent entering the Bay such that the ratio of wastewater to freshwater inflow is expected to double by the year 2000. As our technology to treat domestic effluent has increased, so has our society's ability to produce more toxic materials as both agricultural and industrial waste. Some of the highest concentrations of DDT and heavy metals among the world's estuaries have been observed in the sediments of San Francisco Bay. Organic compounds such as PCBs and PAHs are also found in Bay organisms and in some cases have been implicated in reproductive failure.

People visiting the Bay area are sometimes tempted to question the impacts of the problems presented this morning. The sun rising over wispy fog and blue water presents a wonderful view to the visitor perched on the hills overlooking the Bay. The striped bass fisherman, the avid bird watcher, the beachcomber seeking shellfish in the mudflats, and the beachgoer during summer months, each suffer a small loss of quality in the Bay resources. They combine to represent a powerful environmental lobby to protect one of California's most important natural resources.

The Scientific Perspective

The primary purpose of our seminar is to describe the state of our scientific information concerning San Francisco Bay. Luckily, I've brought with me individuals far more knowledgeable about that topic that I, and I only want to briefly refer to the landmarks and "bibles" on San Francisco Bay ecology.

The early history of discovery and scientific exploration of the Bay has been eloquently described by Joel Hedgepeth (1979). Science as politics has its backrooms, and Dr. Hedgepeth manages to find enough old letters and documents to indict even the staid old institutions of Stanford and the University of California in a battle over scientific territory. Not only scientists, but vaudeville actors like John Reber have played a role in stimulating research interest in the estuary. Mr. Reber's desire to convert the Bay into a large freshwater reservoir provided the impetus to construct the Corps of Engineers Hydraulic Model, which has tested Mr. Reber's plan as well as many others. A number of Bay-wide studies have been undertaken but unfortunately, differences in methodology and changes in our understanding of the underlying physical and geological processes have limited the usefulness of this store of information.

This level of effort has yielded a number of significant volumes which should be read by all scientists and managers responsible for determining the future of research and management of the Bay. In 1977, the Pacific Section of the American Association for the Advancement of Science held a conference at San Francisco State University on San Francisco Bay and in 1979, published a volume entitled San Francisco Bay: The Urbanized Estuary (Conomos, 1979). This excellent work brings together much of the recent work done by the U.S. Geological Survey personnel on estuarine circulation, chemistry, and biology. It also provides summaries of general geomorphology of the estuary, wetland geology and biology, and fisheries resources. A less successful volume followed in 1982 as an outgrowth of another Pacific Section-sponsored symposium at the University of California at Davis (Conomos et al. 1982). Entitled San Francisco Bay: Use and Protection, this book discusses impacts of shoreline development, sewage treatment, water diversion, and dredging on the estuary. The U.S. Fish and Wildlife Service, in its community profile series, sponsored the completion of a profile of tidal marshes in San Francisco in 1983 (Josselyn, 1983) and has now contracted for profiles on freshwater tidal marshes and the soft-bottom benthos.

The most recent addition to this list of scientific literature is the book edited by Cloern and Nichols (1985). The purpose of the volume is "to examine the temporal dynamics of [estuarine] properties and processes in the San Francisco Bay estuary", in which "temporal" is defined as time scales from tidal to interannual. It provides updated information from the U.S. Geological Survey work as well as research sponsored by the U.S. Bureau of Reclamation, California Department of Fish and Game, and California Water Resources Center. In the volume, both the individual authors and the editors comment on the areas needing further research.

Areas of Recommended Research Effort

As I prepared for this presentation, I contacted a number of individuals who have or are currently involved in research on San Francisco Bay. Most agreed that the work mentioned above has provided a sound framework for more detailed scientific efforts. It is apparent from the efforts of the U.S. Geological Survey and the Four Agencies Ecological Study Program (a group comprised of the Department of Fish and Game, Department of Water Resources, State Water Quality Control Board and the Bureau of Reclamation) that large scale coordinated programs have yielded significant data linking physical, chemical, and biological processes. At the same time, individual research on specific groups or hydrologic cycles has also yielded important new information on the estuary. Both levels of effort are needed. Table 3 indicates some of the major research needs as summarized by Cloern and Nichols (1985) with some additions as suggested by my colleagues.

Research of itself has led to major breakthroughs in our understanding of estuarine processes. At the same time, the urbanized nature of San Francisco Bay estuary requires that we use this research to solve immediate management needs. The next

Table 3
Research Priorities for the San Francisco Bay Estuary

ROLE OF INFLOW ON ESTUARINE PROCESSES

- Circulation and residence times
- Salt balance
- Sedimentation and transport
- Geochemical cycles
- Fisheries resources

BIOLOGICAL PROCESSES

- Microbial ecology
- Micozooplankton biology
- Role of seasonal and tidal wetlands
- Benthic vegetation: eelgrass and algae
- Scale of temporal variability in biotic communities

WATER QUALITY

- Long-term monitoring of biotic communities
- Sources and fates of toxics
- Development of new techniques to measure impacts of toxics
- Nutrient budgets for the estuary

Table 4
Major Management Issues for San Francisco Bay

- Freshwater diversion from Delta and Bay*
- Toxic waste discharge to ground and surface waters*
- Agricultural drainage
- Loss of wetlands*
- Decline of fisheries
- Sea level rise
- Dredging to deepen channels

*Signifies those issues of high significance.

several decades will bring significant new stresses on the estuarine system which will equal, if not exceed the historic human impacts on the region. Table 4 provides a short list of these management needs.

REFERENCES

Cloern, J.E. and F.H. Nichols, 1985: Time scales and mechanisms of estuarine variability, a synthesis from studies of San Francisco Bay. In Cloern, J.E. and F.H. Nichols (eds.). Temporal Dynamics of an Estuary San Francisco Bay. D.W. Junk Publishers, Dordrecht, The Netherlands.

Conomos, T.J., R.E. Smith and J.W. Gartner, 1985: Environmental setting of San Francisco Bay. In Cloern, J.E. and F.H. Nichols (eds.). Temporal Dynamics of an Estuary: San Francisco Bay. D.W. Junk Publishers, Dordrecht, The Netherlands.

Hedgepeth, J.W., 1979: San Francisco Bay: The unsuspected estuary. In Conomos, T.J. (ed.). San Francisco Bay: The Urbanized Estuary. Pacific Div. AAAS, San Francisco, Ca.

Josselyn, M.N., 1983: The Ecology of San Francisco Bay Tidal Marshes: A Community Profile. U.S. Fish and Wildlife Service, U.S. Department of the Interior, Report No. FWS/OBS-83/23.

Nichols, F.H., J.E. Cloern, S.N. Luoma, and D.H. Peterson, 1986: The modification of an estuary. Science 231:567-573.

ESTUARINE CIRCULATION AND MIXING

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Abstract

Tidal-period and low-frequency variations in sea level, currents, and mixing processes in the northern and southern reaches of San Francisco Bay lead to contrasting characteristics and dissimilar processes and rates in these embayments; the northern reach is a partially mixed estuary whereas the southern reach (South Bay) is a tidally oscillating lagoon (tributary estuary) with density-driven exchange with the northern reach.

The mixed semidiurnal tides are mixtures of progressive and standing waves. The relatively simple oscillations in South Bay are nearly standing waves, with energy propagating down the channels and dispersing into the broad shoal areas. The tides of the northern reach have the general properties of a progressive wave but are altered at the constrictions between embayments and gradually change in an upstream direction to a mixture of progressive and standing waves. The spring and neap variations of the tides are pronounced and cause fortnightly varying tidal currents that affect mixing and salinity stratification in the water column.

Wind stress on the water surface, freshwater inflow, and tidal currents interacting with the complex Bay topography are the major local forcing mechanisms creating low-frequency variations in sea level and currents. These local forcing mechanisms drive the residual flows that, with tidal diffusion, control the water replacement rates in the estuary. In the northern reach, the longitudinal density gradient drives an estuarine circulation in the channels, and the spatial variation in tidal amplitude creates a tidally-driven residual circulation. In contrast, South Bay exhibits a balance between wind-driven circulation and tidally-driven residual circulation for most of the year. During winter, however, there can be sufficient density variations to drive multilayer (2 to 3) flows in the channel of South Bay.

Residence times of the water masses vary seasonally and differ between reaches. In the northern reach, residence times are on the order of days for high winter river discharge and of

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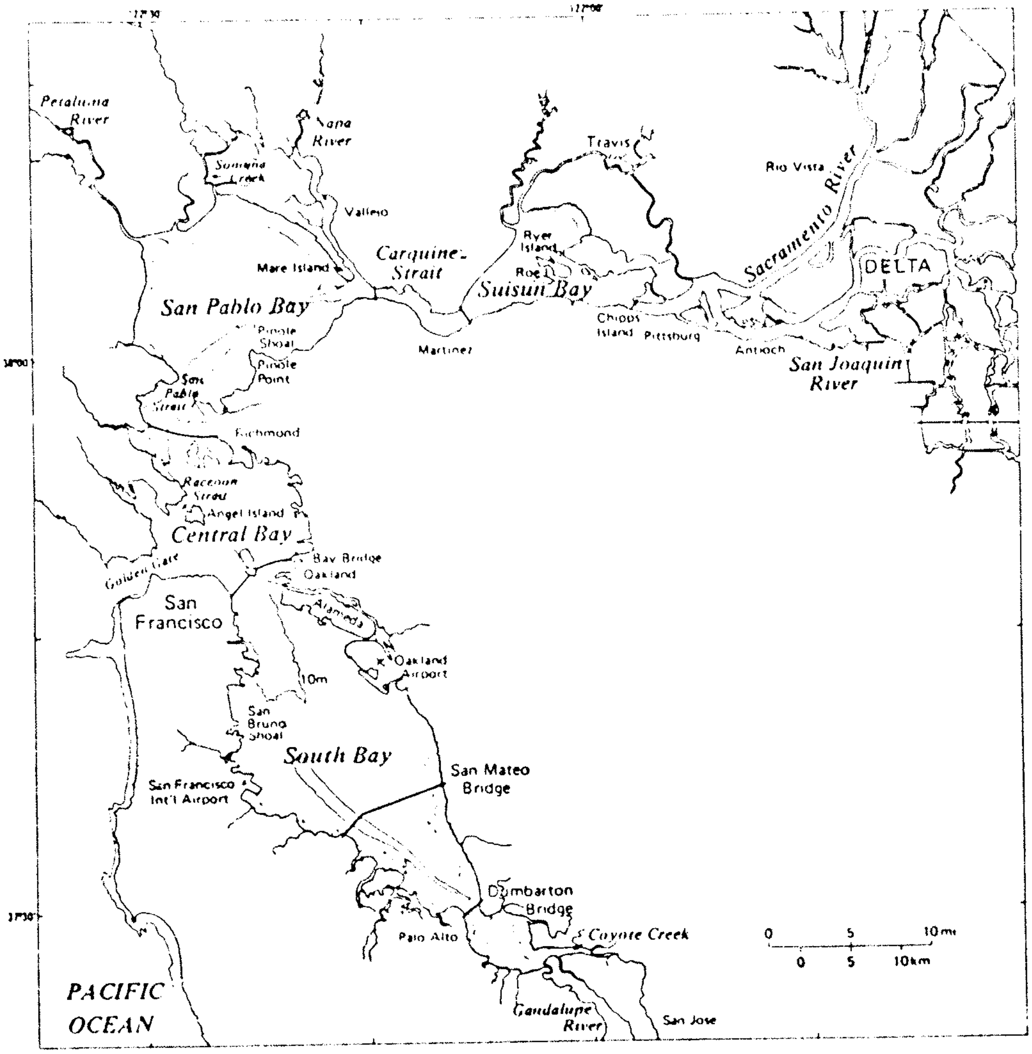

Figure 1. Index Map

months for summer periods. The residence times for South Bay are fairly long (on the order of several months) during summer, and typically shorter (less than a month) during winter when density-driven exchanges occur.

The subject that I would like to deal with is circulation and mixing in the San Francisco Bay estuary. From an overall perspective, perhaps, the physics of an estuary is not quite as glamorous as the chemistry and biology. Nonetheless, it is a very necessary foundation on which distributions in chemistry and biology rest.

The U.S. Geological Survey initially became involved in studies of San Francisco Bay in approximately 1969 through investigations in marine geology. They did one of the first things to study water movements; that is, they dropped a bunch of drifters into the Bay to see where they would go. Immediately, they were involved in controversy because their findings had impact upon possible water deliveries by the California and Federal water projects. Since those controversial beginnings, we have expanded into a comprehensive research group studying aspects of the physics, chemistry, and biology of San Francisco Bay.

What I would like to do now is take you through the present understandings of the circulation and mixing in the estuary.

In the beginning, there was the Ice Age, which had direct implications for San Francisco Bay. The most notable thing was that water held as ice led to the lowering of sea level by as much as 100 meters or so. At this time, the Bay was a river plain, cut by several river channels. As sea level rose, the drowned river valley became the Bay and the relict river channels became the shipping lanes.

What I would like to bring to your attention in Figure 1 is the deepest part of the Bay. You will see immediately that there is a channel that comes entirely down the northern reach of the Bay and out through the Golden Gate. There is also a channel that starts in the southern end and goes out through the opening at the Golden Gate. These are relict river channels.

Most of the freshwater flow comes down the northern reach -- about 90 percent of the total flow into the Bay. The channel left from the last ice age made this area; this area was dry at one time. The ocean shore was out past the Golden Gate on the continental shelf.

The shoals contrast with the rest of the Bay. The depth is of the order of a few meters in the shoals and up to 10-15 meters in the channel, except near the Golden Gate where the depth is about 100 meters.

The bathymetry has a profound affect on the circulation and mixing. High current speed tends to occur where the water is deep, whereas mixing increases with current speed and with decrease in depth.

Next, I'd like to talk about the actual physical processes that drive the circulation. These include the inflow of freshwater, the propagation of tides, and other sea level variations through the Bay, and wind stress on the water surface. The first, the one with the greatest controversy, is the amount of freshwater inflow into the upper end of the Bay. At the seaward boundary there is saltwater, which is relatively dense, approximately 2 percent heavier than freshwater. By contrast, there is freshwater introduced through the Delta, in through Suisun Bay, down through San Pablo Bay, and out through the Golden Gate. A good conceptual model of this system is one of a partially mixed estuary; that is, salt and freshwater mixed in a continuous manner from the Delta down through the Golden Gate in the northern reach. South Bay is what is called a tributary estuary, that is, like an appendage hanging on to the main estuary. In fact, the main estuary determines the type of circulations and exchanges that go on there. This is very similar to the Chesapeake, for instance. Chesapeake Bay is the main stem and there are the tributary estuaries such as the Potomac.

The second physical forcing process is the sea level changes at Golden Gate. It's important to separate different time scales when you're talking about sea level changes.

San Francisco Bay, unlike East Coast estuaries, is very much dominated by tides. If you were to measure sea level and call that the signal, you would find that approximately 95 percent of that signal is the tide. The system is essentially dominated by tides. But the tides go roaring in and the tides go roaring out leaving a small average circulation. This little difference is what is important to the long-term effects, that is, seasonal patterns and the way the biology responds over the seasonal cycles.

So we can consider sea level to be broken into two frequency ranges. One is the tidal period variations, which we'll dispose of shortly. The other is what we call the low frequency or subtidal variations. Now, in perspective, this would include, for example, the 10-day period in the weather that blows up and down the coast of California on the continental shelf. It would involve storms passing through the system, setting up sea level and causing sea level changes. It also can be related to the local rise of sea level.

The third forcing function we should talk about is the wind stress on the water surface. We have considered the seaward boundary condition, mainly sea level, and the landward boundary condition, namely the input of freshwater. We must now examine the surface boundary condition, the wind stress.

The winds in San Francisco Bay, at least in the summer, are characterized by very strong diurnal variations; that is, a land/sea breeze that is driven by the temperature difference between the land and the sea. During the winter, when storms come through, this whole pattern is upset, and there are very strong winds from the southwest and sometimes from the northwest. This has a tendency to create perturbations in the circulation, after which time it returns to a more steady rate.

Let's talk in more detail about tides. The variations in sea level at the Golden Gate create a tidal wave which propagates into the Bay. The tidal characteristics between the north and south ends of the Bay are quite different. The south end of the Bay has what one would call a standing wave; that is, as you look at the windward side of a fixed object in the water, you would see a reflected wave and an incident wave. These two waves propagate against each other, creating a standing wave. Now, one characteristic of a standing wave is that the maximum velocities occur when the tide is in the midpoint between its extreme.

The characteristics of the tide in the northern region is a combination of a standing and a progressive wave; that is, the current speed is maximum at the crests and troughs, like wind waves on a lake. There is quite a phase lag as the wave propagates up the reach, perhaps three or four hours before it comes to Suisun Bay.

Sea level is, of course, continuous across central San Francisco Bay. However, the water currents have a different phasing as you traverse the central bay area. What you find is that the tide turns first in South Bay and then later in the northern reach. For instance, when the tide turns and starts to flood, it will change first and start flooding in South Bay because it changes at the mid-tide level, whereas it's not going to change in the northern part until several hours later. Water flows out to the northern reach, into the South Bay, while the water is starting to flood into Golden Gate. Eventually, the water will turn and start propagating up the northern reach. What you have is an unusual but very effective way to pump water between the north and south reach of the Bay.

Looking at the tides as they propagate through the Bay from the Golden Gate, you can see, if you look at tidal amplitudes, that the amplitude of the wave is increased as it goes south, which is a characteristic of a standing wave. Phase differences here are small, that is, everything happens simultaneously. In the northern reach, there is a tendency for local reflections to occur, for example, at the eastern end of San Pablo Bay. In fact, the phase increases in a monotonic manner up the northern reach. The tidal currents in San Francisco Bay are quite large. At Golden Gate, there is a constriction, leading to currents of up to 5 knots.

Next consider the salinity distribution. The largest freshwater inflows occur in winter and spring. The lowest salinity occurs in the upper end of the estuary, in the northern reach. You can see this in Figure 2. The first contour on the right is for two parts per thousand. You can see salinity is depressed into San Pablo Bay, due to the high freshwater inflow. In this case, Suisun Bay is becoming more like a river than an estuary.

The salinity near Golden Gate is depressed slightly while that in South Bay remains fairly high, again attesting to the fact that there is little freshwater inflow into South Bay. Typically in summer, you will find that the salinities are very much raised in the upper estuary because of the reduction of the freshwater inflow.

I'm going to start at the north end of the estuary, Suisun Bay, and come down to Golden Gate, giving an overview of the circulation, and then touch upon South Bay. In the upper end of the estuary, Suisun Bay, the river input comes from the Delta, the confluence of the Sacramento and San Joaquin Rivers. As the rivers comes out through Suisun Bay, you can see the sediment pattern as it flows out between the islands and passes the reserve fleet on the northwest shore.

There are two types of circulation. One is a horizontal circulation pattern that is more or less uniform in depth and is driven by the freshwater flows and by tidal effects. Then in the vertical, there is a circulation with dense saltwater intruding on the bottom and freshwater flowing out on the surface. This is called estuarine circulation. Each of the different kinds of circulation causes a different kind of mixing. In the case of Suisun Bay, there is a net outflow due to freshwater inflow. Because of the small residual tidal effect, there is also a net counterclockwise circulation, through the islands and up the main channel. And because of the estuarine circulation, there are also density currents coming up the channel. Figure 3 is a schematic representation of how the currents flow. Look in particular at the one called "water flow". What you can see is the river coming in from the left, more or less uniformly with the depth, while the saltwater flows from the ocean on the bottom. There is a mixing zone, which usually occurs somewhere in Suisun Bay. There is some mixture of this fresh- and saltwater which then flows out as a surface layer. In San Francisco Bay, because there's so much tidal energy, the water column is well mixed in the vertical. There is a horizontal decrease in salinity going up estuary, and you still see an estuarine circulation.

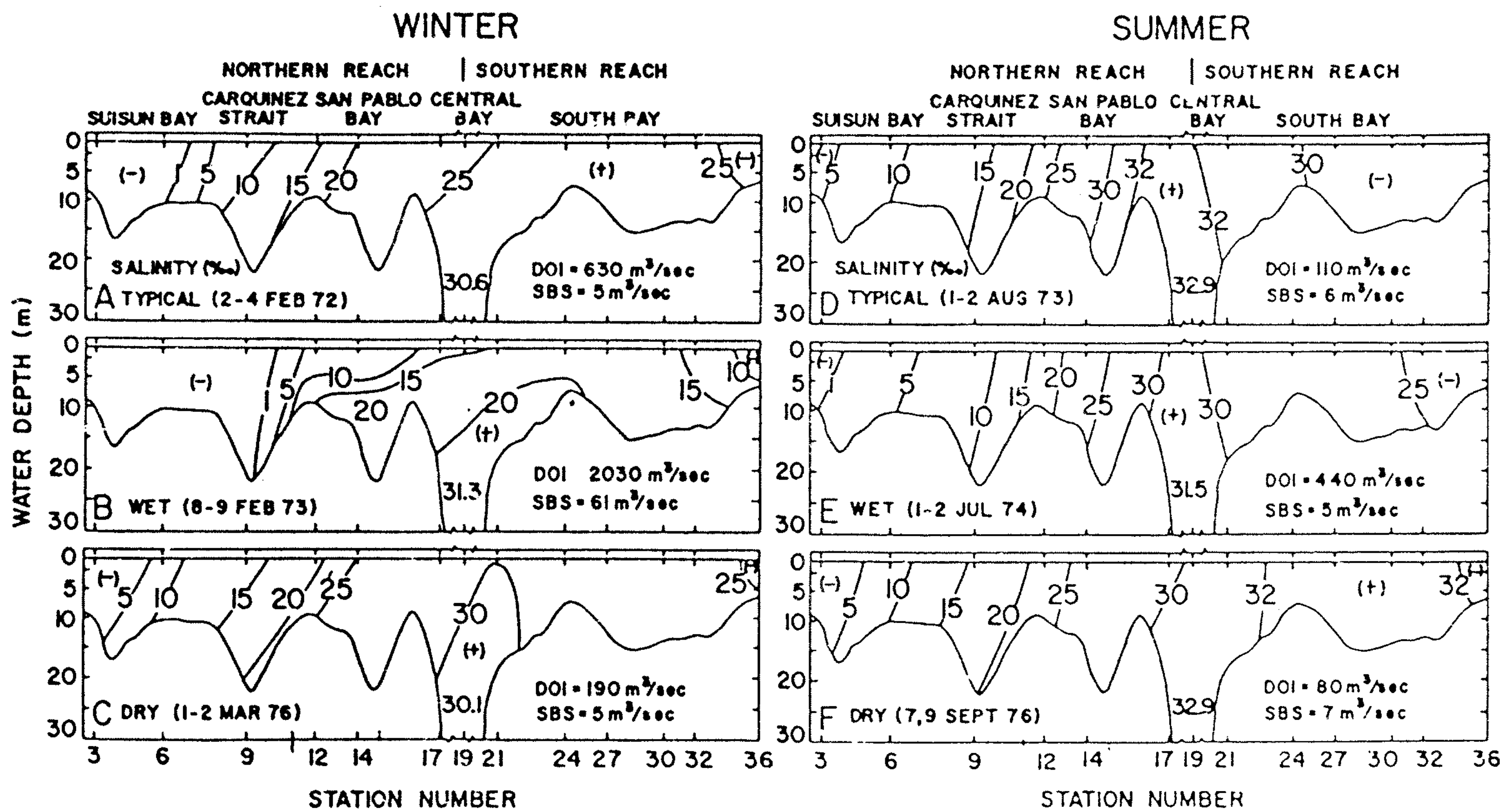

Figure 2. Vertical distribution of salinity during winter and summer periods (from Conomos, 1979).

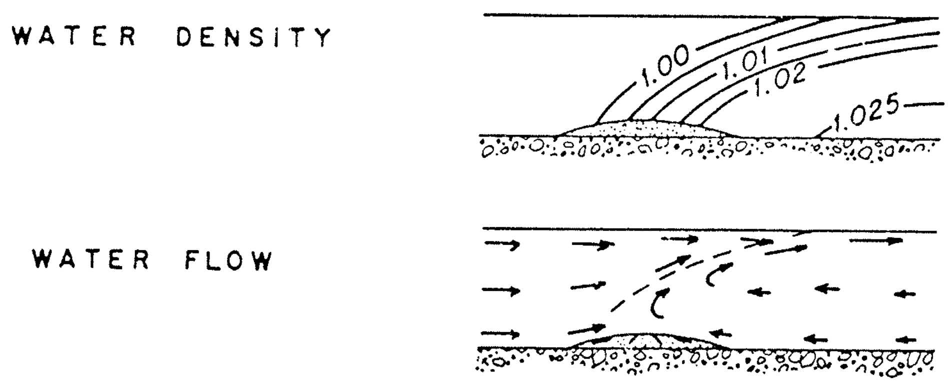

Figure 3. Schematic of a density current with the ocean water on the right and freshwater inflow on the left. There is a density current from the ocean flowing up-estuary on the bottom and a compensating return flow at the surface. Modified from Cloern, 1979.

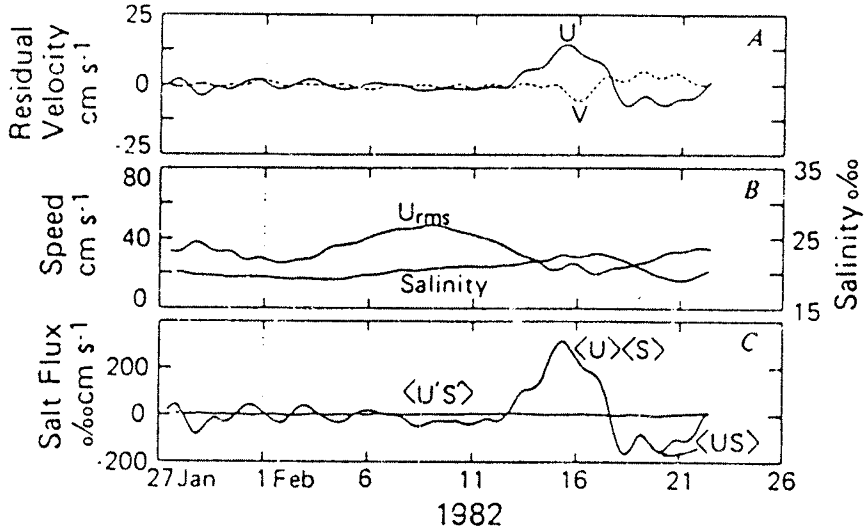

Figure 4. A time series of (A) residual velocity (U is the longitudinal component, positive up estuary), (B) salinity and (C) salt flux components at a current meter station south of San Bruno Shoal in South Bay. The current peak around February 16 depicts a density current inflow into South Bay during neap tides. Note also the rise in salinity and the peak in salt flux at the time. From Walters et al., 1985

The horizontal circulation is in fact a very effective mixing mechanism. The point I want to bring out is that mixing is very complicated, much more complicated than most East Coast estuaries. When you anticipate or plan modifications in the estuary, it is really difficult to say with any certainty what is going to happen in more than a qualitative sense.

We skipped over San Pablo Bay, which is very similar to Suisun Bay in that there is still a large horizontal, rotating residual current. There are the outflowing currents which occur at the surface in the channel. There are density currents going up the channel. But the density currents are interesting in San Pablo Bay, and they're very similar to those in South Bay. So I'll point to this example.

One of the important features here is the shoal area in the center of the channel in San Pablo Bay. The density currents that come into the Bay are stronger where the water is deeper. This density current moves up through the northern reach of the Bay. Because the water is so shallow in the center of San Pablo Bay, it can't really sustain this density current. What in fact happens is that the density current more or less vanishes on the shoal, and then re-forms on the other side of the shoal toward Carquinez Strait.

It's really an interesting feature. You might ask yourself how the salt is getting past the shoal. Apparently, it's doing this by tidal pumping. That is, on the flooding tide, saline water flows over the shoal, into the channel. On the ebb, less saline surface water flows out over the shoal. So there is a tidally induced exchange over the shoal.

In South Bay, something very similar occurs. Because South Bay is a tributary estuary with little freshwater inflow, the freshwater has to come from the north end, from Central Bay. For most of the year, South Bay is at oceanic salinity. It's just sitting there equilibrated with Central Bay.

During winter, with the big freshwater flows coming down from the northern reach, the salinity in Central Bay is depressed and the water in South Bay then drains out as a density current. When freshwater inflows decrease, the salinity starts to go up in Central Bay; the water in Central Bay then drives back into South Bay as a density current in the opposite direction. There is again the dispersion mechanism of tidal pumping over the shoal.

In fact, that is the big event of the year in South Bay, especially for mixing. Figure 4 depicts this. After freshwater inflow peaks and South Bay salinity is increasing, there is a density current being driven into the channel. But because of the tide, when there are spring tides, there's a lot of vertical mixing, and the currents are very sluggish and slow. During neap tides, when the tidal energy is low, there is less vertical mixing and the density currents really pick up speed. You can see in the top picture, there is a very strong density current occurring over the shoal. There is, in this case, mid-level outflow similar to that occurring in Baltimore Harbor.

I'll just say in closing that we are riding a new wave of understanding. One of the most important recent events in the studies of San Francisco Bay was when NOAA/National Ocean Service, with cooperation from USGS, did a sea level and current meter survey in 1980. We're at the point now where we're fully involved in the interpretation of this data set. For those people interested in further information, we have recently prepared an article summarizing the current state of understanding of circulation and mixing in San Francisco Bay (Walters et. al. 1985).

REFERENCES

Cloern, J.E., 1979: Phytoplankton ecology of the San Francisco Bay system: The status of our current understanding, in T.J. Conomos (ed.), San Francisco Bay: The Urbanized Estuary. Pacific Division, American Association for the Advancement of Science, San Francisco, Ca. 64-72.

Conomos, T.J., 1979: Properties and circulation of San Francisco Bay waters, in T.J. Conomos (ed.), San Francisco Bay: The Urbanized Estuary. Pacific Division, American Association for the Advancement of Science, San Francisco, Ca. 38-50.

Walters, R.A., R.T. Cheng, and T.J. Conomos, 1985: Time scales of circulation and mixing processes of San Francisco Bay waters. Hydrobiologia 129:13-36.

INTERANNUAL VARIABILITY IN DISSOLVED INORGANIC NUTRIENTS IN NORTHERN SAN FRANCISCO BAY ESTUARY

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Abstract

Nearly two decades of seasonal dissolved inorganic nutrient-salinity distributions in northern San Francisco Bay estuary (1940-1980) illustrate interannual variations in effects of river flow (a nutrient source) and phytoplankton productivity (a nutrient sink). During winter, nutrient sources dominate the nutrient-salinity distribution patterns (nutrients are at or exceed conservative mixing concentrations). During summer, however, the sources and sinks are in close competition. In summer of wet years, the effects of increased river flow often dominate the nutrient distributions (nutrients are at or exceed conservative mixing concentrations), whereas in summers of dry years, phytoplankton productivity dominates (the very dry years 1976-1977 were an exception for reasons not yet clearly known). Such source/sink effects also vary with chemical species. During summer, the control of phytoplankton on nutrient distributions is apparently strongest for ammonium, less so for nitrate and silica, and is the least for phosphate. Furthermore, the strength of the silica sink (diatom productivity) is at a maximum at intermediate river flows. This relation, which is in agreement with other studies based on phytoplankton abundance and enumeration, is significant to the extent that diatoms are an important food source for herbivores.

The balance or lack of balance between nutrient sources and sinks varies from one estuary to another just as it can from one year to another within the same estuary. At one extreme, in some estuaries river flow dominates the estuarine dissolved inorganic nutrient distributions throughout most of the year. At the other extreme, phytoplankton productivity dominates. In northern San Francisco Bay, for example, the phytoplankton nutrient sink is not as strong as in less turbid estuaries. In this estuary, however, river effects, which produce or are associated with near-conservative nutrient distributions, are strong even at flows less than mean annual flow. Thus northern San Francisco Bay appears to be an estuary between the two extremes and is shifted closer to one extreme or the other, depending on interannual variations in river flow.

Abstract from:

Cloern, J.E. and F.H. Nichols (eds.), 1985: Temporal Dynamics of an Estuary: San Francisco Bay. D.W. Junk Publishers, Dordrecht, the Netherlands.

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THE IMPACT OF WATER DIVERSIONS ON THE RIVER-DELTA-ESTUARY-SEA ECOSYSTEMS OF SAN FRANCISCO BAY AND THE SEA OF AZOV

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Abstract

A review of the long-term impact of river diversions on the hydrological and biological features of the estuarine ecosystems of San Francisco Bay and the Sea of Azov (once Russia's richest fishing ground) indicates that despite differences in scale and in climatic, hydrographic, and physiographic regimes, the ecological status of these systems, involving the River-Delta-Estuary and adjacent coastal zone, depends on cumulative river runoff fluctuations. In the past, before human intervention, these systems were naturally maintained by stochastic processes, but as a result of regulation of river flow during the last 30-40 years, these conditions have become primarily deterministic, artificially manipulated by man. Analysis of the relationships between water supply variables and parameters such as salinity and catch of anadromous fish in both San Francisco Bay and the Sea of Azov indicates that steady reduction of annual and spring freshwater supply by diversions exceeding 30 percent of the natural limits of the dominant fluctuations of these estuarine ecosystems has resulted in drastic declines in the fisheries.

Unprecedented changes in ecological conditions have appeared 5-7 years after a period of 10-15 years of relatively stabilized seasonal stream flows. These flows were at 30-65 percent of the mean historical water supply. The residual inflow onto the estuary cannot entrain enough water to flush wastes and excess salt into the sea and cannot provide the optimal ranges of nutrients, salinity, and other dissolved constituents necessary for the survival of estuarine species.

In the Sea of Azov, flow reductions have resulted in increased salt intrusion from the Black Sea and have led to a massive invasion of <u>scyphozoan</u> <u>medusae</u>, resulting in radical declines in the economic and recreational significance of the Sea since the late 1970s.

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Introduction

Adaptation of estuarine organisms to a wide range of annual and seasonal fluctuations in biochemical and biological characteristics is the result of centuries of evolution, in response to the probabilistic nature of runoff variation. This process has resulted in the ability to populations of estuarine organisms to recover from extreme hydrological conditions, e.g., drought-produced, catastrophic declines in runoff leading to salt intrusion, sporadic algal blooms, anoxia, etc. (Hedgpeth, 1970; L'vovich, 1974; Bronfman, 1977; Mann, 1982; and Rozengurt, 1974, 1983b). It is evident that the maintenance of estuarine characteristics such as biological productivity and flushing capacity are determined by the natural cycles of fluctuations of freshwater supply to the system (Baydin, 1980). This inflow is a renewable but limited resource.

Geophysical and climatological properties of the watershed determine its volume and are important physical limitations that should be considered an essential component of overall estuarine resource management. Natural flow is a most essential factor to be considered in analyzing any system (Champ et al. 1981; Cronin, 1967; Lauff, 1967; Officer, 1976; and Vorovich et al.) to determine what quantity of water can be diverted without seriously damaging the estuary. However, the definition of "natural flow" has been confused with a more limited concept of "historic flow" based on the residual regulated flow, i.e., what is left after upstream and within Delta diversions. From this perspective "historic flow" is the unregulated runoff that occurred during some past period, according to hydrological definitions established by UNESCO (1974), and Sokolov and Chapman (1974). Both recommend performing basin analyses on unimpaired flow fluctuations over periods of at least 50-60 years.

To avoid confusion, it would be best to use the term "historic" or "natural" when the figure concerned is the unimpaired flow for all recorded years, and state the period during which these baseline observations were made. Residual flow should be considered as the net "regulated" rather than "historic" flow.

Background

In estuaries which have a mean inflow significantly higher than their total volume, the prevailing fluctuations of mean freshwater supply (5 year running means of natural annual or spring runoff under natural conditions) vary within 25 percent of normal 50-60 year averages. Hence, if diversion within a cycle, especially during periods of less than average flow, does not exceed the natural deviations from the average flow, the cumulative supply of the watershed may compensate for these water withdrawals. In such a case, the estuarine ecosystem would survive regulated water supply fluctuations because they are within range of natural conditions. If diversions exceed these natural limits for prolonged periods, there will be little prospect of recovery because the natural resilience of the system will be reduced and deteriorating conditions will produce serious damage to its resources (Aleem, 1972; Rozengurt and Haydock, 1981; and Rozengurt and Herz, 1981). In many parts of the world, massive water diversions from estuaries have greatly reduced or eliminated major fisheries, with annual losses amounting to hundreds of millions of dollars, as a result of destruction of habitats and degradation of conditions necessary for reproduction and maturation (Aleem, 1972; White, 1977; Cross and Williams, 1981).

In 1980, these problems were examined by the National Symposium on Freshwater Inflow to Estuaries in San Antonio, Texas. The Summary and Recommendations of this Symposium included the following:

> Published results regarding water development in rivers entering the Azov, Caspian, Black and Mediterranean Seas in Europe and Asia all point to the conclusion that no more than 25-30 percent of the historical river flow can be diverted without disasterous ecological consequences to the receiving estuary. Comparable studies on six estuaries by the Texas Water Resources Department showed that a 32 percent depletion of natural freshwater inflow to estuaries was the average maximum percentage that could be permitted if subsistence levels of nutrient transport, habitat maintenance, and salinity control were to be maintained. (Clark and Benson, 1981, page 524).

In the San Francisco Delta-Bay system where annual freshwater flows have been reduced by as much as 62 percent (Nichols et al. 1986), fish populations have declined radically. The striped bass population is down to 20 percent and egg production is at 10 percent of levels of the 1960s (Striped Bass Working Group, 1982) and Chinook salmon population has declined to 30 percent of 1960 levels (Kjelson et al., 1982). Many other investigators have attempted to quantify the relationship between river flow and fish abundance with varying degrees of success (Chadwick, 1971; Stevens, 1977; Smith and Kato, 1979).

Materials and Methods

In order to establish ecological criteria and make recommendations for management and protection of the San Francisco Bay estuarine system, two crucial questions must be answered:

1. How much can be diverted from the watershed before permanent damage is done to the ecosystem?

2. How much water must be released into the system in order to mitigate the negative impact of water quality after diversions have produced such damage, and is it possible to maintain optimal levels of resources in the estuarine system?

The Sea of Azov provides a comparative example of the impact of water withdrawals on the physical and biological characteristics of an estuary. In the large body of literature produced in the Soviet Union since the 1920s, the Sea of Azov is cited as the most productive low salinity region in the world. According to Zenkevich (1963, p 465) the total fish catch was 80 kg/hectare in some years. The case history of the Sea of Azov is strong evidence in support of the concept that freshwater inflow from its two main rivers, the Don and Kuban, plays a major role in maintaining the biological productivity of the Sea and its estuarine systems (GOIN, 1972; Bronfman, 1971; Volovic, 1986).

The purpose of this research is to: (1) examine the changes in the San Francisco Bay and the Sea of Azov ecosystems (Table 1 and Figure 1) associated with freshwater diversion patterns between 1921-1978; (2) analyze the relationship between the modification of annual and seasonal river inflow, the water quality of the ecosystem, and the status of its living and non-living resources; and (3) attempt to define the levels of river flow needed to meet the freshwater needs of these resources while also satisfying the requirements of California's agricultural, industrial, and municipal users.

The following data have been used in our analyses:

1. Monthly and annual natural and regulated river inflow to the Delta, and the corresponding Delta outflow to the Bay, for the period 1921-1978 (California Department of Water Resources 1980; Kelley and Tippets, 1977).

2. Commercial and sport catches of anadromous fish (striped bass [<u>Morone</u> <u>saxatilis</u>], and shad [<u>Alosa sapidissima</u>], from 1884 to 1982 (Skinner, 1962; California Department of Fish and Game, 1983).

3. Monthly and annual values of combined natural and regulated river inflow to the Sea of Azov, salinity of sea water, and commercial catch records (1930-1980) of major species of anadromous fish (publications of the Ministry of Fisheries of the U.S.S.R., All Union Institute of Fisheries and Oceanography, and the Azov-Black Sea Institute of Fishery and other sources).

TABLE I

MORPHOMETRIC AND HYDROLOGICAL CHARACTERISTICS OF THE RIVER-DELTA-ESTUARY-SEA ECOSYSTEM

Basin	Area Km^2	Volume Km^3	Historical Runoff Km^3	Annual Water Withdrawals (% Historic runoffs)	Salinity (ppt) Historical Range	Salinity (ppt) Present Range	Salinity Average (ppt) Historical	Salinity Average (ppt) Present
Azov Sea[1]	38,000	324	43	50	8.5-11.5	12.0-16.0	9.5	15.0
Don River Delta (1912-1980)	540	?	29.4	35	.05-3.0	.1-10.0	0.3	1.0?
Kuban Delta (1912-1980)	300	?	13.6	79	.05-3.0	.5-15.0	0.3	1.0?
San Francisco Bay[2]	1,140	8.34	33.7	50	.1-30.0	.5-33.0?	20?	23?
Sacramento-San Joaquin Delta (1921-1978)	159	1.57	33.7	50	.01-1.8	.5-12.0	0.2?	1.0?

[1]Calculated from data presented in Goldman and Maysky (1972), Present and Projected Water and Salt Balance of the U.S.S.R. (1972); Remisova (1984a,b) and other sources.

? = Estimates based on incomplete historic data.

[2]Calculated from California Departments of Public Works (1923-31) and Water Resources (1922-1978), U.S. Geological Survey (1969-76) data.

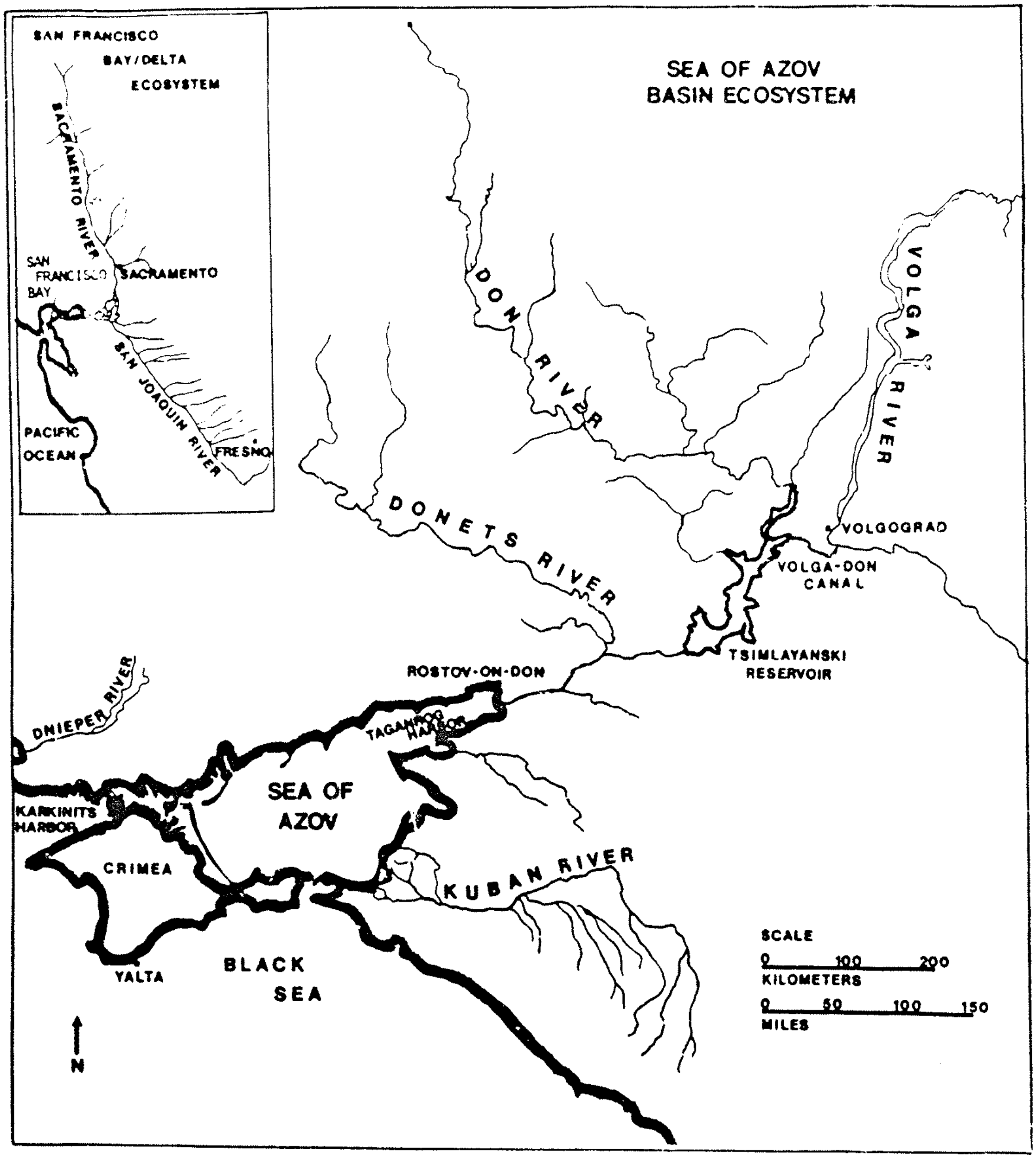

Figure 1. Geographical maps of the Sea of Azov and its basin watershed in the southern USSR and of the San Francisco Bay/Delta watershed in the western United States (common scale used for both maps).

Results

The trend in fluctuations in natural runoff reflects climatic cycles and their variations over large regions and is not radically modified by man's activities (Figure 2). Analysis of natural runoff cycles (11-15 years as described by L'vovich, 1979) in both the San Francisco Bay and Sea of Azov drainage basins indicates the two are almost in phase, and therefore suggests that any changes detected in regulated runoff are the result of human modification rather than climatological factors. An unusual feature of these variations is that the deviations of mean runoff in each cycle vary within 25 percent of the average perennial volume regardless of the magnitude of the annual mean or seasonal discharges into either drainage basin.

Since the late 1950s, water withdrawals from the San Francisco Bay watershed have increased from 20-30 percent of the natural annual runoff to as much as 63 percent in 1977 (Figure 3A), and for the spring months of April, May, and June, they have grown from 30-35 percent to 60-85 percent. For the Sea of Azov, diversions have grown to as high as 46 percent (1974; Figure 3B). This radical reduction of runoff superimposed on natural cycles has diminished the water supply of the Delta and Bay to levels below those observed for natural fluctuations for annual or spring runoffs.

The deviations (for running averages of any 5-year period) of regulated water supply to the Delta and Bay from "normal" runoff have predominant ranges of -35 percent to -60 percent (annual), and -40 percent to -85 percent for spring (April-June). Deviation for both natural, annual, and spring 5-year running means of Delta outflow, on the other hand, generally vary around 15-25 percent of the mean (Figure 4 A-D). This indicates that such extreme negative deviations did not occur in the natural state of this estuarine system and have only been seen since the onset of major human regulation.

Between 1955 and 1978, the period after the completion of the Central Valley Project (CVP) and State Water Project (SWP), major water storage and transport facilities, diversions amounted to a total of 296 km^3 of freshwater (240 MAF; Figure 5B), equivalent to 40 times the volume of the San Francisco Bay. Of this, 202 km^3, or 164 million acre-feet (MAF), was diverted from the rivers for irrigation and domestic water supply and 94 km^3 (76 MAF) was removed from Delta outflow for agricultural and other needs. In other words, for 23 years, an average of 8.8 km^3 (7.1 MAF)/year was withdrawn from river inflow to the Delta and 4.0 km^3 (3.3 MAF) was removed from Delta outflow to the Bay, yielding a total of 12.8 km^3 (10.4 MAF) per year that never reached San Francisco Bay. For the same period, (Figure 5A) the total losses of freshwater supply to the Sea of Azov accounted for almost 250 km^3, or about 11 km^3/year.

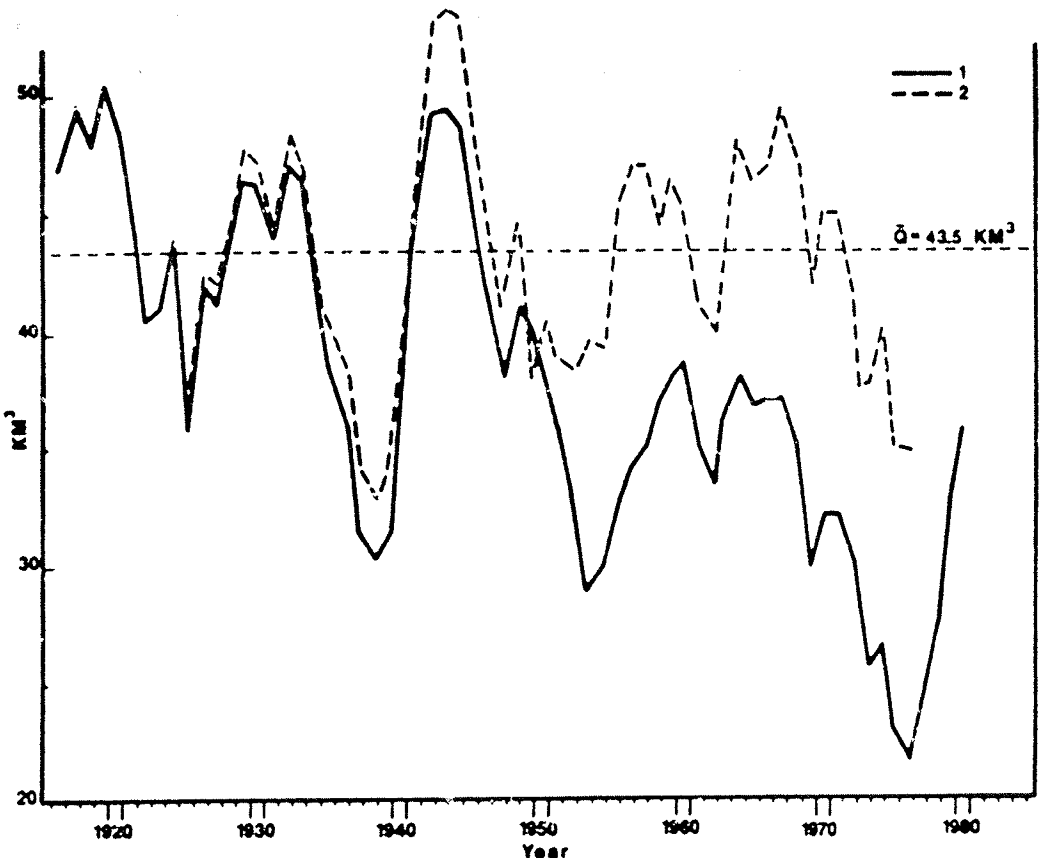

Fig. 2A. Fluctuations of the 5-year running mean (1) combined natural and (2) combined regulated river inflow to the Sea of Azov (dashed line represents the average natural river inflow to the Sea of Azov, 1916-1980).

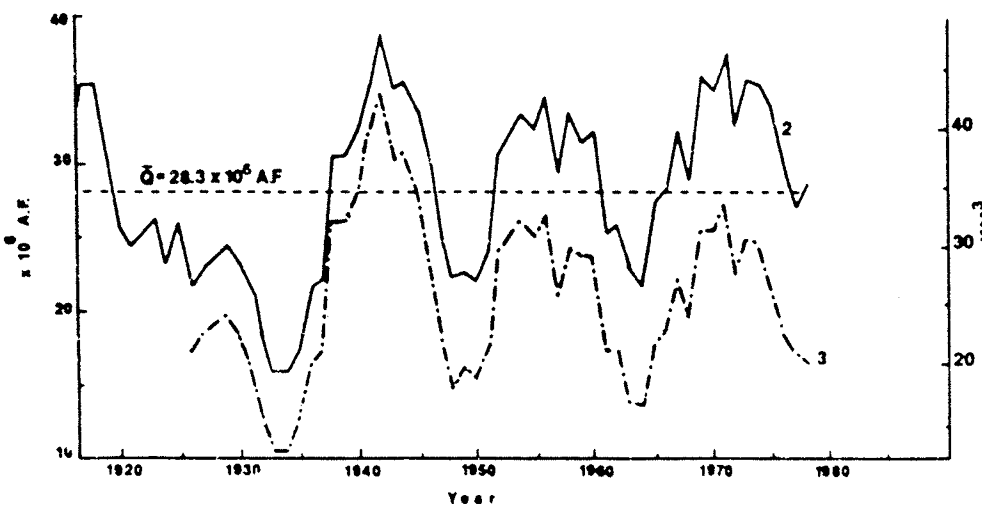

Fig. 2B. Fluctuations in the 5-year running average of (2) natural inflow to the Sacramento-San Joaquin Delta and (3) regulated Delta outflow to San Francisco Bay (dashed line represents the natural river inflow to the Delta, 1921-1978).

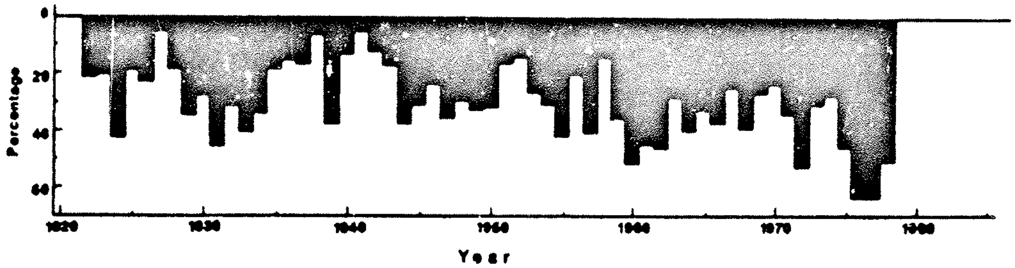

Fig. 3A. Fresh water diversions from the Sacramento-San Joaquin river system expressed as the percentage of the annual natural river inflow to San Francisco Bay.

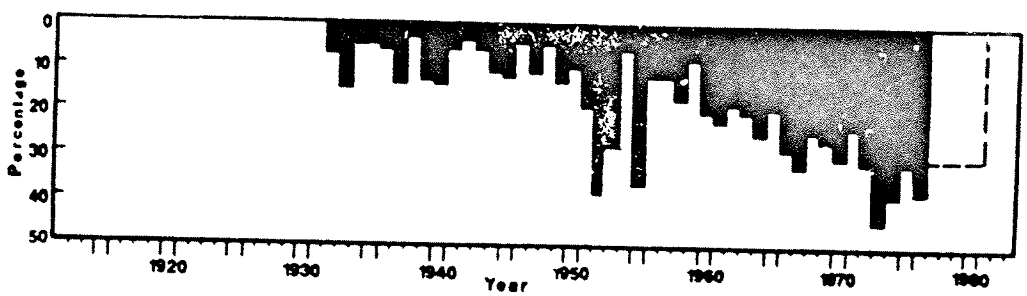

Fig. 3B. Fresh water diversions from the Don-Kuban river system expressed as the percentage of the annual natural river inflow to the Sea of Azov.

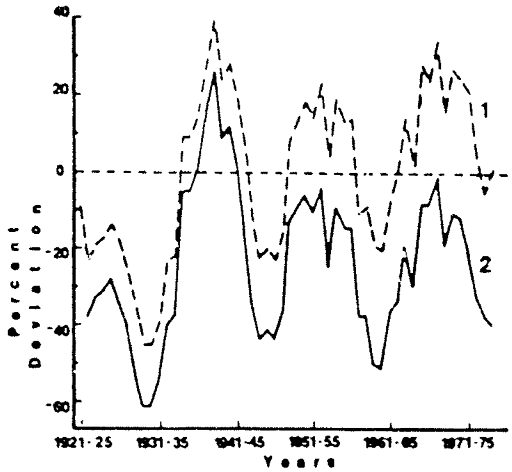

Fig. 4A. Annual percentage deviation of natural (1) and regulated (2) Delta outflow from mean natural Delta outflow (1921-1978 computed with 5-year running means (annual mean natural Delta outflow, 1921-1978 = 27.7 million acre feet).

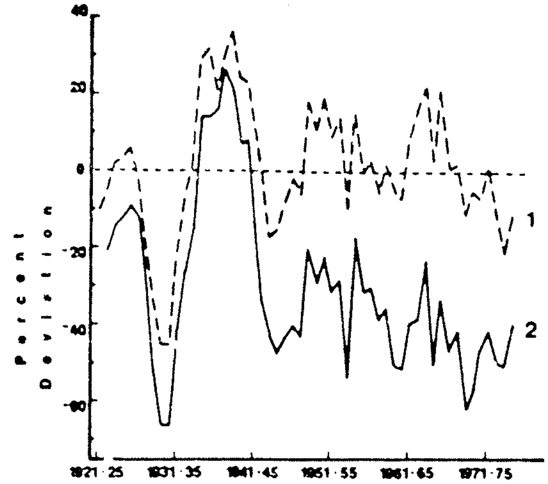

Fig. 4B. Percentage deviation for the month of April of natural (1) and regulated (2) Delta outflow for April (1921-1978), computed with 5-year running means (April mean natural Delta outflow, 1921-1978 = 4.10 million acre feet).

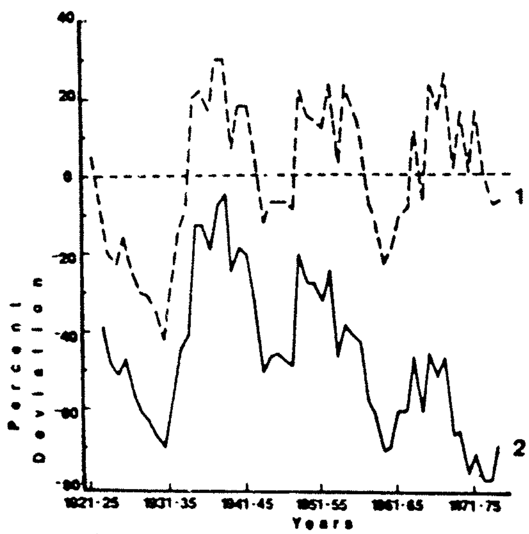

Fig. 4C. Percentage deviation for the month of May of natural (1) and regulated (2) Delta outlfow from mean natural Delta outlfow for May (1921-1978), computed with 5-year running means (May mean natural Delta outflow, 1921-1978 = 4.15 million acre feet).

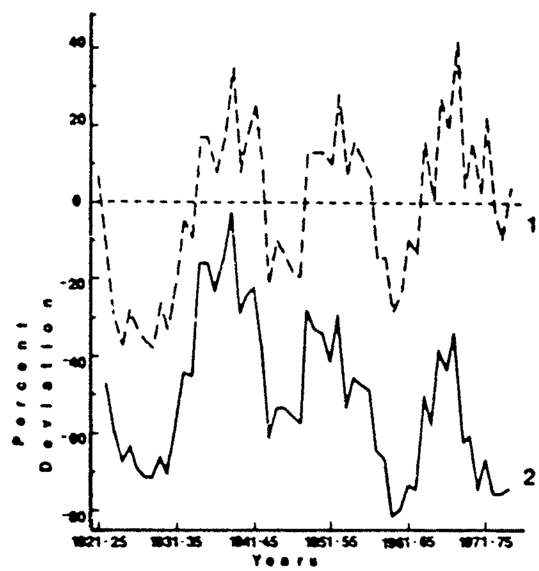

Fig. 4D. Percentage deviation for the month of June of natural (1) and regulated (2) Delta outlfow from mean natural Delta outflow for June (1921-1978), computed with 5-year running means (June mean natural Delta outflow, 1921-1978 = 2.51 million acre feet).

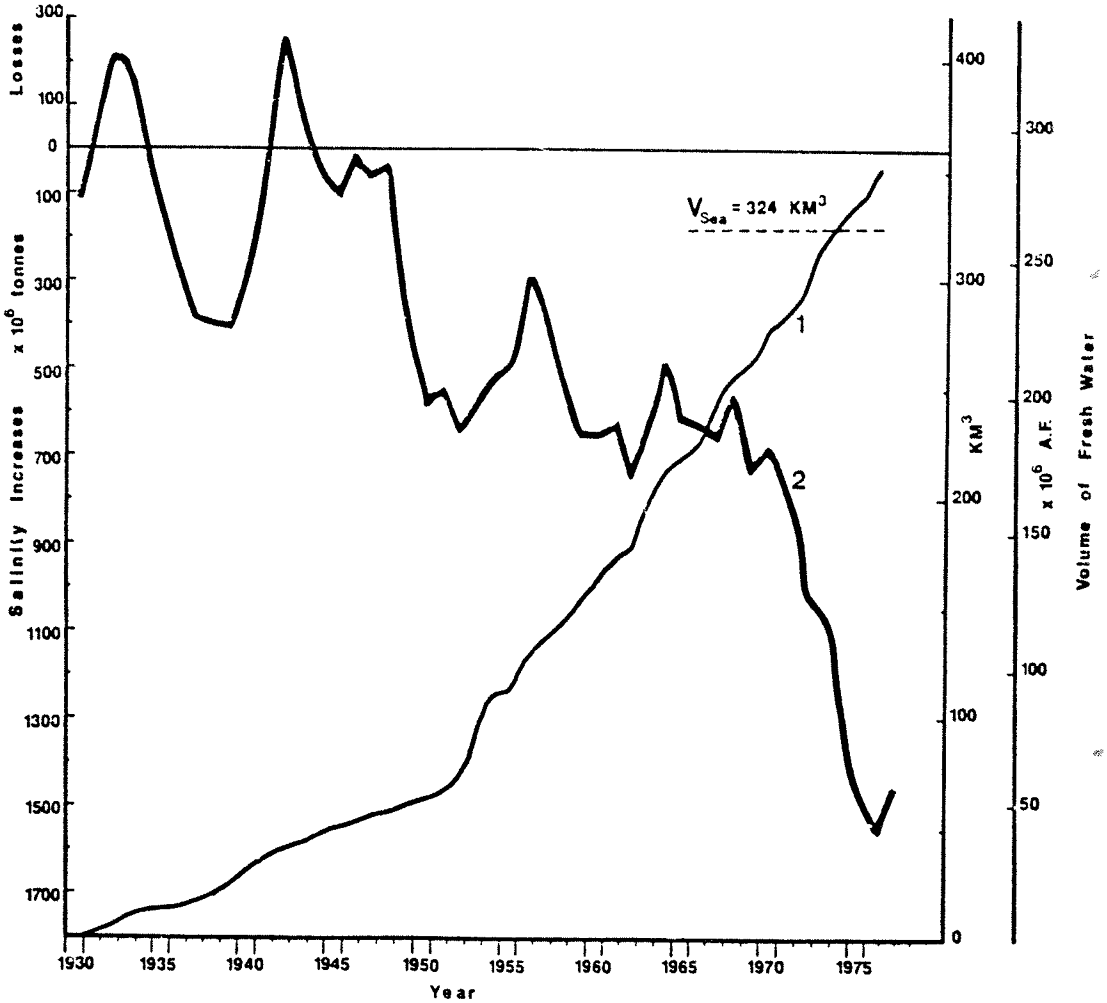

Fig. 5A. Cumulative curves: (1) freshwater losses and (2) accumulation of salinity in the Sea of Azov.

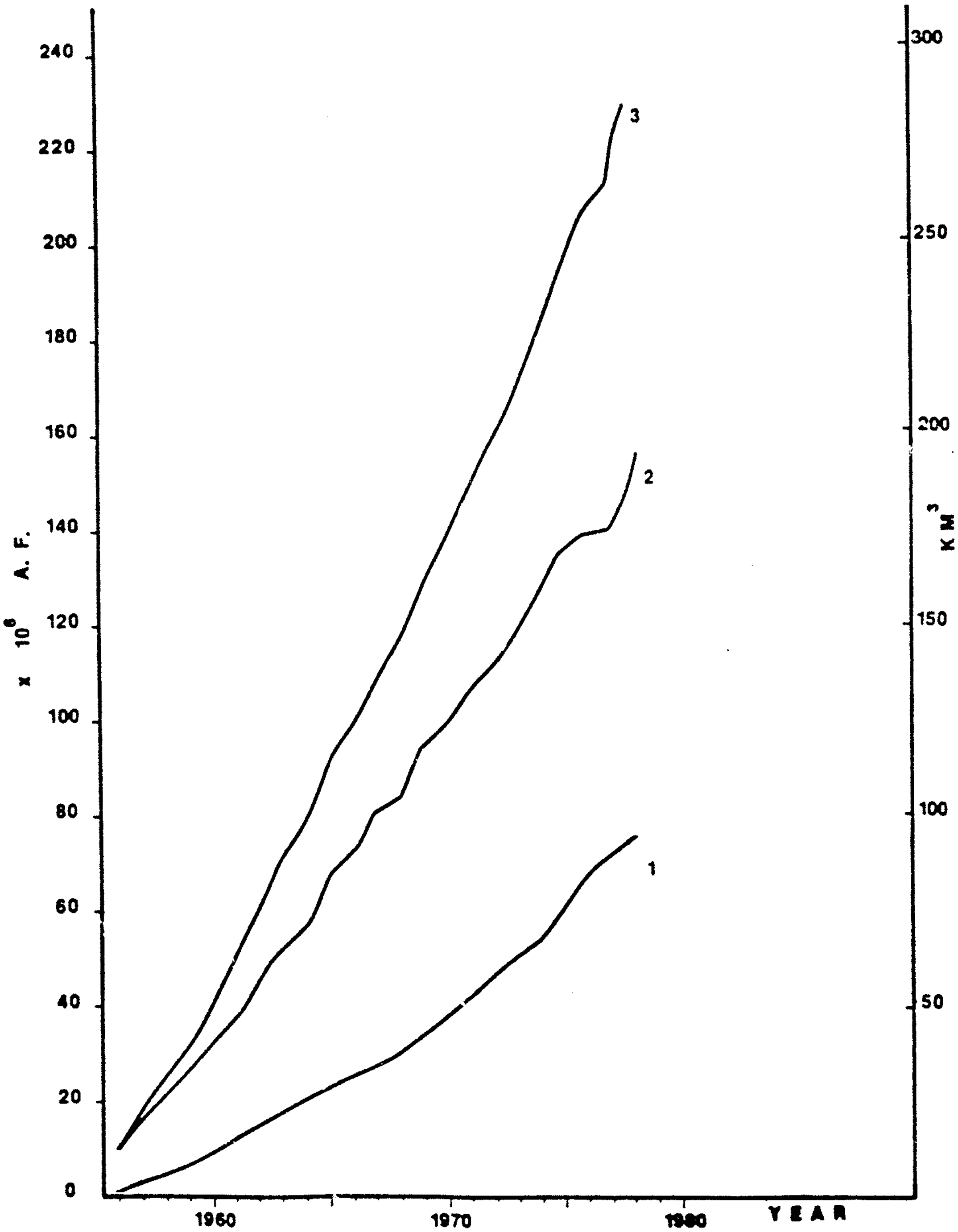

Fig. 5B. Cumulative quantity of freshwater diverted (and so lost to the Delta/Bay system) from withdrawals (1) within the Delta, (2) upstream of the Delta and (3) combined.

This pronounced trend of declining water supply had a number of negative impacts on physical properties and biological productivity of both the Sea of Azov and the San Francisco Bay estuarine systems:

1. An increase in the frequency of salt intrusion into the upper part of the Delta and Bay (Cloern and Nichols, 1985a; Nichols et. al. 1986) and, in the case of the Sea of Azov, into the Don and Kuban River estuarine systems (Bronfman, 1977; Remisova, 1984a, b).

2. An increase of mean salinity in San Francisco Bay from approximately 20 ppt (under outflow conditions of 34.2 km^3 or 27.7 MAF; Rozengurt, 1983b) to 27 ppt (15-17 km^3 or 12.2-13.8 MAF) and, for the same period for the Sea of Azov, from 9 ppt (43.0 km^3) to 16 ppt (21-25 km^3). These changes represent mean increases of 0.3 ppt and 0.4 ppt per hyrological year, respectively, for the two water bodies.

3. Significant reduction in the size and biological productivity of the "entrapment" (null) zones have occurred in the Delta and San Francisco Bay during the summer months. Compression of these nursery zones, their upstream movement, and the resulting changes in their biochemical and biological properties have been implicated as factors responsible for low survival rates of eggs, larvae, and fry and for significant population decreases (California Department of Fish and Game, 1976; Herrgesell et. al. 1983; Cloern and Nichols, 1985b).

4. Reduction of sediment load discharge to the Delta-Bay Coastal Zone ecosystem (60-75 percent of the $8x10^6$ tonnes discharged per year for mean natural runoff conditions; Krone, 1979). This leads us to speculate that the absence of sediment may be partially responsible for levee failures in the Delta as well as for increased beach erosion in the near coastal zone, since both depend on deposition of sediment (each receives at least 30 percent of the Delta and Bay's sediment load; Kockelman et. al. 1982).

5. In the Sea of Azov, there has been a 60 percent reduction in primary and secondary productivity and over 95 percent reduction in catches of anadromous fish (Goldman and Maysky, 1972; Makarov, et. al. 1982; Remisova, 1984a, b: Figure 6A) resulting from diversions of more than 60 percent of historic spring (and more than 45 percent of annual) flows. Russian scientists have determined that the reduction of runoff of about 1 km^3 reduces the Sea of Azov anadromous

fish stocks by about 3,000 tonnes (Marti and Musatov, 1973; Bronfman, 1977).

These flow modifications have also led to a 40-60 percent reduction in nutrient supply, decreases of 60-70 percent of sediment load and 80 percent reduction in spawning and nursery areas, with salt intrusion compressing the null zone into the pre-Delta and Delta areas and salinity increasing from 0.5 to 10 ppt (Baydin, 1980; Makarov, et al., 1982; Remizova, 1984a,b; Volovic, 1986). Numerous attempts to stop the destruction of the Sea of Azov have failed. The institution of extensive fishery regulations and the release of more than 5.5 billion hatchery-reared fry in 1976 and hundreds of millions of fry of anadromous and semi-anadromous fish between 1956-76 did not mitigate the detrimental effect of excessive water diversions on living resources of the ecosystem.

Further, when the mean salinity of the Azov seawater stabilized at 14-16 ppt in the late 1970s (compared to 9.5 ppt in the 1930s), there was an invasion of marine species. The billions of medusae (Figure 6B) that moved into the Sea of Azov (Makarov, et al., 1982) and into its formerly less brackish Taganrog Harbor and Don River Delta (Figure 1) from the Black Sea presented a serious threat to the survival of many indigenous species. These jellyfish have created severe problems in the Sea of Azov such as food competition between them and fish, and public health problems along hundreds of kilometers of beaches created by accumulation of dead medusae.

6. Although the San Francisco Bay estuarine system has not yet deteriorated to the level of the Sea of Azov, the impact of freshwater diversion on the survival of living estuarine resources in both systems has many alarming similarities: accumulation of organic and inorganic compounds from agricultural drainage; saltwater intrusion along the deep channels into the Bay and Delta (Orlob, 1977); gradual salt buildup throughout the estuary; and spontaneous algal blooms (Cloern and Nichols, 1985a; Nichols et al., 1986). In addition, the alteration of the Delta into a sophisticated plumbing system has led to disruption of fish migration routes and their spawning and nursery areas (Moyle, 1976; California Department of Fish and Game, 1976, 1983; Striped Bass Working Group, 1982; Herrgesell, et al., 1983) and a significant reduction of flushing intensity and circulation in all parts of the Bay (Rozengurt, 1983a; Cloern and Nichols, 1985a). All of these factors have contributed to diminishing

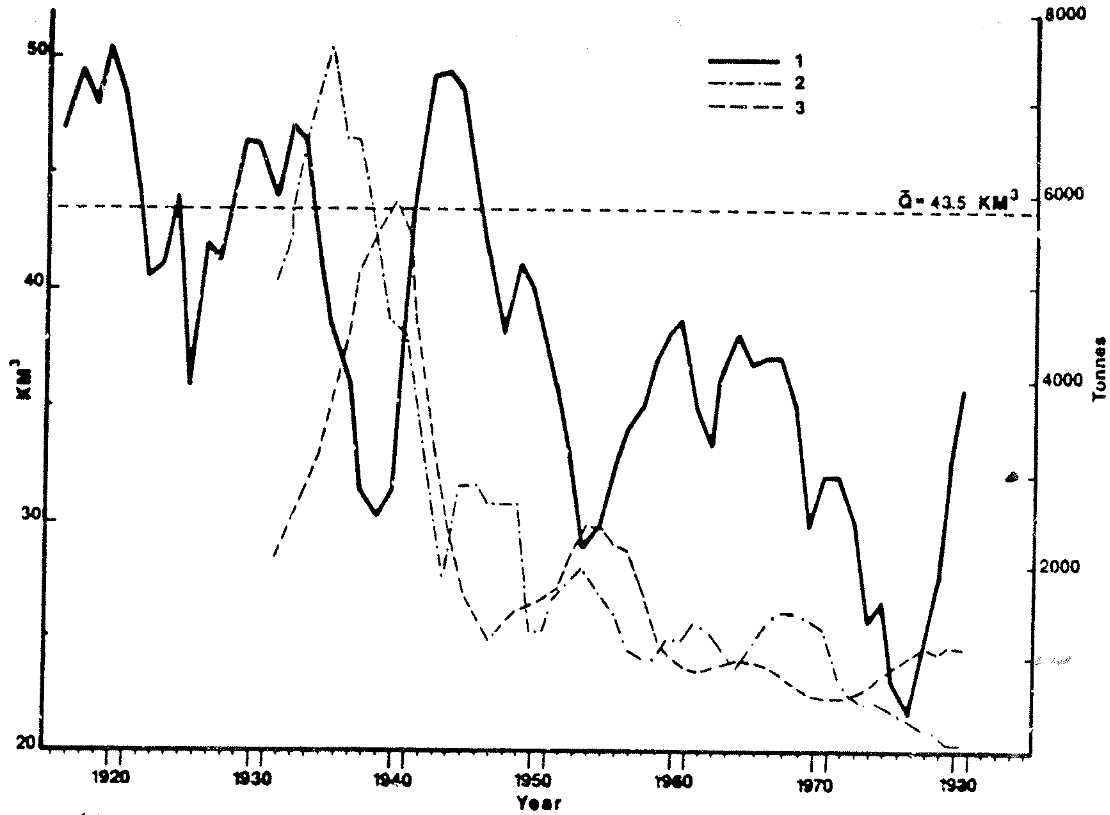

Fig. 6A. Fluctuations in the 5-year running average of (1) regulated combined river inflow to the Sea of Azov and commercial catch of anadromous fish (2) Russian sturgeon (Acipenser guldenstadti), Beluga (Huso huso L.) and sevruga (Acipenser stellatus Palas), (3) Kerch (Black Sea) shad (Alosa kessleri pontica).

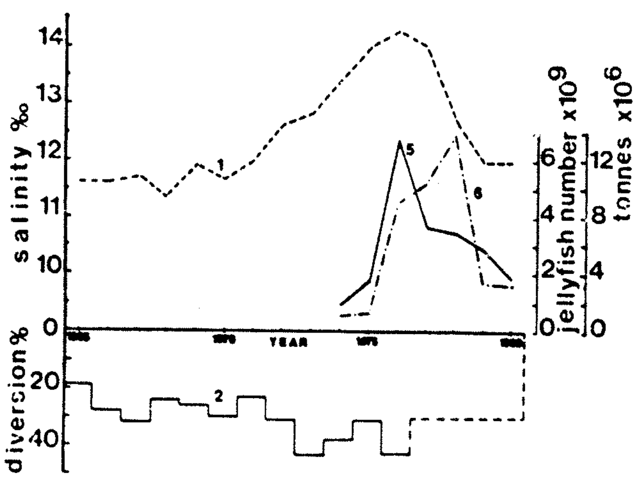

Fig. 6B ·Population explosion of the marine jellyfish (Aurelia) inside the formerly brackish Sea of Azov as a result of increased freshwater diversions and the resulting rise in salinity concentrations. (1) Annual average salinity, (2) combined average annual freshwater diversions expressed as a percentage of the natural runoff to the Sea of Azov, (5) raw weight of jellyfish (Aurelia aurita and Rhizostoma) in millions of tonnes, (6) combined number of jellyfish in billions.

catches of anadromous fish in the Bay and the adjacent coastal zone, and threaten the sport landing of fish and shellfish in the Bay as a whole.

7. Correlations of records of commercial catches of salmon, striped bass, and shad with spring runoff to the San Francisco Bay (2-4 year means) for pre-project years (1915-1940) indicate that there were significant landings only when spring Delta outflows were 3.7-6.2 km^3 (3-5 MAF) for the preceeding 2-4 years. High correlations between mean annual Delta outflow and landings of striped bass, salmon, and shad strongly support the hypothesis that at least 23.4 km^3 (19.0 MAF) or 70 percent of the long-term average must reach the Bay during the 3-5 years prior to the year of catch to ensure successful commercial landings. The use of lag times or averages of water flow over several years to predict fishery abundance has been documented in other estuarine systems (Therriault and Levasseur 1986; Sutcliffe et al., 1977). It is important to use averages which correspond to the reproductive maturity of the fish. Figure 7 A-D shows some of these correlations. In contrast, the current range of mean annual and spring water supply to the Bay for the same time lag is 1.5-2.5 and 2-5 times less than the long-term average, respectively. The relative value of negative deviations of 5-year running mean freshwater supply to the Bay has dropped 60-85 percent below "normal" spring, and 45-60 percent below "normal" annual Delta outflow for the period 1921-1980.

In recent years, commercial fishing has been prohibited in San Francisco Bay and Delta waters (since the late 1950s for salmon and shad, and since 1935 for striped bass). Nevertheless, sport catches of these species have declined to as little as 30 percent of levels of 20 years ago despite a great increase in sportfishing effort, improved treatment of sewage discharges, and massive hatchery releases.

8. Figure 8A illustrates the steady decline of 3-year running means of regulated spring Delta outflow since 1954. The deviations (negative) of water supply to the Bay from mean natural Delta outflow were nearly 80 percent for most of the springs of the 1970s (Figure 8B). This demonstrates that the estuarine system was deprived of significant amounts of freshwater and implies that the high levels of diversion are responsible for the drastic decline in striped bass catches (Figure 8C) and the Striped Bass Index (Figure 8D). Note the relationship between flow (Figure 8A), and catch (Figure 8C) with 3-year lag, e.g., 1954-56

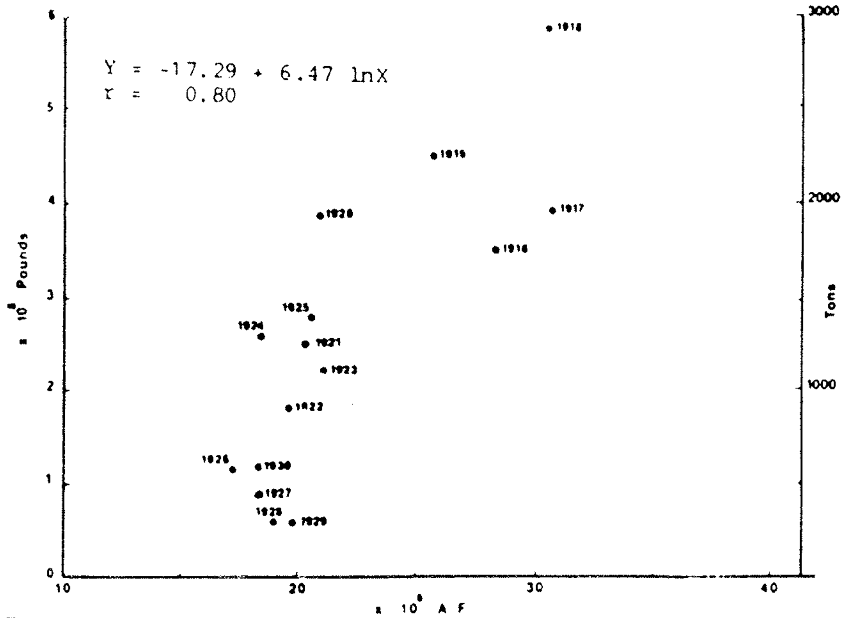

Fig. 7A. The relationship between annual salmon catch in the Sacramento-San Joaquin rivers and upper San Francisco Bay and the mean regulated Delta outflow to San Francisco Bay for five running years. Each salmon catch is the amount caught in the last year of five previous running years of outflow (e.g. salmon catch for 1918 is based on outflow for 1914-1919).

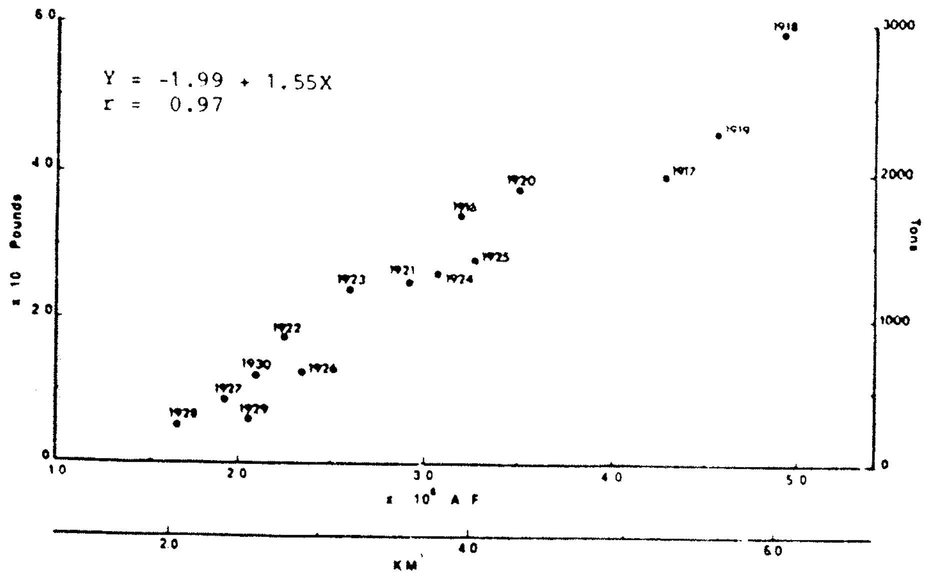

Fig. 7B. The relationship between annual commercial salmon catch in the Sacramento-San Joaquin rivers and upper San Francisco Bay and the mean Delta regulated outflow for a period of three running months (April-May-June). Each year's salmon catch is based on a lag outflow period of two years after the last spring Delta outflow to the Bay and for two years previous (e.g. salmon catch for 1916 is based on April-May-June outflow for 1912-1914).

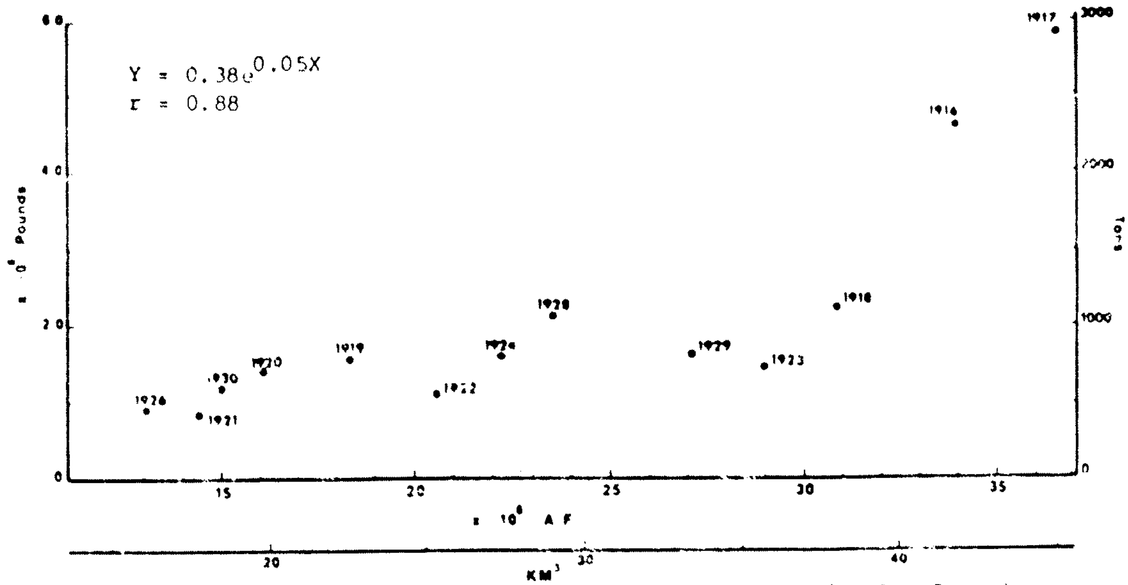

Fig. 7C. The relationship between annual shad catch in the San Francisco Bay area and the mean regulated Delta outlflow to San Francisco Bay for two running years. Each annual catch is based on a lag outflow period of one year after the last of two years of previous Delta outflow (e.g. shad catch for 1916 is based on outlfow for 1914-1915).

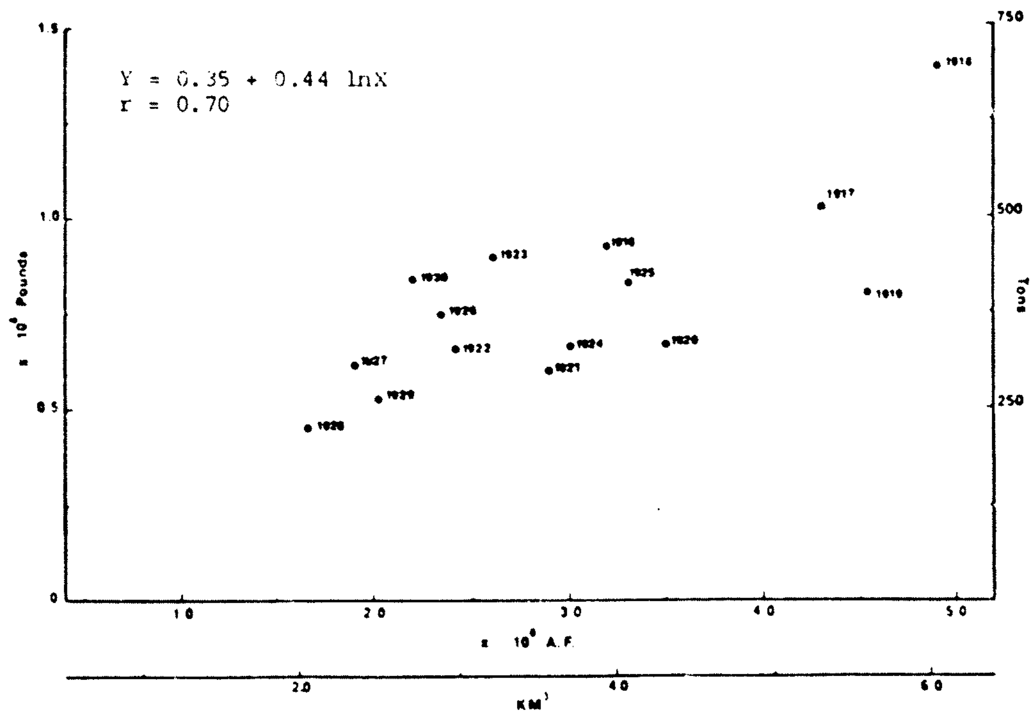

Fig. 7D. The relationship between annual striped bass catch in the San Francisco area and the mean Delta regulated outflow to San Francisco Bay for a period of three running months (April-May-June). Each annual striped bass catch is based on a lag outflow period of two years after the last spring Delta outflow to the Bay and for two years previous (e.g. striped bass catch for 1917 is based on April-May-June outflow for 1913-1915).

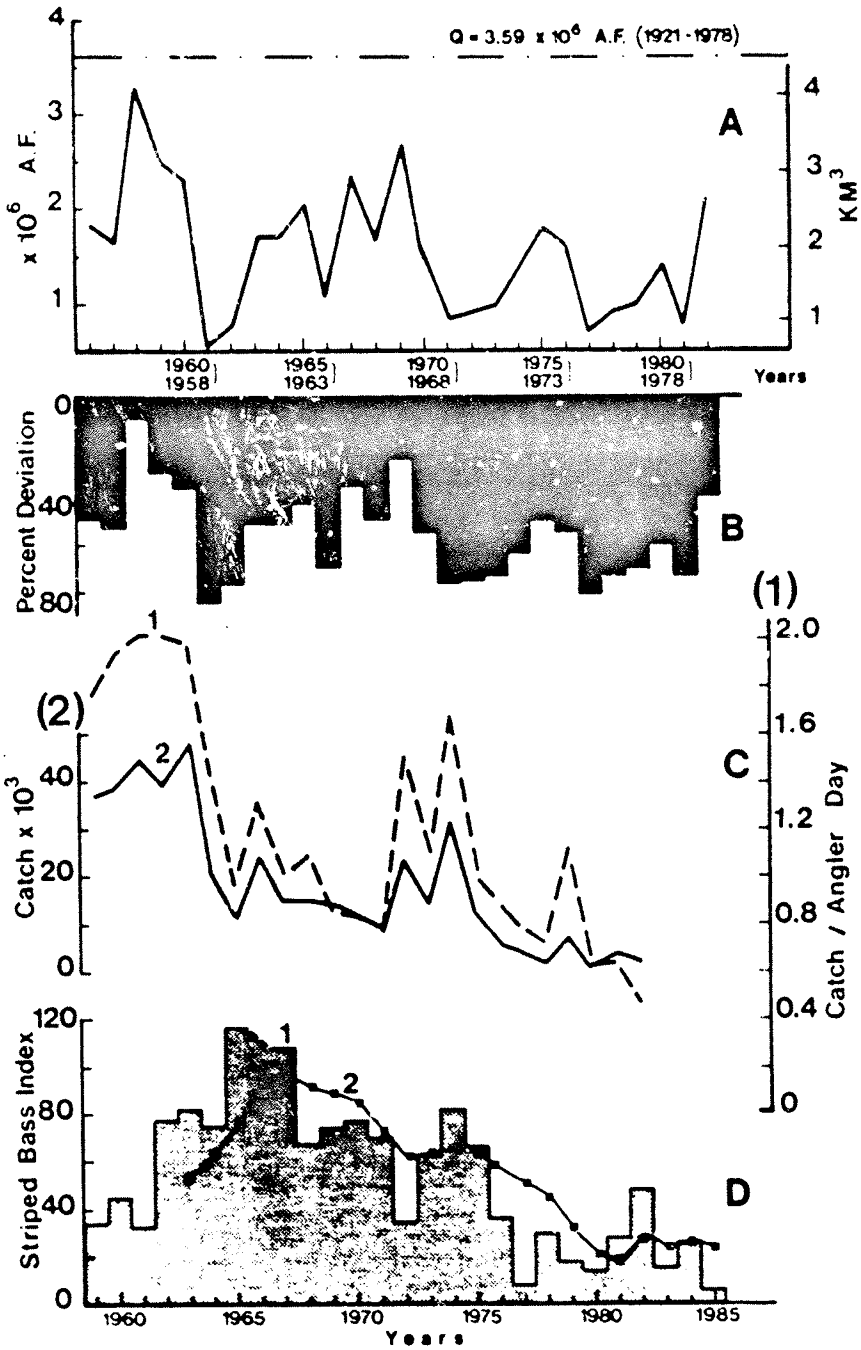

Fig. 8. (A) Fluctuations of Delta regulated water supply to San Francisco Bay during spring (April-June). Data represent 3-year running means (e.g., 1958-1960). (B) Deviation in percentage of Delta regulated water supply to San Francisco Bay of mean spring natural runoff. (C-1) San Francisco Bay striped bass party boat catch/angler day (1959-1982). (C-2) Total striped bass party boat catch/season in number of fish (1959-1982). (D-1) Annual juvenile striped bass abundance index (1959-1985). (D-2) Five-year running means of striped bass abundance index (1959/63-1981/85).

flow/1959 catch). Regressions between sportfishing catches of striped bass for this period and Delta outflow for the 3 years preceeding the year of catch with a 0-2 year time lag are similar to those between striped bass commercial catch and flow shown in Figure 8.

9. In the literature on the status of Chinook salmon spawning populations in the Sacramento-San Joaquin watershed, four factors have been proposed to explain their precipitous population decline: dams, water diversions, pollutants, and the loss of habitat (California Department of Fish and Game, 1983). The early winter run is considered a major source of recruitment for this stock (Hallock and Fisher, 1985). Between 1967-1982, when reliable counts were made of winter salmon runs, the 5-year running means of regulated spring water supply to the estuary was about 35-80 percent of spring perennial mean runoff (1921-1978). The average annual volume of water diversion was approximately 12.2 km^3 (11.0 MAF; Figure 9) and cumulative withdrawals from the Sacramento-San Joaquin river water supply to the estuarine system reached about 190 km^3 (158 MAF; Figure 9A) between 1967 and 1982. During the same period the number of winter-run Chinnok salmon returning to spawn in the upper part of the Sacramento River was reduced as much as 60 times (Figure 9D, Hallock and Fisher, 1985) despite attempts to mitigate this decline with release of millions of hatchery-reared juveniles (Figure 9C, California Department of Fish and Game, 1983).

While all of the factors mentioned above may contribute to reduction of the salmon population in this watershed, our data strongly suggest that overall reduction of runoff and cumulative losses of water and biochemical constituents resulting from diversions will continue to be the principal factors governing migration, spawning success, and recruitment in this stock. Kjelson et al. (1982) also attribute decreases in salmon populations to increases in water diversions. They found that the March-June runoff of up to a total of 8.6 km^3 (7 MAF), lagged 2.5 years, may provide optimal conditions for Chinook salmon spawners during nursery migration. Similar deterioration of ecological conditions and biological productivity following excessive freshwater withdrawals has occurred in estuaries in Africa, Asia, Australia, Europe, and the United States. (Hedgpeth, 1970; Aleem, 1972; Baydin, 1980; Cross and Williams, 1981; L'vovich, 1974; Meleshkin et al., 1973; Mancy, 1979; Rozengurt, 1971, 1974, 1983a, b; Rozengurt and Herz, 1981; Mann, 1982; Tolmazin, 1985; and White, 1977).

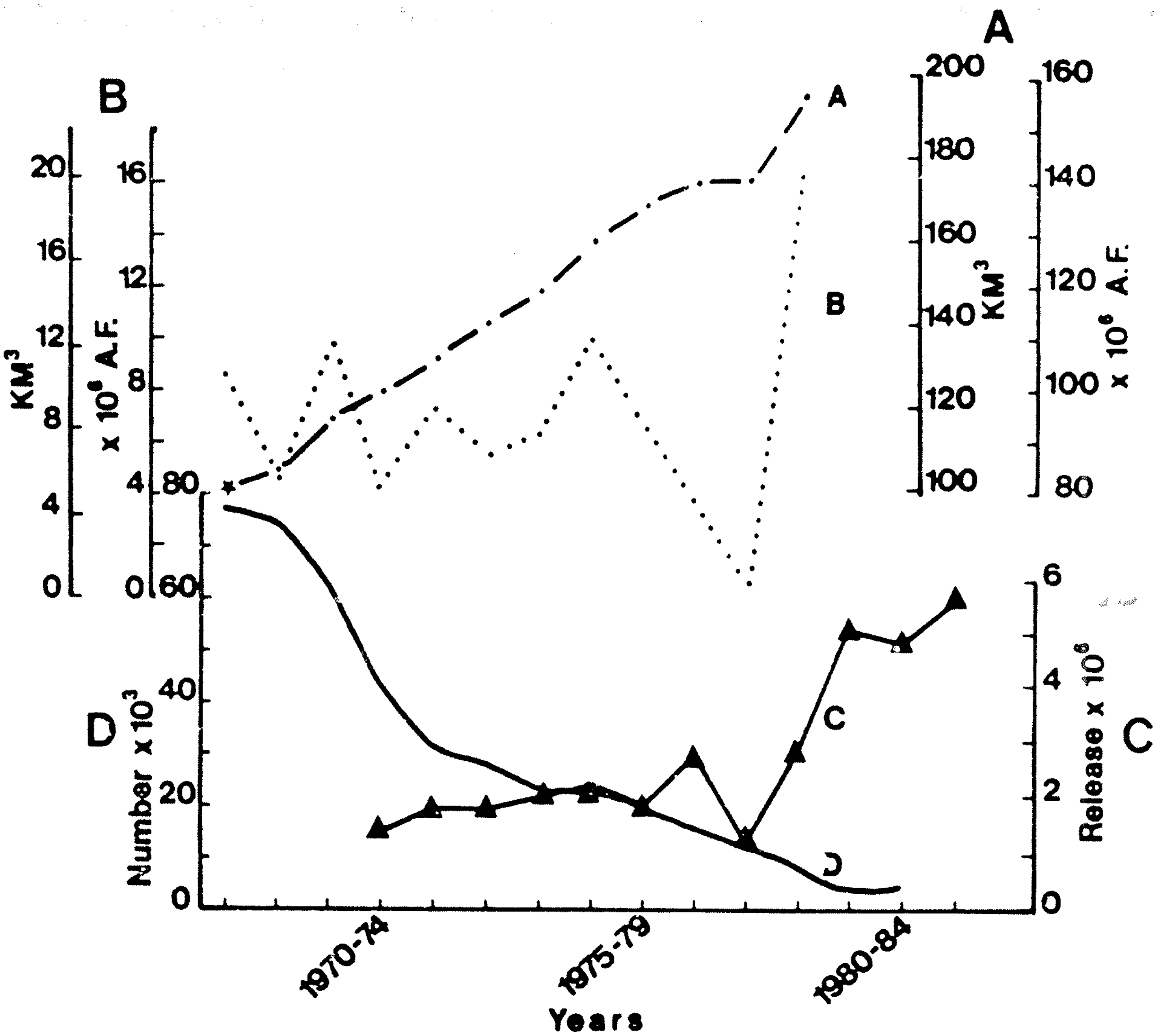

Fig. 9. (A) Cumulative combined upstream diversions of the Sacramento-San Joaquin river systems (1967/69-1977/78). First data point is sum of diversions from 1955-1967. (B) Annual gross upstream diversions of the Sacramento-San Joaquin river systems (1967-1978). (C) Annual release of yearling chinook salmon juveniles from California State hatcheries (1970-1981). (D) Five-year running mean of winter-run spawning salmon past the Red Bluff diversion dam (1967/71-1980/84).

Conclusions

Since the late 1950s, diversions of water from the San Francisco Bay watershed have increased from 20-30 percent to as much as 63 percent annual runoff and from 30-35 percent to 60-85 percent for spring runoff (April-June). During the same period, the predominant ranges of negative deviations from the "normal" runoff (1921-1978) for the 5-year running means of annual discharges (regulated) to the Delta and Bay is 35-60 percent, the range is 40-85 percent for the spring discharges. Without regulation, outflow deviations of natural water supply for both annual and spring 5-year running means of normal runoff varied only 15-25 percent from the same mean value. Overall, between 1955 and 1978, (a period when the major water storage and diversion facilities were fully operational about 286 km^3 (240 MAF), or as much as 40 times the volume of San Francisco Bay, was diverted from the system.

These reductions of freshwater flow to the estuary have: greatly increased salt intrusion into Delta waters, threatening agricultural and municipal water intakes; produced massive reduction of nutrients and sediment load; and greatly reduced flushing and circulation activity formerly accomplished by heavy spring inflows.

Concurrent with these flow-related changes, there have been massive reductions of fish populations. Salmon are down to 30 percent of 1960s levels, while striped bass are down to 20 percent of their levels of 20 years ago. Statistical analyses reflect an underlying relationship between catch of salmon, striped bass, and shad and freshwater flow to the estuary for the preceeding 2-4 years.

High correlations obtained between commercial fish catches (prior to construction of California water projects) and running mean Delta outflow indicate that annual water supply had to be at least 23.0 km^3 (19.0 MAF) and spring runoff (April-June) in the range of 3.1-3.7 km^3 (2.5-3.0 MAF), 69 percent and 68-84 percent of the historic unimpaired flow, respectively, for the 2-4 preceding years to ensure optimal commercial catch. Similar analyses for successful sportfishing catches (post project construction) show that annual mean flows of 21.0 km^3 (17.0 MAF) and spring Delta outflows of 2.5-3.1 km^3 (2.0-2.5 MAF) are needed for the 2-3 preceding years to ensure significant catches. However, during 1967-1982 (CVP and SWP operating at full capacity), the 3-5 year running mean spring and annual water supply into and out of the Delta was several times less than this.

The result has been a major impact on recruitment and recreational catches of striped bass and salmon since the late 1960s. Salmon and striped bass natural reproduction has been reduced 65 percent and 80 percent, respectively, over the past

20 years (California Department of Fish and Game 1983). The direct economic impact for the last two decades has been losses of about 1.3 billion dollars (Meyer Resources, 1985).

In the Sea of Azov, diversions of more than 60 percent of historic spring (and more than 45 percent of annual) flows have resulted in:

1. Distortion of circulation dynamics and reduction in vertical mixing (increases in vertical stability index) as much as 3-5 times resulting in significant increases in frequency of anoxic conditions in deep water near the bottom, covering as much as 60 percent of the sea area (Volovic, 1986).

2. Accumulation of more than 1,500 x 10^6 tonnes of salt and an overall increase of the mean salinity from 9-9.5 to 14-16.0 ppt and in the pre-Delta areas from 0.5-3.0 to 6-10.0 ppt for the last two decades.

3. Reduction of 60-75 percent (2 x 10^6 tonnes) in sediment load, and 80 percent in spawning and nursery areas.

The resulting economic losses for fisheries since the late 1960s have been tens of millions of dollars per year (Meleshkin _et_. _al_. 1973, 1981; Vorovich _et_. _al_. 1981).

These and other similar historical examples of the relation between human needs for freshwater and protection of estuarine environments (Mann, 1982; Meleshkin, 1981; Rozengurt and Tolmazin, 1974; Rozengurt and Herz, 1981) indicate that special consideration should be given to the consequences of timing and volume of water withdrawals on recruitment and landings of anadromous fish, because of their sensitivity to cumulative fluctuations in freshwater supply. It may be possible to alleviate these problems and to protect freshwater intakes in the Delta if limits to water diversion can be agreed upon. Perhaps this can be done through the establishment of salinity and flow standards for San Francisco Bay (neither of which currently exists). In addition, Rozengurt (1983a) has suggested a restraining channel be constructed in part of the existing ship channel in San Pablo Strait (2 walls 1-3 kilometers long and 200 meters apart, extending from the bottom to just above the high tide level). Hydrological model testing of this design will be required to determine its effectiveness in limiting salt intrusion into Suisun Bay and the Delta (Rozengurt, 1971, 1974).

Acknowledgements

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References

Aleem, A.A., 1972: Effect of river outflow management on marine life. Marine Biology. 15:200-208.

Baydin, S.S., 1980: Redistribution of river runoff between sea basins and its role in the environmental complex of seas and river mouths. Soviet Hydrology: Selected Papers, 19:86-93. (American Geophysical Union)

Bronfman, A.M., 1977: The Azov Sea water economy and ecological problems; investigations and possible solutions. In G.F. White (ed.) Environmental Effects of Complex Estuaries. Boulder, CO. Westview Press, 39-58.

California Department of Fish and Game, 1976: Report to the State Water Resources Control Board on the Impact of Water Development on Fish and Wildlife Resources in the Sacramento-San Joaquin Estuary. Sacramento, CFG Exhibit #3, November, 1976.

California Department of Fish and Game (Anadromous Fisheries Branch), 1983: Salmon Management in California. Prepared for the Pacific Fisheries Management Council.

California Department of Fish and Game (Division of Planning), 1980: California Central Valley Natural Flow Data. Sacramento, CA, State of California Resources Agency.

Chadwick, H.K., 1971: Striped bass and water development in the Sacramento-San Joaquin Estuary. In A Symposium on the Biological Significance of Estuaries, Vol. II. Washington, D.C., Sport Fishing Institute, 58-68.

Champ, M.A.; Villa, O; and Bubeck, R.C. (1981): Historical overview of freshwater inflow and sewage treatment plant discharges to the Potomac River estuary with resultant nutrient and water quality trends. In: Proceedings of the National Symposium on Freshwater Inflows to Estuaries. Vol. II. San Antonio Fish and Wildlife Service, U.S. Dept. of Interior, 350-373.

Clark, J. and Benson, N.G., 1981: Summary and recommendations of symposium. In R.D. Cross and D.L. Williams (eds.) Proceedings of the National Symposium on Freshwater Inflow to Estuaries, Vol. II, Washington, D.C., U.S. Department of Interior, 523-528.

Cloern, J.E., and Nichols, F.H., 1985a: Time Scales and mechanisms of estuarine variability; synthesis from studies of San Francisco Bay. In J.E. Cloern and F.H. Nichols (Eds.) Temporal Dynamics of an Estuary-San Francisco Bay. Dordrecht, Netherlands. Dr. W. Junk Publishers, 229-237.

Cloern, J.E., and Nichols, F.H., (eds.), 1985b: Temporal Dynamics of an Estuary-San Francisco Bay. Dordrecht, Netherlands. Dr. W. Junk Publishers.

Cronin, L.E., 1967: The role of man in estuarine processes. In: G.H. Lauff. (ed.), Estuaries. Washington, D.C., American Association for the Advancement of Science, Publication No. 83, 667-689.

Cross, R.D., and D.L. Williams (eds.), 1981: Proceedings of the National Symposium on Freshwater Inflow to Estuarine, Vols. I and II, Fish and Wildlife Service, FWS/OBS-81?04, Washington, D.C., U.S. Dept. of the Interior.

GOIN, 1972: Present and projected water and salt balance of the southern seas of the U.A.S.R. Moscow, U.S.S.R. Transactions of the Government Oceanographic Institute. (GOIN), No. 108 (In Russian).

Goldman, E.J., and V.N. Maysky, 1972: Dynamics of commercial fish catch of the Sea of Azov and the causes of their fluctuation. In Investigations of the Fisheries of the Sea of Azov: Conference Proceedings, June 13-15, 1972. Postov-on-Don, Ministry of Fisheries of the U.S.S.R. (In Russian).

Hallock, R.J., and F.W. Fisher, 1985: Status of Winter-Run Chinook Salmon, Onchorhynchus tshawytscha, in the Sacramento River. AFB Office Report. Sacramento, California Department of Fish and Game, Anadromous Fisheries Branch.

Hedgpeth, J.W. 1970. Statement in The Nation's Estuaries: San Francisco Bay and Delta. Subcommittee on Government Operations, House of Representatives, 91st Congress, 2nd Session, 361-386.

Herrgesell, P.L.; R.G. Schaffter; and C.J. Larsen, 1983: Effects of Freshwater Outflow on San Francisco Bay Biological Resources, Sacramento, CA, Department of Fish and Game, State of California Technical Report #7.

Kelley, D.W.; and W.E. Tippets; 1977: Delta outflow and San Francisco Bay. A report prepared for the Delta Environmental Advisory Committee of the California DWR, 32pp.

Kjelson, M.A.; Raquel, P.F.; and Fisher, F.W., 1982: Life history of fall-run juvenile Chinook Salmon, Onchorhynchus tshawytscha, in the Sacramento-San Joaquin estuary, California. In V.S. Kennedy, (Ed.) Estuarine Comparisons, New York, Academic Press, 393-411.

Kockelman, W.T.; T.J. Connors; and A.E. Leviton (eds.) 1982: San Francisco Bay: Use and Protection. San Francisco. Pacific Division of the AAAS.

Krone, R.B., 1979: Sedimentation in the San Francisco Bay system. In T.J. Conomos, (ed.) San Francisco Bay: The Urbanized Estuary. San Francisco. Pacific Division of the AAAS.

Lauff, G.H. (Ed.), 1967: Estuaries. Washington, D.C., American Association for the Advancement of Science, Publication No. 83.

L'vovich, M.T., 1974: World Water Resources and Their Future. Translation, 1979. American Geophysical Union.

Makarov, E.H.; V.P. Zakutskij; and V.V. Guskov, 1982: The assessment of the stock of the Azov Sea-Black Medusae and recommendations for their utilization in the national economy. In Biological Productivity in the Azov and Caspian Seas, Ministry of Fisheries of the V.S.S.R., Moscow, VNIRO, 107-113. (In Russian).

Mann, K.H., 1982: Ecology of Coastal Waters, A Systems Approach. Berkeley, CA, University of California Press.

Mancy, K.H., 1979: The Aswan High Dam and Its Environmental Implications. Nairobi, Kenya. Socita Internationalis Limnologiae Workshop on Limnology of African Lakes. December, 1979.

Marti, U.U., and Musatov,, A.D., 1973: Management of water regimes is responsible for the success of fisheries. In: The Problems of Regulation and Use of Water Resources. Moscow, Nauka (Science), p. 179-192.

Meleshkin, M.T., 1981: Econologic Problems of the World Oceans. Moscow, Economics, 279pp.

Meleshkin, M.T.; Rozengurt, M.A.; and Tolmazin, D.M., 1973. The problems and methods of improving efficiency of use of water resources of the Sea of Azov basin: economic and hydrological aspects. ODESSA Journ. The Problems of the Economy of Sea and the World Ocean, Ac. of Sci., UKSSR V. 2. 3-15.

Meyer Resources, 1985: The Economic Value of Striped Bass, Morone saxatilis, Chinook salmon, Oncorhyncus tshawytscha, and Steelhead Trout, Salmo gairdneri, of the Sacramento and San Joaquin River Systems. Sacramento, CA. Dept. of Fish & Game, Anadromous Fisheries Branch, Administrative Report No. 85-3.

Moyle, P.B., 1976: Inland Fishes of California. Berkeley, University of California Press.

Nichols, F.H.; J.E. Cloern; S.N. Luoma; and D.H. Peterson, 1986: The modification of an estuary. Science, 231:567-573.

Officer, C.B., 1976: Physical Oceanography of Estuaries (and Associated Coastal Waters.) New York, J. Wiley & Sons.

Orlob, G.T., 1977: Impact of upstream storage and diversions on on salinity balance in estuaries. Estuarine Processes, V. 2. Ac. Press, 3-17.

Remisova, S.S., 1984a: Water balance of the Sea of Azov. Journal of Water Resources, 1:109-121.

Rozengurt, M.A., 1971: Analysis of the impact of the Dniester River regulated runoff on the salt regime of the Dniester Estuary. Kiev, Scientific Thought, Ac. of Sci., USSR, 132pp. Library of Congress GB2308.B55R69.

Rozengurt, M.A., 1974: Hydrology and prospects of reconstruction of natural resources of the north-western part of the Black Sea estuaries. Kiev. Scientific Thought, Ac. of Sci. USSR, 224pp. Library of Congress GB2308.B55R69.

Rozengurt, M.A., 1983a: On environmental approach to protecting estuaries from salt intrusion. In O.T. Magoon and H. Converse (eds.) Coastal Zone '83: Proceedings of the Third Symposium on Coastal and Ocean Management, Vol. III., New York. American Society of Civil Engineers, pp. 2279-2293.

Rozengurt, M.A., 1983b: The Environmental Effect of Extensive Water Withdrawals on the River-Estuary-Sea Ecosystem, Part II. Sacramento, CA, State of California Resources Agency, Department of Water Resources, 157 p.

Rozengurt, M.A. and I. Haydock, 1981: Methods of computation and ecological regulation of the salinity regime in estuaries and shallow seas in connection with water regulation for human requirements. In R.D. Cross and D.L. Williams (eds.) Proceedings of the National Symposium on Freshwater Inflow to Estuaries, Vol. II. Washington, D.C., U.S. Dept. of the Interior, 474-506 pp.

Rozengurt, M.A. and M.J. Herz, 1981: Water, water everywhere, but just so much to drink. Oceans, 14:65-67.

Rozengurt, M.A. and Tolmazin, D.M., 1974: The conflict between energetics and nature. Kiev, Science and Society, No. 10, 6-9.

Skinner, J.E., 1962: An Historical Review of the Fish and Wldlife Resources of the San Francisco Bay Area. Sacramento, CA. Department of Fish and Game, Water Projects Branch, Report #1.

Smith, S.E., and S. Kato, 1979: The fisheries of San Francisco Bay: Past, present, and future. In Conomos, T. (Ed.) San Francisco Bay: The Urbanized Estuary, San Francisco. Pacific Division of the AAAS 445-468pp.

Sokolov, A.A., and T.G. Chapman (eds.) 1974: Methods for Water Balance Computations. Paris. UNESCO Press.

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

Striped Bass Working Group, 1982: The Striped Bass Decline in the San Francisco Bay-Delta Estuary. Sacramento, CA. California State Water Resources Control Board.

Tolmazin, D.M., 1985: Changing coastal oceanography of the Black Sea. In: M.U. Angel and R. Smith (eds.) Progress in Oceanography Volume 15. New York, Pergamon Press, 217-276pp.

UNESCO, 1974: International Glossary of Hydrology. Geneva, UNESCO Press, p. 90.

Volovic, S.P., 1986: The fundamental features of transformation of the Sea of Azov ecosystems in connection with industrial and agricultural development in its watershed. Voprocy Ikhtiology (The Problems of Ichthyology). Ac. of Sci., USST, V. 6. 1:33-47. (In Russian; English translation, Scripta Technica, Wiley & Sons, 1986).

Vorovich, I.A., Gorstko, A.B., and Dombrovsky, U.A., 1981: Rational use of the Sea of Azov resources: mathematical modeling. Nauka ("Science"), Moscow, 359pp.

White, G. (ed.) 1977: Environmental Effects of Complex River Development. Boulder, CO. Westview Press.

Zenkevitch, L. 1963: Biology of the Seas of the U.S.S.R. London, George Allen and Unwin, Ltd.

THERMAL DYNAMICS OF ESTUARINE PHYTOPLANKTON: A CASE STUDY OF SAN FRANCISCO BAY

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Abstract

Detailed surveys throughout San Francisco Bay over an annual cycle (1980) show that seasonal variations of phytoplankton biomass, community composition, and productivity can differ markedly among estuarine habitat types. For example, in the river-dominated northern reach (Suisun Bay), phytoplankton seasonality is characterized by a prolonged summer bloom of netplanktonic diatoms that results from the accumulation of suspended particulates at the convergence of nontidal currents (i.e. where residence time is long). Here turbidity is persistently high, such that phytoplankton growth and productivity are severely limited by light availability, the phytoplankton population turns over slowly, and biological processes appear to be less important mechanisms of temporal change than physical processes associated with freshwater inflow and turbulent mixing. South Bay, in contrast, is a lagoon-type estuary less directly coupled to the influence of river discharge. Residence time is long (months) in this estuary, turbidity is lower and estimated rates of population growth is high (up to 1-2 doublings d^{-1}) but the rapid production of phytoplankton biomass is presumably balanced by grazing losses to benthic herbivores. Exceptions occur for brief intervals (days to weeks) during spring when the water column stratifies so that algae retained in the surface layer are uncoupled from benthic grazing, and phytoplankton blooms develop. The degree of stratification varies over the neap-spring tidal cycle, so South Bay represents an estuary where: (1) biological processes (growth, grazing) and a physical process (vertical mixing) interact to cause temporal variability of phytoplankton biomass; and (2) temporal variability is highly dynamic because of the short-term variability of tides. Other mechanisms of temporal variability in estuarine phytoplankton include zooplankton grazing, exchanges of microalgae between the sediment and water column, and horizontal dispersion, which transports phytoplankton from regions of high productivity (shallows) to regions of low productivity (deep channels).

Multi-year records of phytoplankton biomass show that large deviations from the typical annual cycles observed in 1980 can occur, and that interannual variability is driven by variability of annual precipitation and river discharge. Here, too, the nature of this variability differs among estuary types. Blooms occur only in the northern reach when river discharge falls

within a narrow range. The summer biomass increase is absent during years of extreme drought (1977) or years of exceptionally high discharge (1982). In South Bay, however, there is a direct relationship between phytoplankton biomass and river discharge. As discharge increases so does the buoyancy input required for density stratification, and wet years are characterized by persisent and intense spring blooms.

REFERENCES

Cloern, J.E. and F.H. Nichols (eds.), 1985. Temporal Dynamics of an Estuary: San Francisco. D.W. Junk Publishers, Dordrecht, The Netherlands.

BENTHIC ECOLOGY AND HEAVY METAL ACCUMULATION

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Abstract

The benthos of San Francisco Bay (the community of invertebrates living in bottom sediments) is an important source of food for fish, birds, and humans, and is dominated by exotic species introduced during the past 130 years. These species are largely small, hardy, short-lived, rapidly-reproducing species (much like weeds) whose distributions and abundances vary widely in both space and time. As a result, they appear resilient in the face of both natural and human-induced disturbances.

The Bay's benthic organisms are contaminated to varying degrees and, in some cases, physiologically affected by wastes. Contaminant concentrations vary seasonally, annually, and with proximity to contaminant sources. There is an apparent but not clearly understood relationship between river flow and the accumulation of wastes in the estuary's sediments and organisms. However, effects at the community level are not easily distinguished from natural variability.

Variations in river flow can have a marked effect on the distributions and abundance of benthic animals, thereby affecting local food web dynamics. During periods of persistently low flow, for example, benthic invertebrates can become relatively more important in the northern part of San Francisco Bay and, as a result, compete with the small pelagic animals (that are food for fish) for the phytoplankton produced there. The benthos is apparently important in preventing eutrophication in San Francisco Bay by consuming phytoplankton before it can grow to nuisance levels.

Introduction

The "benthos" is the community of invertebrate animals (worms, clams, shrimps, etc.) living on the bottom of aquatic environments. These animals consume organic matter that grows on or settles to the bottom and, in turn, become food for fish and other consumers, including humans. They are often sessile, living most of their life in the same location. Thus, they provide a continuing record, through changes in species composition or abundance or the effects of both short- and long-term changes in the environment. This feature had lead to their use as indicators of water pollution.

Introduced Species

Today, the benthos of San Francisco Bay is composed largely of introduced exotic species, many having arrived with the oysters that were shipped from the U.S. East Coast for growing in the Bay. Others arrived in ballast water or burrowed into the wood hulls of ships arriving from ports all over the world (Carlton, 1979). These are hardy, opportunistic species, much like weed plants, that are seemingly resilient to disturbance. They may be temporarily eliminated from a given location in the Bay as a result of some natural (e.g., a storm or a prolonged wet or dry period) or human-induced (dredging) disturbance. However, these animals typically return soon after the disturbance has ceased. It is against this background of high variability and apparent resilience that we must assess human effects.

Effects of Waste Discharge

The effects of waste discharge into the Bay were noted as early as 1900, when oyster beds were observed to be contaminated with human and industrial sewage. Soon thereafter, the taste of the harvested oysters began to deteriorate, and growth was impaired. By the 1930s, the oyster industry had failed. Through the 1950s, raw or poorly treated sewage killed bottom organisms through lack of oxygen, and shellfish were contaminated with human enteric bacteria. Beginning in the 1960s, the construction of facilities to treat waste began to resolve the oxygen and coliform bacteria problems, and by the 1970s, these problems had been largely resolved (Nichols et. al. 1986).

Now, industrial chemicals (some of which are known to be toxic) have become the primary concern. The tissues of mussels and clams contain varying levels of industrial chemicals depending on their proximity to sources of contaminants, time of year and, apparently, the relative rate of freshwater inflow. For example, concentrations of the trace metal silver (a contaminant whose sources are largely the photographic and electronics industries) in South Bay clams vary seasonally and between years (Luoma et. al. 1985). Highest seasonal levels are found following the initial storms and runoff of winter while highest annual levels are found during driest years, These results suggest that river flow is important in the assimilation and/or flushing of contaminants from the Bay. However, the mechanisms are not well understood. Experimental studies have shown that, through genetic flexibility, some individuals within a species can survive in environments with high contaminant levels while other cannot (Luoma et. al. 1983). These studies have demonstrated that clams are physiologically stressed during periods when contaminant levels in the environment are highest.

Despite clear evidence that individuals of many species contain contaminants, we have difficulty demonstrating a relationship between contaminated individuals and a threatened population. That is, we have not clearly demonstrated that there have been significant declines in either the abundance of the species Bay-wide or in the importance of these species in the Bay's food webs because of contamination with toxic chemicals. This difficulty results from: (1) the extreme variability in the seasonally and interannual patterns of abundance that are most easily ascribed to natural causes; (2) the apparently hardy nature of many of the species; and (3) the lack of appropriate studies to prove or disprove cause and effect (Nichols et. al , 1986).

Effects of the Benthos on the Pelagic Food Web

Because the estuary is shallow and the water in it well mixed, phytoplankton (microscopic single-celled plants growing in the water column that form the base of aquatic food webs) are directly available to benthic animals that filter food particles out of the water. Because of their great abundance, benthic filter feeders may act as a natural biological control on eutrophication -- the growth of nuisance phytoplankton blooms in aquatic systems in response to enrichment with nutrients such as nitrogen and phosphorus (Cloern, 1982). Eutrophication in estuaries often leads to the depletion of oxygen in the water and the subsequent death of aquatic animals. By removing phytoplankton as fast as they grow, benthic invertebrates in San Francisco Bay convert sewage-derived nutrients directly into animal biomass. Thus, the Bay is not subject to noxious accumulations of excess phytoplankton (Nichols et. al. 1986). We can conclude from this finding that processes that could selectively disturb the benthos, such as severe contamination with pollutants, might permit the development of nuisance blooms and anoxia in San Francisco Bay. Occasionally, localized, thick mats of decaying macroalgae become deposited on intertidal mudflats and smother resident benthic animals (Nichols and Thompson, 1985). These occurrences are unpredictable and only partially understood.

Whether the direct removal of phytoplankton by benthic filter feeders actually inhibit overall productivity of the estuary is not clear. However, during the 1976-77 drought, the high salinity of northern San Francisco Bay during two successive winters permitted the establishment of large populations of benthic animals that, in turn, may have been responsible for the unusual declines in phytoplankton, zooplankton, shrimp, and larval striped bass (Nichols, 1985). The implication from these observations is that during any future periods of persistently low flows when winter salinity levels remain high, the food web in northern San Francisco Bay may shift from pelagic type, culminating in the striped bass, to a benthic type, culminating perhaps, in less important demersal fish species.

REFERENCES

Carlton, J.T. 1979: Introduced invertebrates of San Francisco Bay. in T.J. Conomos, (ed.), San Francisco Bay, the Urbanized Estuary. Pacific Division, Amer. Assoc. Adv. Sci., San Francisco, Calif, 427-444.

Cloern, J.E. 1982: Does the benthos control phytoplankton biomass in south San Francisco Bay? Mar. Ecol. Prog. Ser. 9:191-202.

Josselyn, M.N. and J.A. West, 1985: The disturbance and temporal dynamics of the estuarine macralgal community of San Francisco Bay. Hydrobiologia 129: 139-152.

Luoma, S.N., D.J. Cain, K. Ho, and A. Hutchinson, 1983: Variable tolerance to copper in two species from San Francisco Bay. Mar. Environ. Res. 10: 209-222.

Luoma, S.N., D.J. Cain, K. Ho, and C. Johansson, 1985: Temporal fluctuations of silver, copper, and zinc in the bivalve Macoma balthica in five stations in South San Francisco Bay. Hydrobiologia 129: 109-120.

Nichols, F.H., 1985: Increased benthic grazing: an alternative explanation for low phytoplankton biomass in northern San Francisco Bay during the 1976-77 drought. Estuar. Coast. Shelf Sci. 21:379-388.

Nichols, F.H., J.E. Cloern, S.N. Luoma, and D.H. Peterson, 1986: The modification of an estuary. Science 231:567-573.

Nichols, F.H. and J.K. Thompson, 1985: Time scales of change in the San Francisco Bay benthos. Hydrobiologia 129:121-138.

AGENCY COOPERATION AND FISHERY STUDIES IN SAN FRANCISCO BAY

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Abstract

The people of California have been divided on many environmental issues, but governmental cooperation and coordination at both state and Federal levels is beginning to mitigate the impacts of this division. Four agencies (California Department of Water Resources, California Department of Fish and Game, U.S. Bureau of Reclamation, and U.S. Fish and Wildlife Service) have signed a Memorandum of Agreement that established the Interagency Ecological Study Program. This program has provided for the performance of studies necessary to obtain a thorough understanding of the requirements of the fish and wildlife resources in the estuary and how these requirements relate to water projects. This has helped bridge the gap between environmentalists and water developers. One of these interagency studies is documenting the importance of freshwater flows and water project activities to the Bay system downstream of the Delta. The Delta Outflow/San Francisco Bay Study has shown that fish and shrimp abundance and distributions appear to be related to freshwater inflows from the Delta. If divisive environmental issues are to be adequately resolved in California, continued studies as well as continued financial and political support are needed. Early results from the biological portion of the Delta Outflow Study must be quantified and related to results from the recently implemented hydrodynamic elements. Finally, a long standing controversy regarding the Federal Central Valley Project's role in protecting beneficial uses in the system has been resolved to the state's satisfaction in the Coordinated Operations Agreement (COA).

The Bible describes how a group of people were led from Egypt and came to the waters of the Red Sea. The account relates that their leader raised his staff and divided the waters so that the people could pass through and escape destruction from their enemies. In California, this age-old story has been reversed. If one reviews the history of the state's water policy development, he will find that water, through its unequal distribution in the state, has divided the people. Most of the population and, therefore, the political power resides in the relatively dry, southern part of the state, while most of the rainfall occurs in the northern part of the state and flows through the San Francisco Bay estuary to the Pacific Ocean.

Because of this fact divisions have developed between citizens of the north and south, between farmers, and the urban dwellers, between developers and environmentalists, and between politicians and the lay public. These groups became more polarized, when the Bureau of Reclamation in about 1951, and the State Department of Water Resources in about 1968, began diverting water from rivers in the northern part of the state, such as the Sacramento and the San Joaquin, for use in the south.

One can make three basic points about California water and its management as it relates to fish and wildlife resources in California: (1) California is divided in many ways on many environmental issues, but government cooperation and coordination, at both the state and Federal levels is beginning to mitigate the impact of this division; (2) multi-agency, scientific fish and wildlife studies are documenting the importance of freshwater flows and water project activities on the Bay system; and (3) continued studies are needed, in addition to continued financial and political support, if divisive environmental issues are to be adequately resolved.

Government Cooperation and Coordination

In 1970, when it became common knowledge that fish and wildlife problems existed in the estuarine system, and that one of the factors responsible for those problems was the Federal Central Valley Project and the State Water Project, four state and Federal agencies executed an Interagency Memorandum of Agreement. These agencies were: the Department of Water Resources (DWR), California Department of Fish and Game (DF & G), the U.S. Bureau of Reclamation (USBR), and the U.S. Fish and Wildlife Service (USFWS). The purpose of this agreement was to provide for the performance of studies that would be necessary to obtain a thorough understanding of the requirements of the fish and wildlife resources in the estuary. These studies also represented significant follow-up efforts to cooperative work that began early in the 1960s between the DWR and DF & G.

All the agencies in this group agreed that it was necessary to define design and operation criteria for the projects, in order that resource protection could be assured. This cooperative alliance between water development agencies and fish and wildlife agencies was the first major fish and wildlife accomplishment associated with water policy in California.

The intent of this so-called "Interagency Ecological Study Program" was good, but true to California's divisive nature, the estuary was divided into two components, and only the upstream Delta portion of that system was studied in detail. Cooperative work was carried out during the early 1960s and 1970s and yielded much information about fishery resources and their relationship to water diversion projects. Specifically, these studies and cooperative efforts learned six important things: (1) striped bass and pelagic fish eggs were being diverted from the system; (2) the louver fish screen efficiencies at the intake of state and Federal water diversions, depending on the species and life stages, were quite low, ranging from about 5 to 80 percent, (3) water diversions act as density independent sources of mortality for young striped bass; (4) flow reversals which were associated with pumping confuse young adult fish migration; (5) pumping increases flow velocities in channels, and that in turn reduces the standing crop of food organisms that are produced there; and (6) the actual magnitude of flow passing through the Delta into the Bay affects the distribution and abundance of fish and their food organisms.

This information was used for two significant purposes in California. First of all, it was used to develop recommendations for the controversial Peripheral Canal. This was a structure proposed for diverting water around the Delta system for transport to the southern part of the state. Secondly, the information developed by the Interagency Program was used in 1978 by the regulatory State Water Resources Control Board to develop standards to protect beneficial uses in the Delta component of the system. The Board adopted Water Rights Decision 1485, which innovatively established flow/salinity standards necessary to protect fishery resources in the estuary based on information available at that time. However, there was still division. The studies were looking at the Delta and not the Bay portion of the estuary. In adopting D-1485, the State Board took another positive step to bridge this division. They mandated, in D-1485, that flow studies would be carried out in the Bay, downstream of the Delta, and that these studies would be paid for by the water diversion permit holders; in this case, the Department of Water Resources and the Federal Bureau of Reclamation. The Interagency Program already in place became the vehicle to implement this study in 1980.

Biological portions of the Delta Outflow/San Francisco Bay Study began in 1980, but again division occurred. This time, the division was regarding the roles of hydrodynamic and fishery studies. While the fishery studies continued, project biologists and engineers debated the following questions: "What should be the driving force for the Bay outflow study?" In other words, should biology precede hydrodynamic work and provide the basis for the structure of hydrodynamic study plans or should hydrodynamics precede biology? This issue remained unresolved for about four years until it was agreed that the hydrodynamic program should answer "biologically relevant hydrodynamic questions." In other words, the study would be based on the needs of the biological program.

The hydrodynamic study plan which was implemented earlier by DWR was augmented in 1984 and interagency cooperation again bridged another division. At this time, two more agencies joined the Interagency Program. Those agencies were the U.S. Geological Survey (USGS) and the State Water Resources Control Board (SWRCB). Today, a six agency program exists instead of a four agency program.

The overall goal of the Delta Outflow/San Francisco Bay Study is to determine the relationship between freshwater outflows and fish and wildlife resources in the Bay, downstream of the Delta. In order to attain this goal, four general objectives are being pursued. First of all, the study is determining what elements of the Bay biota would be affected by significant changes of the inflow of freshwater from the Delta. Secondly, the project is determining how the flow reductions associated with the state and Federal project operations would change hydraulics and salinity gradients in the Bay. Thirdly, the effect of changes in hydraulics and salinity on the fish and wildlife resources in the Bay will be investigated. Finally, all this information will be used to develop flow and salinity standards (or other management strategies) if necessary to better protect fish and wildlife resources of the Bay.

These objectives are being met through a twofold approach. First of all, fishery studies are being carried out in the Bay itself. By collecting monthly fishery samples at 35 locations in the Bay, the distributions and abundances of fish, shrimp, and crabs are being documented. This data will then be combined with output from the second aspect of the program -- the Hydrodynamic/Physical/Chemical study. This recently expanded study element is evaluating changes in salinity and circulation patterns that are caused by outflow variation. These evaluations are being done using modeling work carried out by a five-member modeling team that is working under the technical supervision of Dr. Ralph Cheng, of the U.S. Geological Survey in Menlo Park, California.

Parenthetically, the Interagency Program represents substantial funding commitments by the agencies involved. For example, the fiscal year 1985 budget for the Interagency Program is about $4,906,000. That money is allocated between five major programs including the San Francisco Bay/Delta Outflow Study. This study alone represents a budget of $1,655,000 for the coming year.

Study Results

To date, the fishery data collected in the outflow program have only been summarized for the first three years, but it is interesting because considerable variation in outflow has occurred during this year. The year 1981 was dry, while 1980 and 1982 were wet years. Of the wet years, 1982 provided the highest amount of outflow to the bay. Additionally, the hydrographs for these years are characterized by pulse periods, when flows were considerably greater than other periods. These pulses are short-term high flows that move through the system, greatly altering physical conditions.

To date, about 109 species of fish have been collected from the Bay. These species have been distributed among 43 different families. More importantly, it appears that fish abundance and distributions are related to freshwater inflow from the Delta. For example, of the 58 species looked at so far, 24 demonstrated a "wet response" to flow. In other words, these species were caught in greater numbers during wet years. Twenty-two species showed a mixed response, while only 12 showed a dry response (Table 1).

Table 1. Number of species with highest catches during various year types.

Salinity Preference Group	Wet Response	Mixed Response	Dry Response
Freshwater	3	3	2
Anadromous	3	3	1
Estuarine	5	2	0
Marine-Estuarine	2	4	2
TOTAL	24	22	12

A surprising thing was learned upon further analysis of these same data when individual species responses were categorized (Table 2). Only one species in the top 15 most abundant species demonstrated a dry response. That species was the jacksmelt. This is interesting because one would expect greater numbers of marine species in the Bay during dry years. This did not occur. It is also interesting to note the estuarine species response (Table 2). Four of the five estuarine species collected occurred in the top 15 of the most abundant species in the Bay, and all of those species demonstrated a wet response showing the importance of freshwater flows to these types of species in San Francisco Bay.

It also appears that outflow affects Bay shrimp abundance in San Francisco Bay. Abundance indices for this species were greater during wet years than during dry years. Preliminary study results also have led to the conclusions that some fish appear to be more widely distributed during wet years.

There are two reasons why fish may change their distribution. First of all, they may change distribution because of salinity alterations. Salinity may increase or decrease above or below species salinity preferences and cause them to move to another area.

TABLE 2. Species response to water year type. Number in parentheses is that fish's rank in the fifteen most abundant species.

	Wet Response	Dry Response	Mixed Response
Fresh			
	Threadfin shad	Sacramento squawfish	Inland silverside
	Carp	Tuleperch	Splittail
	Prickly sculpin		White catfish
Anadromous			
	White sturgeon	Pacific lamprey	American shad (14)
	Green sturgeon		King salmon
	Steelhead		Striped bass (5)
Estuarine			
	Threespine stickleback		Delta smelt
	Yellowfin goby (10)		Bay goby (11)
	Longfin smelt (2)		
	Staghorn sculpin (8)		
	Starry flounder (12)		
Marine-estuarine			
	Pacific herring (3)	Arrow goby	White croaker (9)
	Cheekspot goby	Walleye surfperch (1)	Northern anchovy
			Plainfin midshipman (15)
			Shiner perch (4)
Marine			
	Leopard shark	Bat ray	Night smelt
	Pile perch	Whitre seaperch	Bay pipefish
	Speckled sanddab (7)	Jacksmelt (13)	Barred surfperch
	Diamond turbot	Black perch	Brown rockfish
	Sand sole	Rubberlip seaperch	Lingcod
	California tonguefish	Pacific butterfish	English sole (6)
	Brown smoothound	Boneyhead sculpin	Dwarf perch
	Spiny dogfish		Big skate
	Pacific tomcod		Surf smelt
	Topsmelt		Curlfin turbot
	Showy snailfish		

Secondly, circulation patterns can affect the distribution of the larval stages of many fish. Larval English sole distributions appear to reflect outflow related circulation changes. English sole spawn offshore in the Pacific Ocean. Adult sole usually do not occur in San Francisco Bay. The larvae spawned offshore presumably are carried by gravitational circulation into the Bay. The magnitude of that circulation is related to the magnitude of Delta outflow. Data from 1980-1983 showed that the distribution of larval sole (3-5 mm) was broader during the high flow years than during the low flow year. During the year, larval sole occurred only near the mouth of the Bay, near the ocean, while during the high flows (1983) larvae were found throughout San Pablo and South Bays.

Early study efforts also have found that large, freshwater pulses move through the system in winter and spring and significantly lower salinity in this system. These salinity changes affect fish distribution. As a rule, pelagic species (e.g., northern anchovy) normally found in the Delta, Suisun and San Pablo Bays during dry periods move downstream after these pulses. On the other hand, some bottom species (e.g., juvenile English sole) usually found in Central Bay move upstream during these events.

It also has been found that flow altered distributions of certain species result in increased abundance of these species. For example, a major cause of the year-to-year variation in abundance of <u>Crangon</u> shrimp appears to be survival of the early life stages (i.e., the larvae or juvenile), not to the number of reproductive females present. It has further been found that distribution of the adults that is affected by the flows varies between the years. In wetter years, the reproductive population is further downstream near the Golden Gate. The survival of the juveniles is much higher there. It appears that flow affects distribution of adults, which in turn sets abundance for the year because more juveniles survive.

Future Project Needs

The above provides a quick, general summary of the accomplishments of the Interagency Program and the findings of the Delta Outflow Study, in particular. The remainder of this review will emphasize future project needs.

In order to ensure protection of San Francisco Bay resources, various things are needed. More information on water quality or pollution impacts on fishery resources in the Bay is desperately needed. The Delta Outflow Study has documented flow related effects, but little is being done to determine effects of various waste discharges on fish and shrimp. Once again this points to a division of study effort. One effort to study pollution in the Bay by the Aquatic Habitat Institute is being planned, but without strong local or Federal financial support, this program will not be productive.

Other scientific needs exist and the Delta Outflow Study will be fulfilling these needs in the future. For example, the study has discovered some of the qualitative relationships between fishery resources and freshwater flows, but these relationships must be confirmed and quantified. In other words, how much of a population reduction or increase results if outflows are reduced by some amount? Reported amounts of reduction in other systems that have caused adverse responses range up to approximately 47 percent. In an average rainfall year, approximately 50 percent has been diverted from San Francisco Bay. The study also must develop some predictive capability, through simple fishery models, to be used when the regulatory agencies eventually set protective standards.

The Outflow Study also will need to document relationships between fishery resources and circulation/hydrodynamic patterns. Some organisms use circulation processes for transportation of their young, but the quantitative relationships between outflows and these processes are unknown. Beyond that, it must be determined whether any observed flow-related circulation changes will impact those organisms known to use currents in the Bay and if so, whether or not such impacts will be detrimental.

Policy needs for San Francisco Bay center around two issues. First, in California a long standing controversy regarding the role of the Federal Central Valley Project in protecting beneficial uses has been debated. This issue has recently been resolved to the state's satisfaction in the Coordinated Operations Agreement (COA). Congress must act on this Agreement. Second, continued funding support from the USBR to continue the outflow studies is desperately needed. Study contracts are renewed each year and, from time-to-time, the project has been threatened due to budget cuts in the Bureau program. Long-term, financial support is needed to continue these important studies.

In conclusion, California is a divided state, but through agency coordination and cooperation, and also some sound scientific studies, progress is being made toward protecting and, in fact, in some cases, enhancing fish and wildlife resources.

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):

<u>Anthropogenic Activities</u>

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

2. What are the sources of these pollutants?

<u>Marine Ecosystem Processes</u>

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?

<u>Consequences Attribute to Anthropogenic Activities</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?

<u>Judgemental Processes</u>

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?

<u>Other Compartments</u>

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).

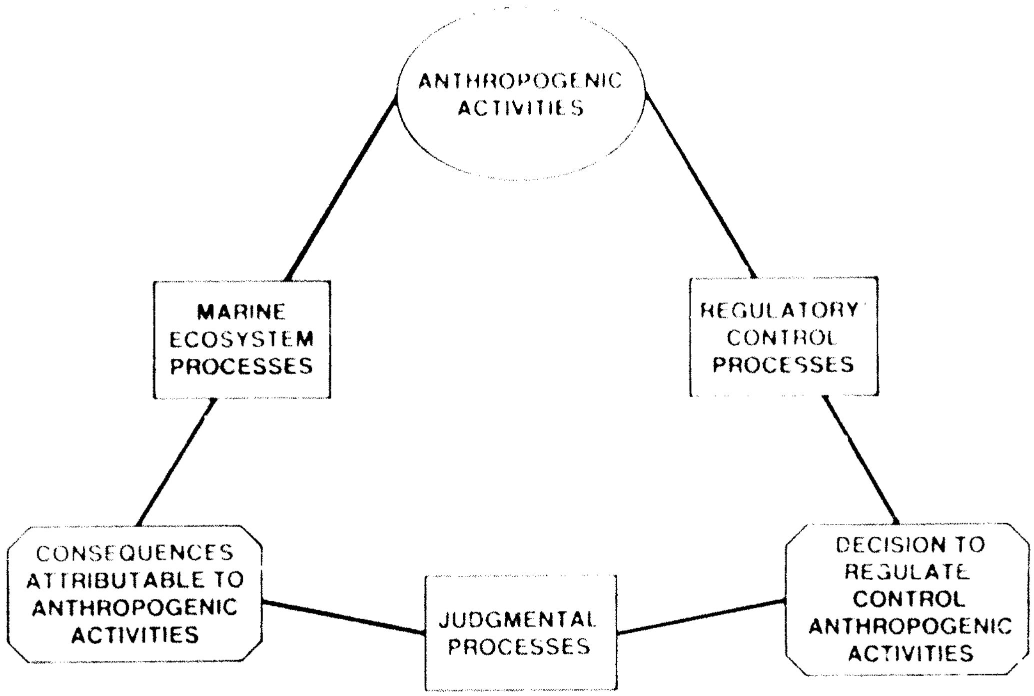

Figure 1. Conceptual representation of Office of Marine Pollution Assessment Research Program. From R.B. Burns, January 19, 1982. "Office of Marine Pollution Assessment (OMPA) Financial Assistance for Marine Pollution Research."

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 <u>et. al</u>. 1985).

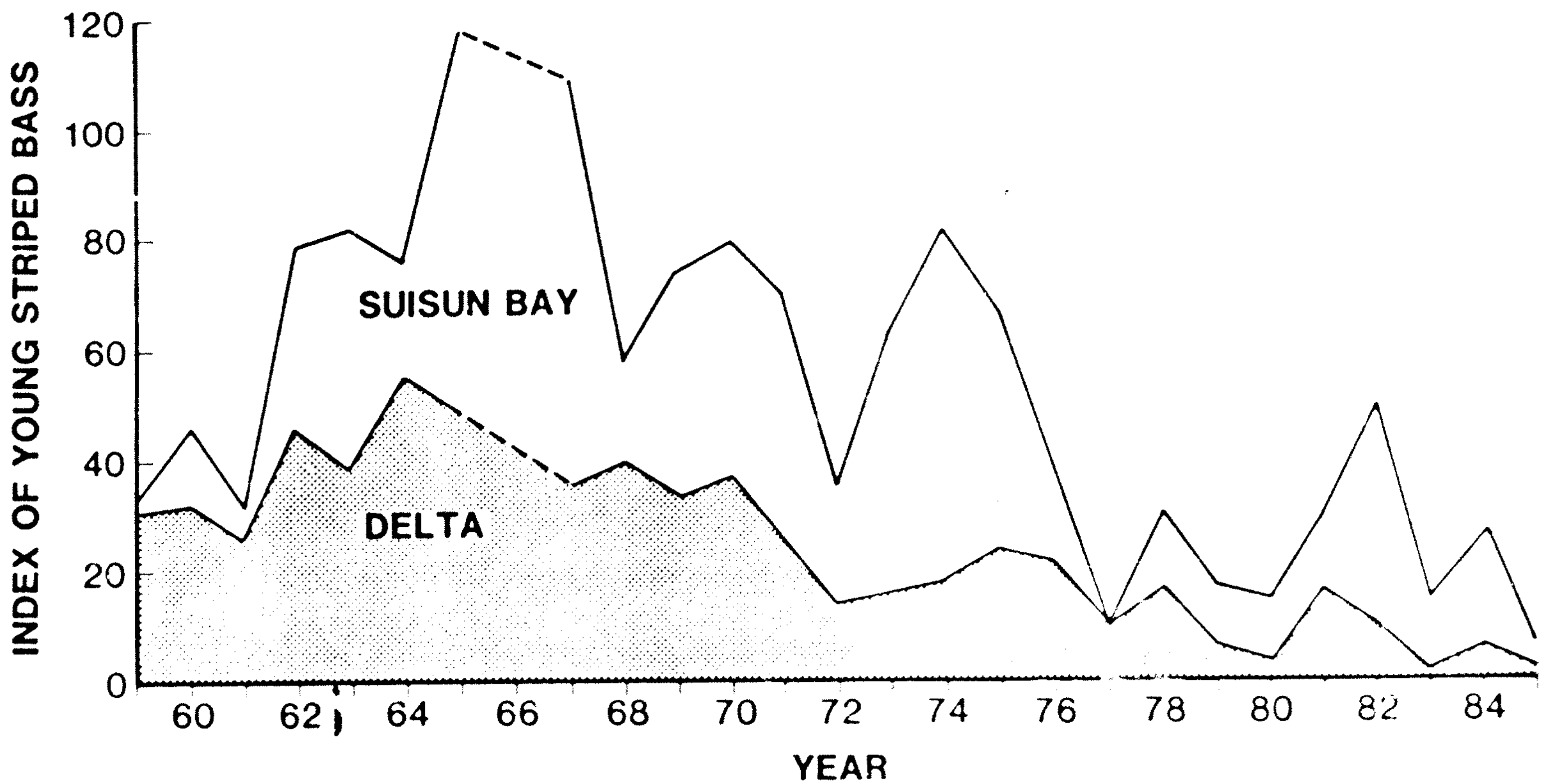

Figure 2A. Decline in the striped bass (*Morone saxatilis*) population in the San Francisco Bay-Delta area (Stevens *et al.*, 1985). Young-of-the-year striped bass (juveniles); change in the index with year. Decline pronounced since 1975.

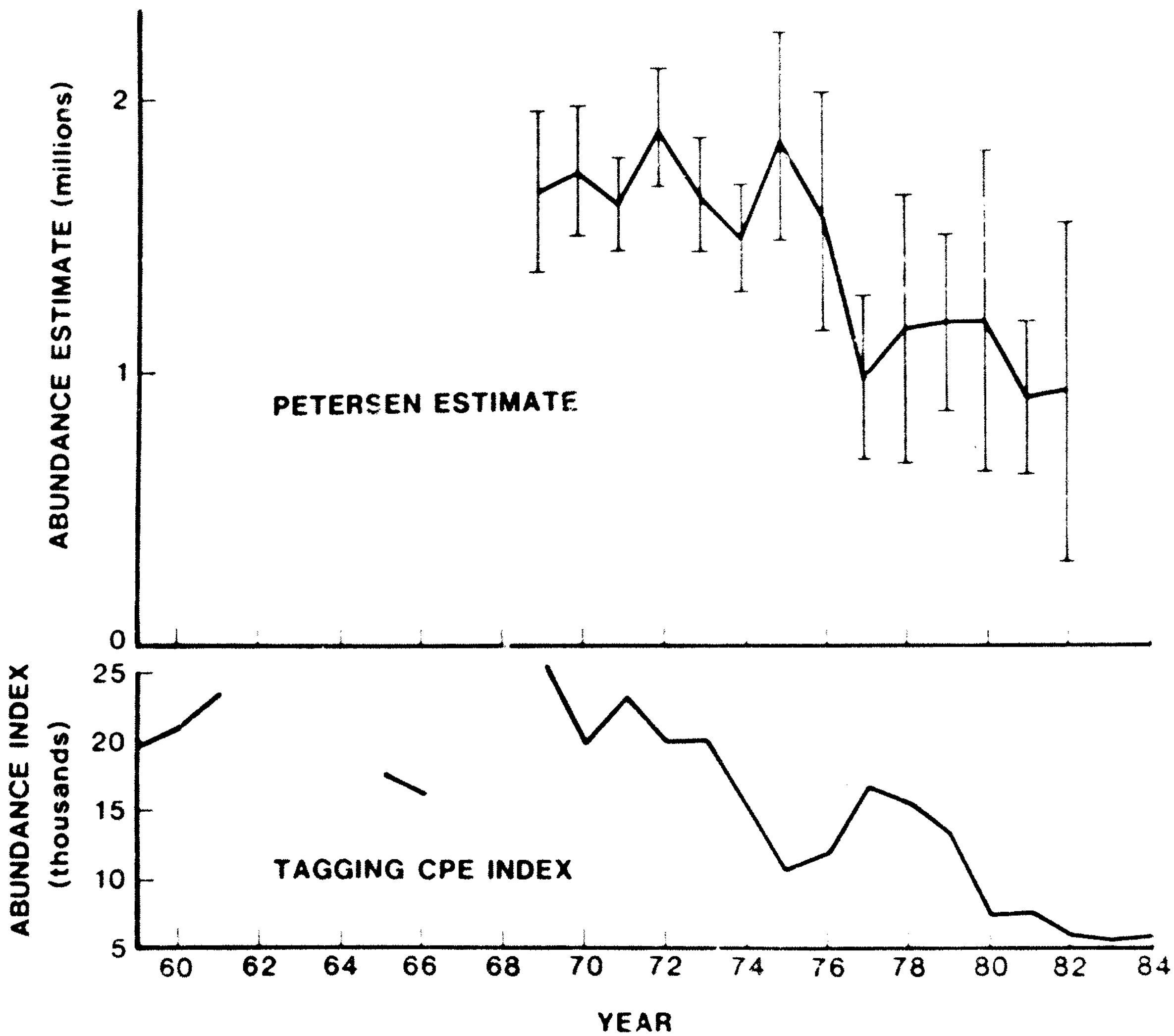

Figure 2B. Two measures of adult striped bass population size; change in Peterson and catch-per-unit effort estimates of adult bass with year. Decline obvious from 1975. (Stevens et.al., 1985)

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 (Lacistorhynchus tenuis) 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.

- 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 Pay/Delta fish appear in the worst health.

2. Sex. 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.

   - 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.

3. Other Factors. 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 1978-1933 Table 1.

   - 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.

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

   - 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		UNIDENTIFIED
	NATURAL FACTORS	POLLUTANT FACTORS	
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.

YEAR[1] (N) VARIABLE	1978 (59)	1979 (42)	1980 (21)	1981 (12)	1982 (7)	1983 (16)	1984[2] (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 Parasite[3] 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. 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.

- 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 et. al. 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, et. al. 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

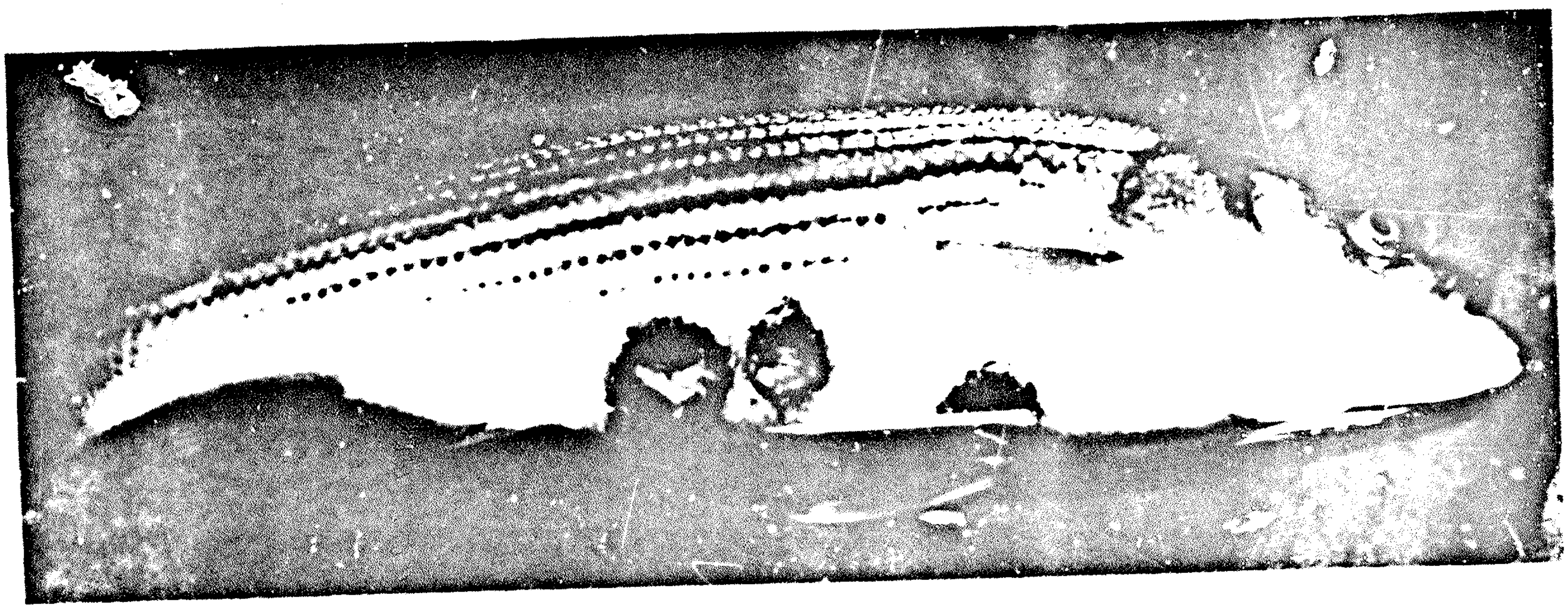

Figure 3. Lesioned striped bass. Open lesion is a result of fish over-reacting to tapeworm larvae infection, followed by bacterial infection. In older bass, lesions may be healed with only scars showing on the surface.

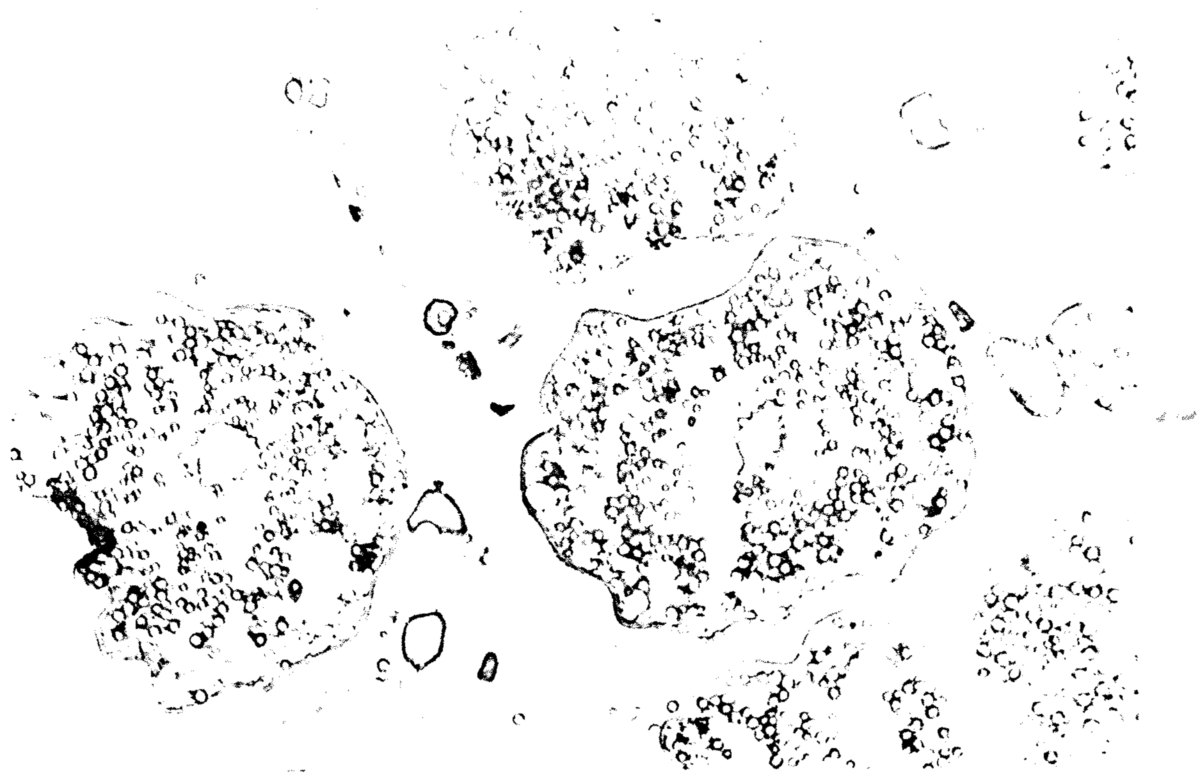

Figure 4A. Eggs from ovaries of striped bass. Normal eggs in secondary to tertiary yolk stage.

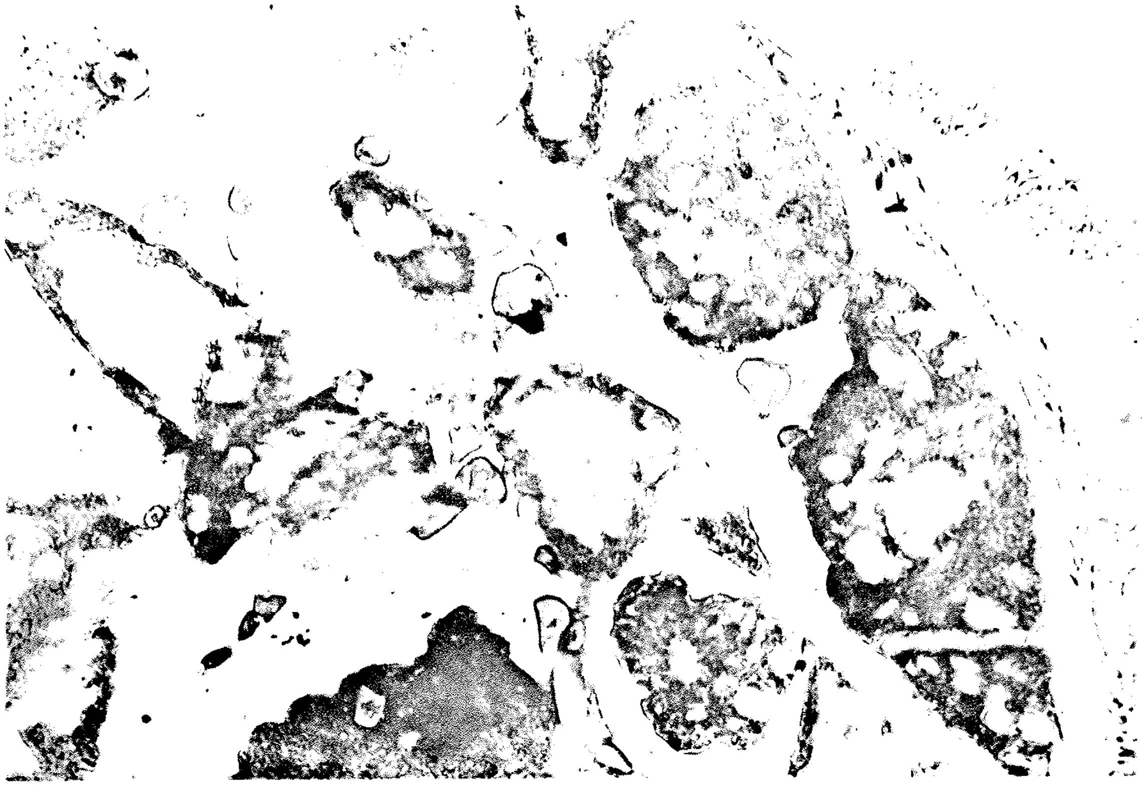

Figure 4E. Abnormal eggs, in varying stages of resorption. This condition is associated with petrochemicals.

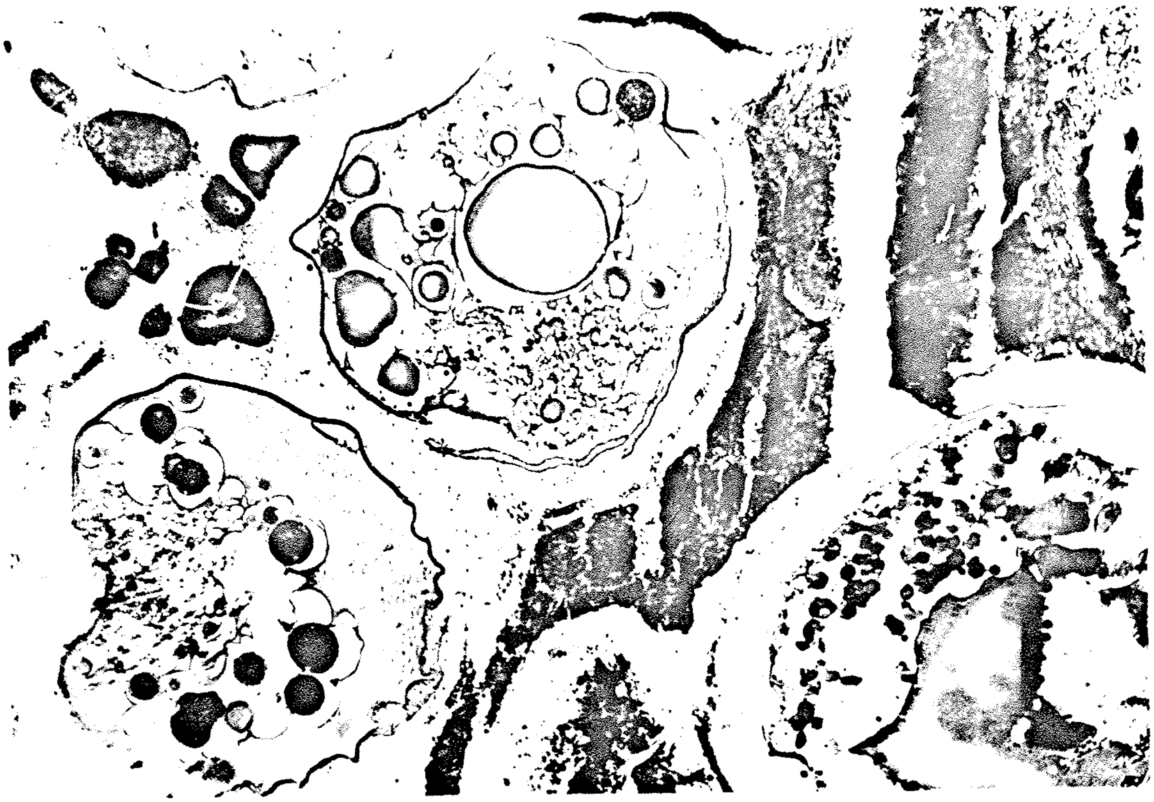

Figure 4C. Abnormal eggs, in late development stage, being resorbed. Note dark areas of melanin-containing melanomacrophages in intercellular areas. This condition is associated with DDT.

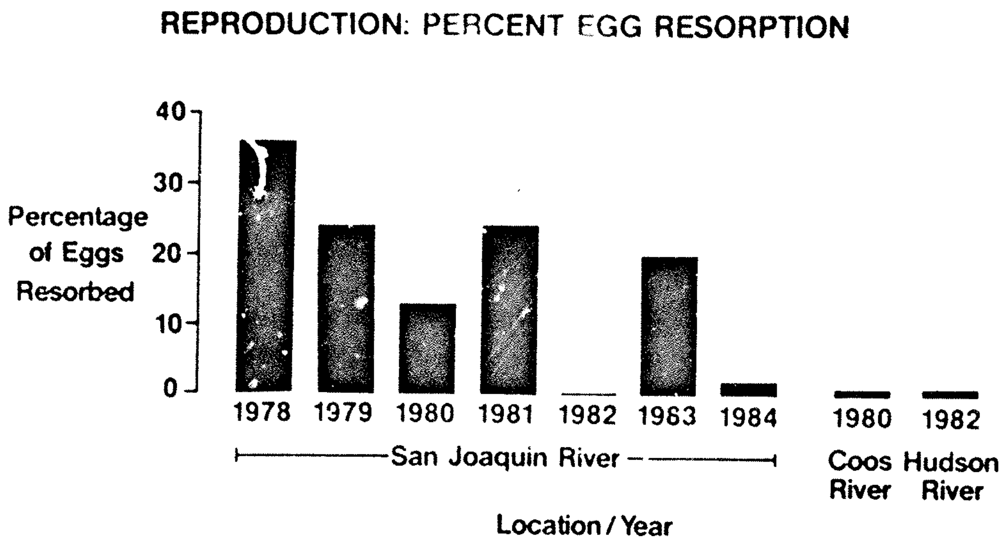

Figure 5. Mean egg resorption in striped bass prespawning females by year (1978-1984) and at different locations.

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.

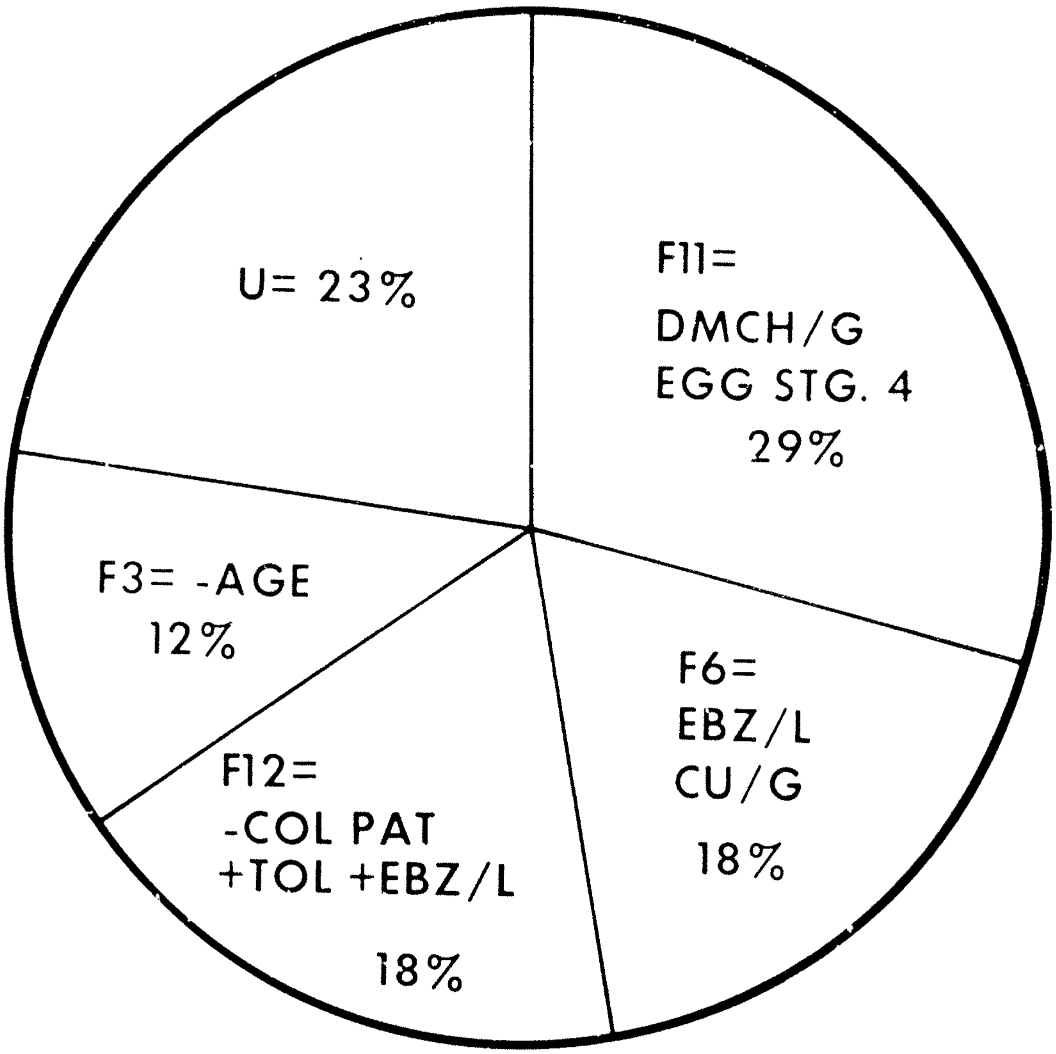

Figure 6. Proportion of total variance in egg condition (egg resorption) accounted for by different factors. Derived from factor equations in factor analysis. Most fish collected in this year had high levels of monocyclic aromatics in the liver and gonads.

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. Laboratory experiments. 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, et. al. 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.

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

- o 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. <u>Population Effects</u>. Although influences other than toxic chemicals (e.g, Delta outflow, larval food supply and entrainment; Stevens <u>et.</u> <u>al</u>. 1985) also are involved in the decline of the striped bass fishery, the following hypotheses were also supported by the study findings.

- o 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 <u>et.</u> <u>al</u>. 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.

- o 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 <u>et.</u> <u>al</u>. (1985), this is probably an important cause of the decline in the striped bass population.

- o 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.

- 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.

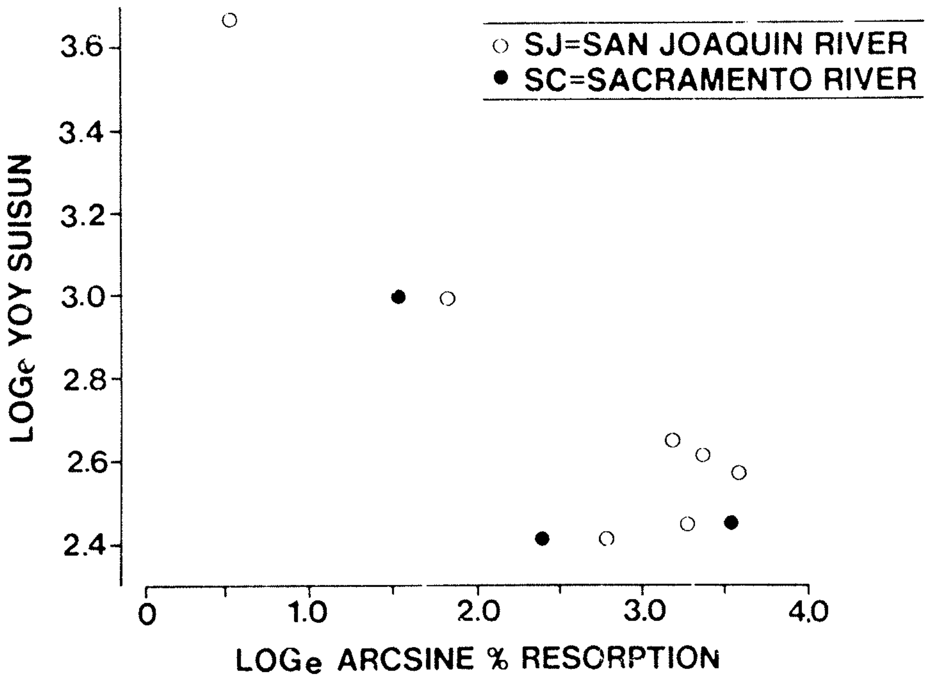

Figure 7. Correlation of yearly mean survival to young-of-the-year juveniles (YOY) with mean egg resorption in adult females of that spawning season. Data on YOY striped bass index from David Kohlhorst

ln YOY Suisun = 3.60 - .341 ln Egg Resorption

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

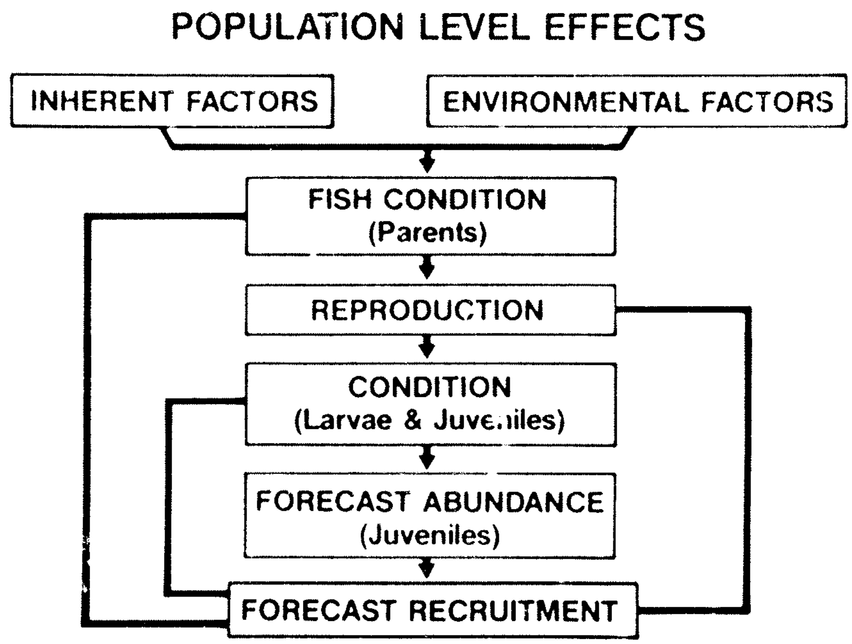

Figure 8. Population level effects. Determining the relationship of environmental factors (e.g. pollutants) on fish condition, reproduction and recruitment to the fishery.

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.

Acknowledgements

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References

Benville, Pete E., Jr. and Korn, Sid, 1977: The acute toxicity of six monocyclic aromatic crude oil components to striped bass (*Morone saxatilis*) and bay shrimp (*Crangon francoscorum*). *Calif. Fish and Game* 63(4):204-209.

Benville, Pete E. Jr.; Whipple, Jeannette A.; and Eldridge, Maxwell B., 1985: Acute toxicity of seven alicyclic hexanes to striped bass *Morone saxatilis* and bay shrimp *Crangon francoscorum*, in seawater. *Calif. Fish and Game* 71(3):132-140.

Eaton, Andrew, 1979: Observations on the geochemistry of soluble copper, iron, nickel, and zinc in the San Francisco Bay estuary. *Environ. Sci. and Tech. Res*. 13(4):425-431.

Eldridge, Maxwell B.; Benville, Pete; and Whipple, Jeannette A., 1981: Physiologic responses of striped bass (*Morone saxatilis*) embryos and larvae to low sublethal concentrations of the aromatic hydrocarbons benzene. *Proc. Gulf Caribb. Fish Inst*. 33:52-68.

Girvin, Donald C.; Hodgson, Alfred T.; Tatro, Mark E.; and Anaclerio, Roy N. Jr., 1978: Spatial and seasonal variations of silver, cadmium, copper, nickel, lead, and zinc in south San Francisco Bay waters during two consecutive drought years. Energy and Environ. Div., Lawrence-Berkeley Laboratory, University of California, Berkely, CA. Final Report UCID-8008.

MacFarlane, R. Bruce and Whipple, Jeannette A., 1984: Striped Bass Health Index. In-House report submitted to Advisory Committee for Aquatic Habitat Program, State Water Resources Control Board. April, 1984.

Moser, Mike; Love, Milton; and Sakanari, Judy A., 1984: Common parasites of California fish. Calif. Dep. Fish and Game, 20 p.

Moser, Mike; Sakanari, Judy A.; Wellings, Sefton; and Lindstrom, Kris, 1984: Incompatibility between San Francisco striped bass, *Morone saxatilis* (Walbaum), and the metacestode, *Lacistrohynchus tenuis* (Beneden 1858). J. Fish Dis. 7:397-400.

Moser, Mike; Sakanari, Judy A.; Reilly, Carol A.; and Whipple, Jeannette, 1985: Prevalence, intensity, longevity, and persistence of *Anasakis* sp. larvae and *Lacistorhynchus tenuis* metacestodes in San Francisco striped bass. NOAA Tech. Rpt. NMFS 29: 4 p.

Nichols, Frederick H.; Cloern, James E.; Luoma, Samuel N.; and Peterson, David., 1986: The modification of an estuary. Science. 231:567-573.

Nie, Norman H.; Hull, Hadlai; Jenkins, Jean G; Steinbrenner, Karin; and Bent, Dale H., 1975: SPSS: Statistical Package for the Social Sciences, second edition. McGraw-Hill, N.Y. 675 p.

Stevens, Donald E.; Kohlhorst, David W.; Miller, Lee W.; and Kelly, D.W., 1985: The decline of striped bass in the Sacramento-San Joaquin estuary, California. Trans. Am. Fish. Soc. 114:12-30.

Vassilaros, D.L.; Eastwood,D.A.; West,W.R.; Booth, G.M.; and M.L. Lee, 1982: Determination and bioconcentration of polycyclic aromatic sulfur in heterocycles in aquatic biota. In M. Cooke, A.J. Dennis, G.L. Fisher (editors). Sixth international symposium for polynuclear aromatic hydrocarbons: Physical and biological chemistry, p. 845-857. Battelle Press, Columbus, Ohio.

Whipple, Jeannette A.; Eldridge, Maxwell B.; Benville, Pete, Jr., 1981: An ecological perspective of the effects of monocyclic aromatic hydrocarbons on fishes. In F.J. Vernberg (editors), Biological Monitoring of Marine Pollutants, p. 483-551. Academic Press, N.Y.

Whipple, Jeannette A. 1982: The impact of estuarine degradation and chronic pollution on populations of anadromous striped bass (*Morone saxatilis*) in San Francisco Bay-Delta, California. Annual research report submitted to NOAA, OMPA. May 15, 1982.

Whipple, Jeannette A. 1984: The impact of estuarine degradation and chronic pollution on populations of anadromous striped bass (*Morone saxatilis*) in San Francisco Bay-Delta, California. A summary for managers and regulators. NOAA, NMFS, SWFC Admin. Rpt. T-84-01, 41 p.

Whipple, Jeannette A.; Bowers, Michael; Jarvis, Brian; and Moreland, Sharon, 1983: Report on the condition and health of May 1982 sample of Hudson River adult, prespawning striped bass. In-house report, NMFS, Tiburon Laboratory. 23 p. (Manuscript in preparation for publication).

Whipple, Jeannette A.; Jung, Marvin; MacFarlane, R. Bruce: and Fischer, Rahel, 1984: Histopathological manual for monitoring health of striped bass in relation to pollutant burdens. Tech. Mem. NOAA-TM-NMFS-SWFC-46, 81 p.

Cooperative Striped Bass Study (COBS) Reports:

Jung, Marvin and Bowes, Gerald, 1980: First progress report on the Cooperative Striped Bass Study (COBS). Calif. State Water Resour. Control Board. Sacramento, CA., 64 p.

Jung, Marvin, Whipple, Jeannette A., and Moser, L. Michael, 1984: Summary report of the Cooperative Striped Bass Study (COSBS). A study of the effects of pollutants on the San Francisco Bay-Delta striped bass fishery. Draft summary report submitted to the California State Water Resources Control Board.

Whipple, Jeannette A. and Jung, Marvin, 1981: Cooperative Striped Bass Study (COBS). Appendix I: Procedures for histopathological examinations, autopsies and subsampling of striped bass. Calif. State Water Resour. Control Board, Sacramento, CA., 46 p.

Whipple, Jeannette A.; Crosby, Donald G.; and Jung, Marvin, 1983: Third progress report: Cooperative Striped Bass Study (COBS). Calif. State Water Resour. Control Board, Sacramento, CA., 208 p.

SUPLETHAL EFFECTS OF CONTAMINANTS ON THE METABOLISM OF METALS AND ORGANIC COMPOUNDS IN THE BAY MUSSEL

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Abstract

Biochemical mechanisms for the detoxification of metals and organic compounds in the bay mussel *Mytilus edulis* were investigated. Mussels exposed to increased levels of copper in the laboratory were shown to have proteins that bind and thereby detoxify some metals. Chronic exposure to metals can cause saturation of the detoxification system, however, and result in metal interaction with sensitive enzymes and proteins. Accordingly, mussels from contaminated ecosystems (South San Francisco Bay and near municipal outfalls in the Southern California Bight) were shown to have increased levels of metals in metabolic pools as compared to mussels from a relatively pristine ecosystem (Tomales Bay).

The ability of mussels to metabolize a trace organic contaminant (o-toluidine) was defined. Mussels were shown to metabolically activate this compound to a mutagenic form and also to detoxify it via basal metabolic pathways. Mussels from a contaminated site in San Francisco Bay demonstrated a diminished ability to handle this contaminant as evidenced by a overall reduction in metabolic rate. Continuing research on mechanisms of biochemical adaptation will provide a better understanding of the adaptive capabilities of mussels from pristine and contaminated ecosystem.

Introduction

Organisms present in aquatic environments may be exposed continually to low concentrations of a variety of metals and organic compounds from anthropogenic sources. Concentrations of these contaminants in the environment are generally below those that cause mortality, but they may be sufficiently high to affect adversely an organism's growth rate, reproductive success, or ability to compete with other species in the ecosystem. Organisms may respond to such sublethal stress through the evolution of reproductive, behavorial, and physiological strategies that confer biological resilience. The goal of our research is to understand the limits of adaptation of basic biochemical processes that confer resilience to aquatic organisms. Our experiments are designed to obtain results that provide a better understanding of the basic mechanisms used by aquatic animals to handle increased quantities of trace metals and organic compounds in the environment.

We focus on detoxification and biotransformation processes and propose to develop methodologies that can be used to identify aquatic ecosystems at risk, to evaluate ecosystem contaminant capacity, and to monitor the impact of contaminants from waste sites or effluent discharges.

Let us consider briefly changes in phsiological response that fishes and invertebrates may undergo in response to increases in environmental stress. These responses may be divided into four phases: normal adjustment, which is controlled by homeostatic processes; compensation, which is maintained without significant cost to the individual; breakdown, which occurs at the limit of compensatory processes; and finally failure, which is characterized by irreversible changes that result in death of the individual (Figure 1). Most of the standards and criteria that have been set were based on single species tests that used mortality as the endpoint. Because concentrations that cause mortality are too high to protect populations, standards and criteria were set not from these values, but from LC50 values that were multipled by an application factor considered to provide the degree of conservatism required. However, what may be more relevant for the maintenance of healthy populations in aquatic ecosystems is the setting of criteria and standards that are based on knowledge of when the limits of compensatory processes are being approached. This is critical because when these limits are exceeded, adverse effects ensue.

The organism we chose to study was the bay mussel Mytilus edulis. This species was selected because it appears to have evolved compensatory (adaptive) strategies that have resulted in the distribution of mussels throughout the world in bays and estuarine that have wide fluctuations in environmental conditions. Furthermore, there is an extensive data base on contaminant levels in populations from pristine and polluted ecosystems (Goldberg et. al. 1978), and studies have been performed to characterize its morphology (White, 1937) and its physiological and reproductive processes (Bayne et. al. 1976).

Metal Metabolism

Let us consider now metal metabolism in aquatic animals. It has been well established that many aquatic animals accumulate significant metal burdens from metal-contaminated ecosystems. Although the biochemical processes associated with metal toxicity have not been completely identified, specific effects have been demonstrated. Evidence is available indicating that the site of toxic action may be enzymes. However, the toxic effects on enzymes may be mitigated by the organism's ability to detoxify metals and eliminate them. It is apparent, then, that an understanding of these toxification and detoxification processes is required.

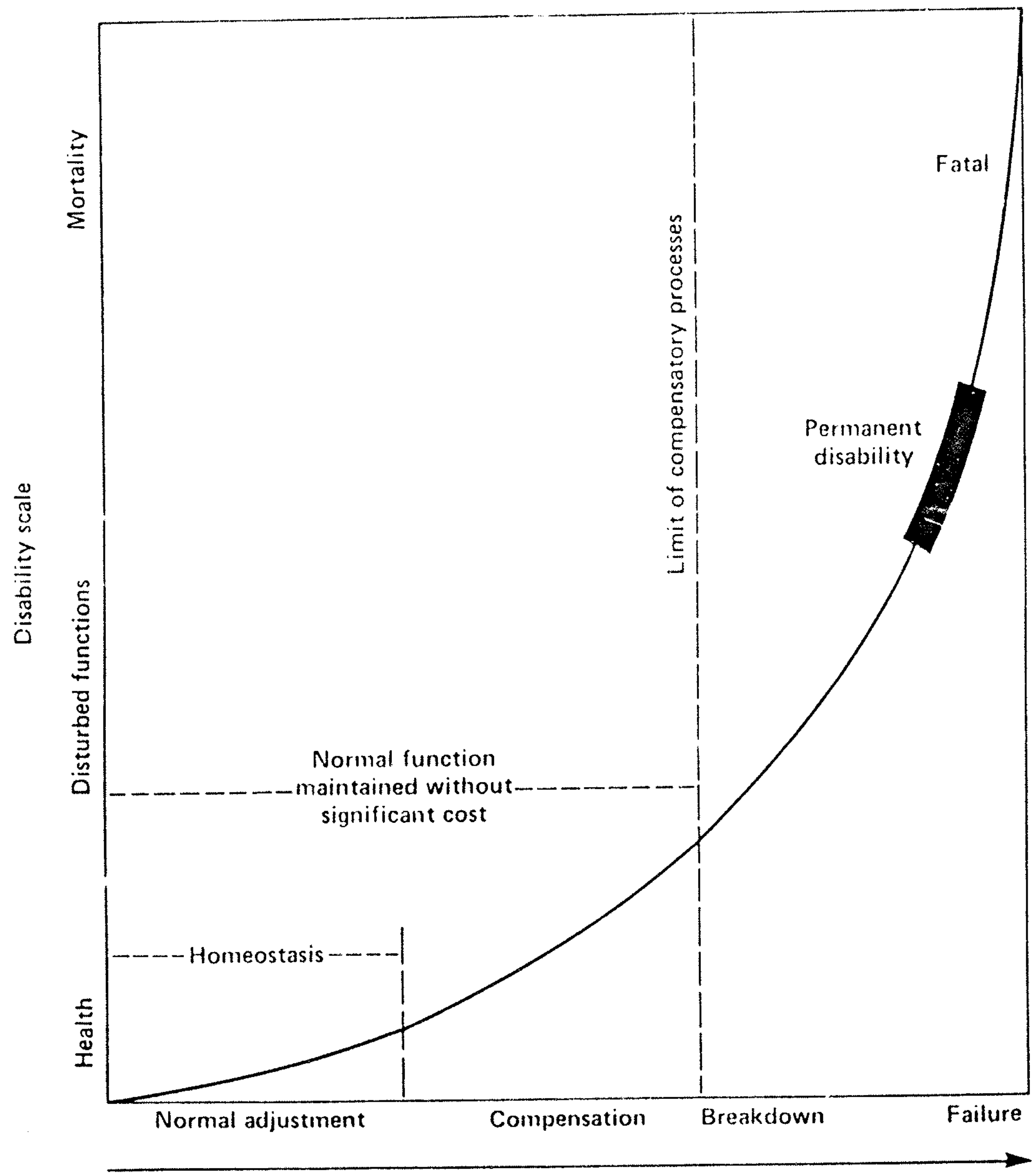

Figure 1. Changes in the physiological responses of aquatic animals to increased levels of stress in aquatic ecosystems. Modified from Hatch (1962).

Toxification may result from alterations in enzyme activity. These alterations may result when excesses of essential metals or nonessential metals bind to enzymes. Metalloenzymes may be rendered nonfunctional by confirmational changes brought about by binding with metals possessing properties different from the metals that are required for optimal activity of the metalloenzymes. Also, nonfunction may be due to induction or conformational changes so that substrate molecules no longer fit into binding sites. Alternatively, nonfunction could result from splitting of enzymes into subunits, which could interfere with feedback control mechanisms. Because any of these reactions could result in impaired metabolic activity, it is not unexpected that adverse effects would occur.

Detoxification mechanisms that have been proposed for metals include binding to metallothioneins (MT), which are proteins having a high affinity for some metals. This mechanism appears to be ubiquitous among organisms; these proteins have been described in organisms throughout the animal kingdom (Kagi and Nordberg, 1979). They were first characterized in mammals and now have been found to have a similar function in fishes, invertebrates, and plants. MT represent a family of inducible, low-molecular-weight (LMW), intracellular, cytoplasmic proteins that normally bind seven to ten atoms of metals per molecule. These proteins have been isolated from kidneys and livers of both vertebrates and invertebrates. MT possess a number of unique structural and functional characteristics. They contain 25 to 35 percent cysteniryl residues and lack histidinyl and aromatic amino acid residues. All cysteinyl-SH groups are involved in complexation of metal ions and do not form either intra- or intermolecular disulfide bonds. The mode of distribution of cysteinyl residues within the amino acid sequence is highly conserved among isoforms of the protein from the same organisms, as well as those isolated from taxonomically distinct organisms. Recently, considerable information has become available on the mode of action and genetic control of MT.

The induction of the synthesis of MT has been demonstrated in aquatic animals exposed to metals. The induction of MT is a very significant process, not only because it appears to be important in detoxification, but also because it can confer increased tolerance to organisms. For some species, this tolerance results in increased survival of aquatic organisms and their communications; this phenomenon is of significance to those managing aquatic resources.

On the west coast, research on MT in fishes and invertebrates has been performed by Dr. Kenneth Jenkins and coworkers at California State University at Long Beach (Jenkins et. al. 1984), Dr. David Brown and coworkers at SCHWRPP (Brown et. al. 1984), Dr. Guri Roesijadi and coworkers at Pacific Northwest Laboratory at Sequim (Roesijadi et. al. 1982, and by our group at Lawrence Livermore National Laboratory (Harrison et al. 1983).

Our investigations of metal metabolism in mussels involved studies of both laboratory and field populations. Standard biochemical methods were used to separate metal-binding proteins. The mussel tissue that was used was the digestive gland, which is known to concentrate metals and is homologous to the liver of mammals. Digestive glands from 25 mussels were pooled, homogenized, centrifuged at 100,000 x g, and then an aliquot of the supernatant fluid was applied to a gel permeation chromatography column. The column effluent was monitored for absorbance in the UV region and collected in a fraction collector. Sample fractions were analyzed for each metal. Two metal peaks are generally found. The first peak represents metals associated with high-molecular-weight (HMW) proteins and the second peak with low-molecular-weight (LMW) proteins. The HMW proteins include metalloenzymes that are necessary for normal metabolic activities and are considered to be the sites of toxic action of metals; the LMW proteins include metallothioneins that are considered to be the sites of detoxification.

The changes in the amounts of copper associated with these two sizes of proteins are shown for digestive glands of mussels that had been exposed for three weeks to 25, 50, and 75 µg Cu/L (Figure 2). The quantities of copper associated with both the LMW and HMW proteins were greater in those exposed to copper. However, whereas the amount in the HMW proteins increased with exposure concentration, that associated with the LMW proteins was highest in those that had been exposed to 50 ug Cu/L. These results indicate that exposure to 75 µg Cu/L for three weeks was not well tolerated. This was indicated also from the mortality data that showed a large percentage of mortality in the group exposed to 75 µg Cu/L. Although the mortality was correlated with the amount of Cu associated with the HMW peak (Figure 3), it does not establish a cause-effect relationship.

A second experiment in which mussels were exposed to 25 ug Cu/L for 12 weeks was performed. The quantities of metals associated with the HMW and LMW proteins was quantified; the amount associated with the HMW proteins continued to increase with time whereas that associated with the LMW proteins MT appeared to plateau (Figure 4). The presence of a plateau indicates that the quantities of MT that are produced are limited, which, in turn, implies that the detoxification provided by this process is also limited.

It has been established that pre-exposure to low concentrations of metals may result in the induction in the synthesis of MT; this phenomenon may account for the large increase between 3- and 6-week samples in the amount of copper associated with LMW proteins. It has also been established that increased concentrations of MT results in increased tolerance to exposure to additional metals. In our experiments, the possibility of increased tolerance to copper was not examined.

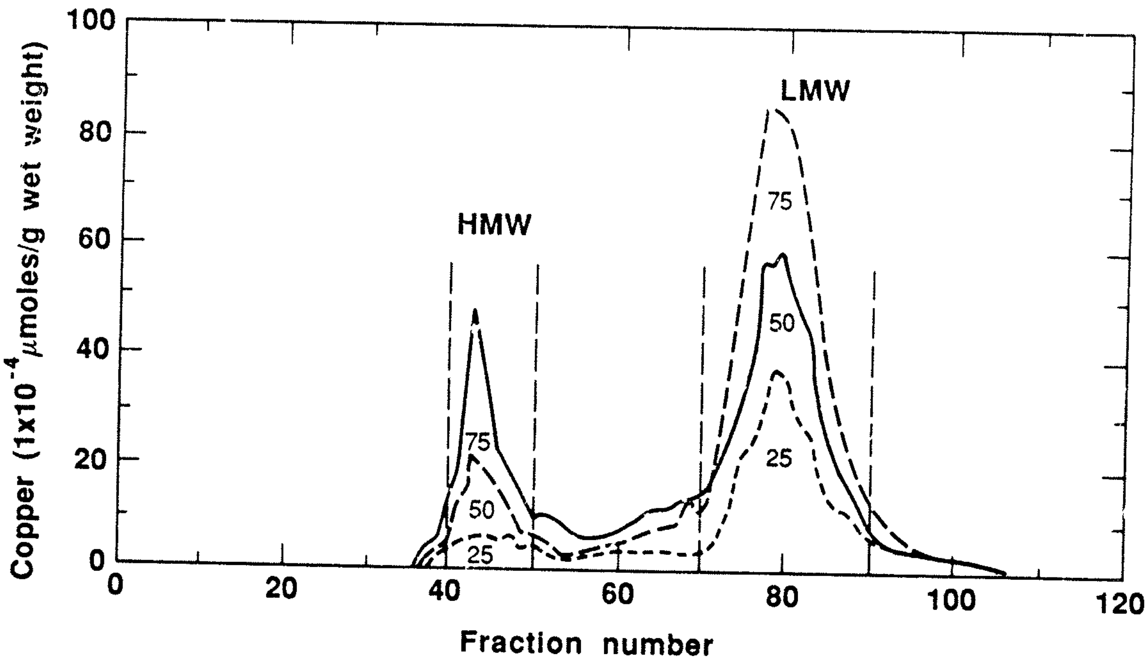

Figure 2. Copper profiles constructed from gel permeation chromatography from 100,000 x g supernatant fluid of homogenized digestive glands from 25 mussels. HMW designates high-molecular-weight protein fraction containing metalloenzymes; LMW designates low-molecular-weight protein fraction containing metallothionein. The numbers adjacent to the curves indicated the concentrations of copper to which the mussels were exposed.

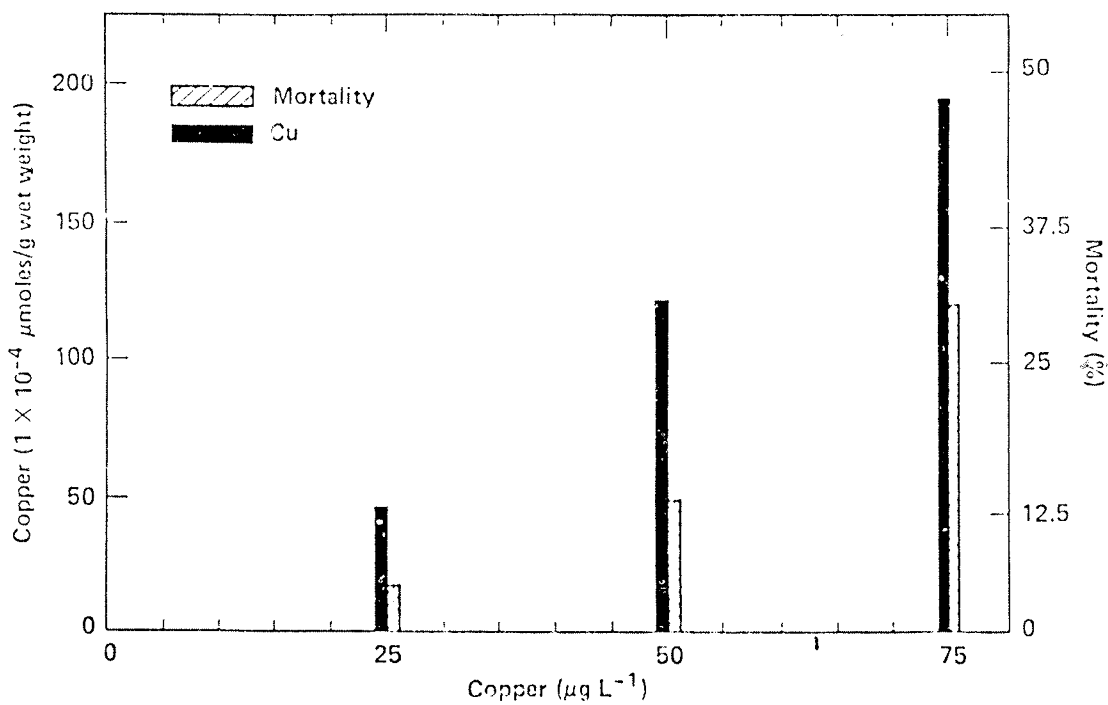

Figure 3. Percent mortality after 21-day exposure to copper compared to the concentration of copper in the high-molecular-weight protein fraction.

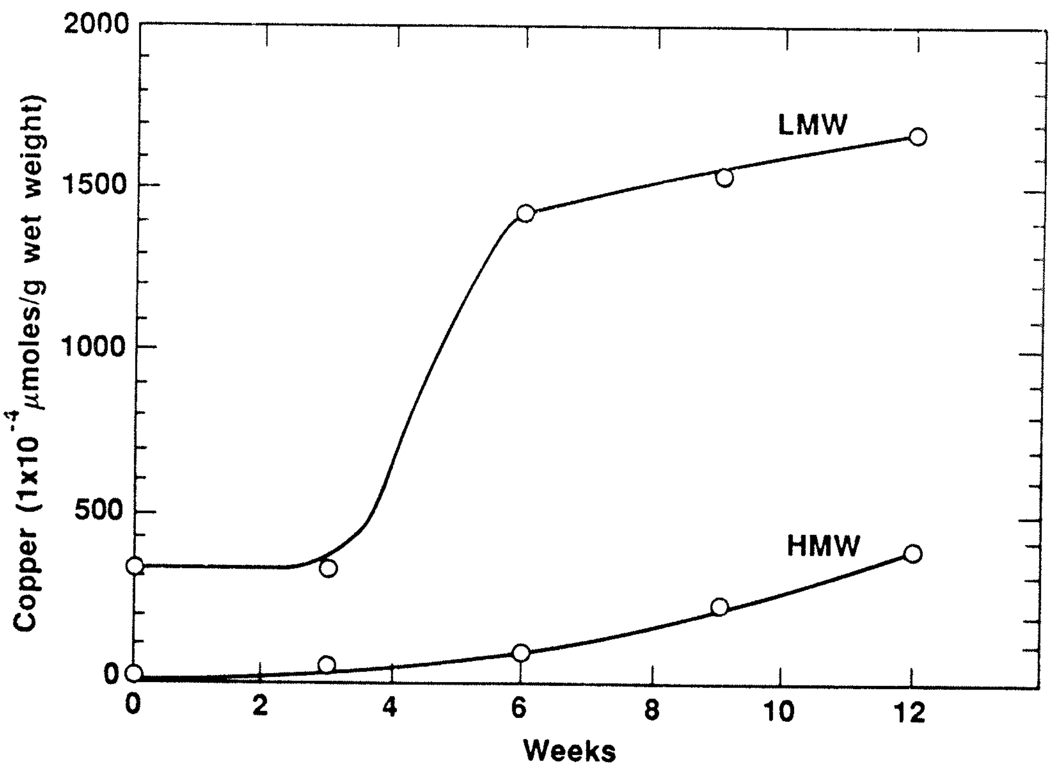

Figure 4. Changes in the quantities of copper in the high-molecular-weight (HMW) and low-molecular-weight (LMW) protein fractions in the supernatant fluid from homogenized digestive glands from 25 mussels that had been exposed to 25 μg Cu/L

A third experiment was performed to determined the effect of exposure to copper for longer periods of time than were used in the first two experiments. Mussels wee exposed to 10 and 25 ug Cu/L for 21 weeks. In those that were exposed to 25 ug Cu/L, there were large increases in the quantities of copper associated with both the HMW and LMW proteins, whereas in those exposed to 10 ug Cu/L, there were large increases only in the LMW proteins (Figure 5). These results indicate that detoxification provided by the MT found in the LMW protein was adequate to prevent built-up of copper in the HMW protein fraction that contains enzymes critical for normal metabolism.

In field studies we investigated the kinds and quantities of metals associated with these same proteins in populations from a pristine environment (Tomales Bay, CA) and in those from a contaminated environment (South San Francisco Bay). In addition, we participated in a mussel-transplant study with Dr. John Martin (California Department of Fish and Game); bagged mussels from Tomales Bay were distributed in an array near a municipal outfall in the Southern California Bight and sampled sequentially with time.

Field populations of mussels from the two sites were found to differ in the distribution of metals between the LMW and HMW metalloproteins (Table 1). It is apparent that the South San Francisco Bay mussel were contaminated highly with copper and cadmium. In mussels transplanted from Tomales Bay to the White Point outfall in the Southern California Bight, the concentrations of metals associated with the LMW and HMW proteins increased significantly after 1- and 3-month exposure to the effluent (Table 2). Copper, cadmium, and zinc were rapidly accumulated in the LMW protein fraction containing the MT, and some displacement of the essential metal, Zn, may have occurred. However, interpretation of the results was confounded because no measurements of the levels of MT were made. We currently have a methodology for quantifying MT, and in our future transplantation studies, we will follow both the concentration of MT and the metals associated with both LMW and HMW metalloproteins. Results from these kinds of experiments will provide a better understanding of metal metabolism and adaptive capabilities of mussels from pristine and metal-contaminated ecosystems.

Organic Compound Metabolism

Marine bivalve molluscs efficiently concentrate organic chemicals present in the water. Whether an organism will be harmed by accumulated contaminants is determined largely by its ability to transform them into more water-soluble (detoxified) forms. Some metabolic transformations, however, result in the production of activated compounds that are more toxic than the original contaminants.

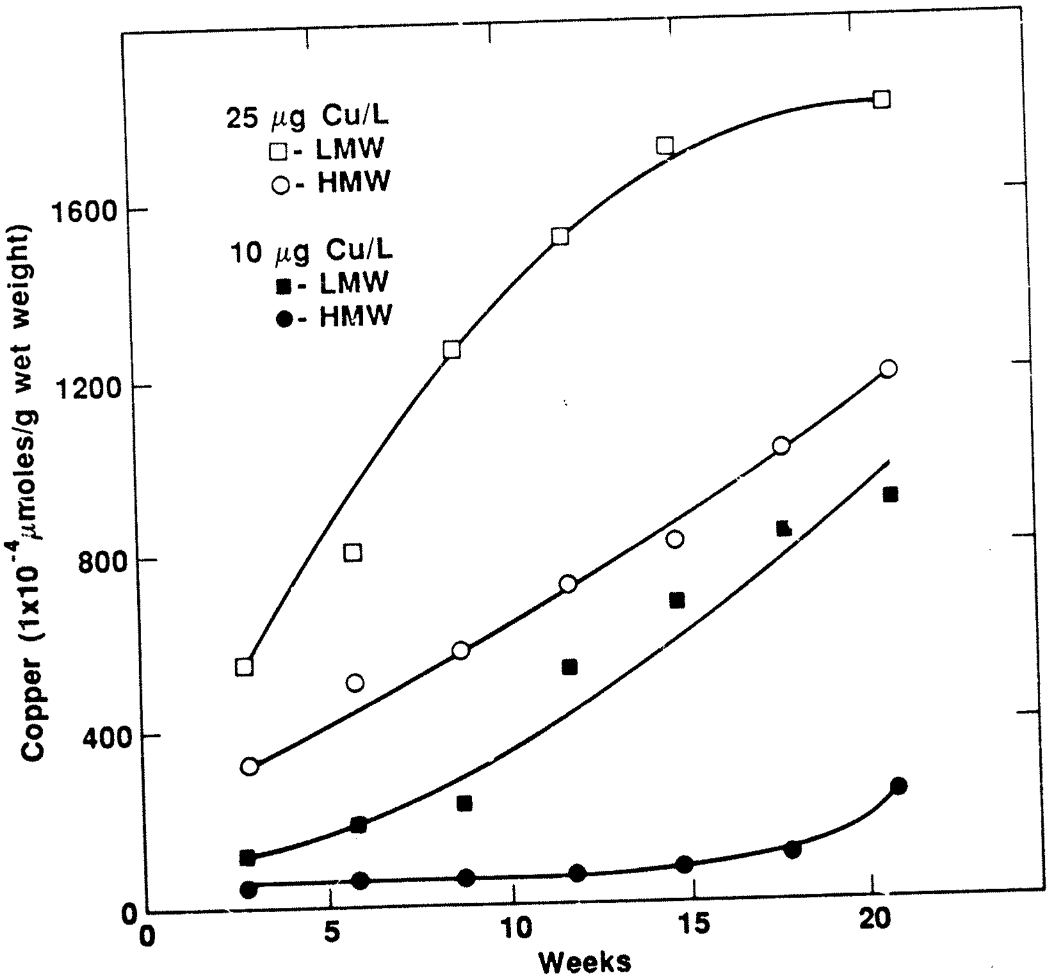

Figure 5. Changes in the quantitites of copper in the high-molecular-weight (HMW) and low-molecular-weight (LMW) protein fractions in the supernatant fluid from homogenized digestive glands from 25 mussels that had been exposed to either 10 or 25 µg Cu/L.

Table 1. Concentrations of metals in the high-molecular-weight (HMW) and low low-molecular-weight (LMW) (1×10^{-4} umoles /g wet weight) protein fractions in the supernatant fluid from homogenized digestive glands from 25 mussels from Tomales Bay and South San Francisco Bay.

	TOMALES BAY		SOUTH SAN FRANCISCO BAY	
	HMW	LMW	HMW	LMW
Zinc	330	770	460	1320
Copper	10	330	480	3600
Cadimum	ND[a]	ND	140	1600
Total	340	1100	1080	6520

a ND, none detected

Table 2. Concentrations of metals in the high-molecular-weight (HMW) and low low-molecular-weight (LMW) (1×10^{-4} umoles /g wet weight) protein fractions in the supernatant fluid from homogenized digestive glands from mussels that were transplanted to the White Point outfall in the Southern California Bight. The first sampling was taken after one month and the second after three months. Each sampling included 25 mussels.

SOUTHERN CALIFORNIA BIGHT

	SAMPLE 1		SAMPLE 2	
	HMW	LMW	HMW	LMW
Zinc	1600	2000	700	1600
Copper	400	1700	550	3500
Cadmium	80	130	430	540
Total	2080	3830	1680	5640

Our studies are concerned particularly with energy-related organic contaminants that are potentially mutagenic or carcinogenic. Many such compounds are present in the water-soluble fraction of fuel oils and are rapidly accumulated by aquatic organisms.

Aromatic amines represent a class of organic contaminants that are present in a variety of industrial and energy-related wastes. The biological hazard posed by these compounds is largely determined by their biotransformation; that is a specific metabolic reaction (N-hydroxylation) is required before they elicit mutagenic or carcinogenic effects. Unfortunately, little is known about the ability of aquatic organisms to metabolize these contaminants. In our studies we have developed experimental protocols that can be used to assess the in vivo metabolic processing of these and other organic contaminants by marine invertebrates. Such basic information is needed because our knowledge of chemical metabolism has been based largely on studies of vertebrate organisms and may not directly apply to invertebrate species. With increased understanding of biotransformation in marine mussels, we will be better able to predict the effects of organic contaminants found in contaminated ecosystems.

For our experiments we chose to study the metabolic transformation of a model aromatic amine (o-toluidine) whose structure is representative of a broad class of potentially mutagenic contaminants. The mussels that we used in our initial experiments were from Tomales Bay. These mussels rapidly accumulated o-toluidine and eliminated metabolites that were significantly different from those produced by vertebrate organisms (Figure 1). Mussels and vertebrate organisms form different metabolites because they have different detoxification mechanisms. In addition to producing mutagenically activated (nitrogen-oxidized) metabolities, the mussels were able to add a single carbon atom to the nitrogen atom and form a novel detoxification product, n-formyl-o-toluidine. This nitrogen metabolizing pathway represents a significant departure from the two-carbon addition (acetylation) that is usually observed in vertebrate of this common detoxification pathway. The common carbon-oxidizing metabolic pathways that we expect to occur in mammals were not found in the mussels; we did verify our experimental techniques by isolating these metabolites from a rat injected with o-toluidine (Figure 6).

The pathways available to mussels for the metabolism of aromatic amines consist of reactions that the organisms normally utilize for the metabolism of amino acids, fatty acids, and proteins. Any change in the organism's ability to metabolize a foreign compound (i.e., o-toluidine) should therefore be indicative of its overall physiological state. We investigated this hypothesis by measuring the metabolic capabilities of

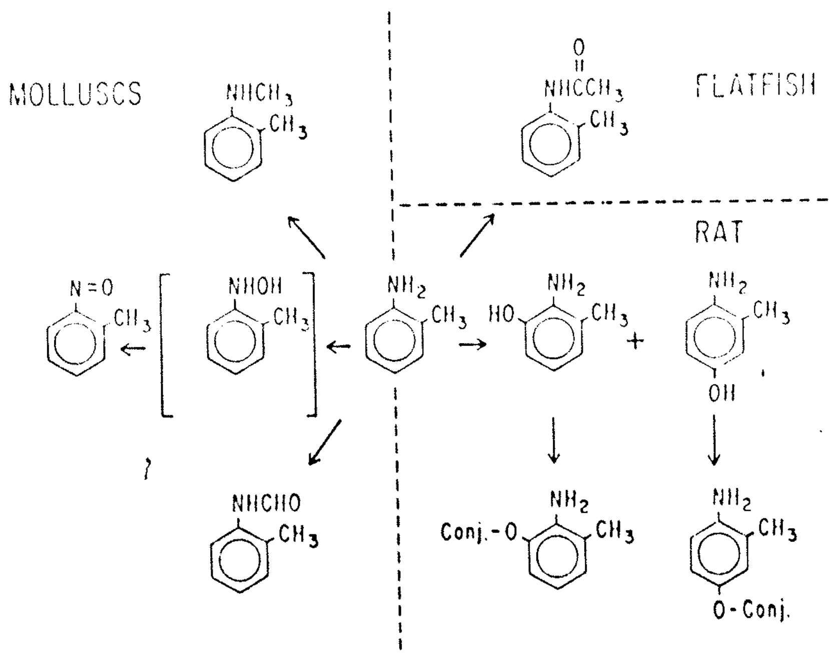

Figure 6. The biotransformation of a model aromatic amine (o-toluidine) by a marine mollusc (bay mussel), marine flatfish (starry flounder), and Sprague-Dawley rat. The nitrogen-oxidizing capability of mussels is significant in as much as all mutagenic and carcinogenic aromatic amines require metabolic activation via this pathway. That is, the aromatic amines themselves are not harmful but their nitrogen-oxidized metabolites are capable of causing damage to biomolecules.

mussels taken from a site of known contamination in San Francisco Bay. Mussels were collected from a site at Redwood City where the California Department of Fish and Game has documented their bioconcentration of metals, synthetic organic chemicals, and petroleum hydrocarbons (Stephenson et. al. 1982). In our comparative study (Table 3) we found that the total extent of o-toluidine metabolism in mussels from South San Francisco Bay was significantly less than mussels from Tomales Bay (Knezovich and Crosby, 1985). These results are in agreement with the findings of Martin et. al. (1984) who reported a diminished physiological condition, as evidenced by a reduced scope for growth, in mussels taken from this site.

We are currently using our understanding of aromatic amine metabolism to better understand the effects of contaminant-induced stress. Mussels transplanted from Tomales Bay are being monitored for changes in their abilities to metabolize both metallic and organic contaminants. The results of this study will help us to define limits of physiological adaptation so that realistic evaluations of impacted populations can be made.

Acknowledgements

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References

Bayne, B.L., ed., 1976: Marine Mussels: Their Ecology and Physiology. Cambridge University Press, London.

Brown, D.A.; S.M. Bay; J.F. Alfafara; G.P. Hershelman; and K.D. Rosenthal, 1984: Detoxification/toxification of cadmium in scorpionfish (Scorpaenaguttata): acute exposure. Aquatic Toxicol. 5:93-107.

Goldberg, E.D.; V.T. Bowen, J.W.; Farrington, G. Harvey; J.H. Martin; P.L. Parker; R.W. Risenbrough; W. Robertson; E. Schneider; and E. Gamble, 1978: The mussel watch. Environ. Conserv. 5:1-25.

Harrington, F.L.; J.R. Lam; and R. Berger, 1983: Sublethal responses of Mytilus edulis to increased dissolved copper. The Science of the Total Environment. 28:141-158.

Hatch, T, 1962: Changing objectives in occupational health. Am. Ind. Hyg. Assoc. 23:1-7.

Table 3. The comparative metabolism of o-toluidine by Mytilus edulis from pristine (Tomales Bay) and contaminated ecosystems (San Francisco Bay).

Metabolites produced in 8 hr. (pmole/mg dry wt.)

Metabolites	Tomales	San Francisco
N-Hydroxy-o-toluidine	2.4(0.1)	ND
2-Nitrosotoluene	22.2(14.2)	9.5(2.7)
N-Methyl-o-toluidine	29.3(16.0)	9.3(3.9)
N-Formyl-o-toluidine	27.9(13.8)	9.7(1.6)
Sum of pathways	81.8(44.2)	28.5(6.6)

ND, non detected

Standard deviation in parentheses.

Jenkins, K.D.; B.M. Sanders; and W.G. Sunda, 1983: Metal regulation and toxicity in aquatic organisms. In T. Singer, T. Mansour and R. Ondarza, eds., Mechanisms of Drug Action. Academic Press, New York, p. 277.

Kagi, J.H.R. and M. Nordberg, 1979: Metallothionein: Proceedings of the First International Meeting on Metallothionein and Other Low-Molecular-Weight Binding Proteins. Birkhauser Verlag, Boston, pp. 378.

Knezovich, J.P. and D.G. Crosby, 1985: Fate and metabolism of; o-toluidine in the marine molluscs Mytilus edulis and Crassostrea gigas. Environ. Tox. Chem. 4:435-446.

Martin, M., G.; Ichikawa, J.; Goetzl, M. De Reyes; and M.D. Stephenson, 1984: Relationship between physiological and trace toxic substances in the bay mussel, Mytilus edulis, from San Francisco Bay, California. Mar. Environ. Res. 11: 91-110.

Roesijadi, G.; A.S. Drum; J.M. Thomas; and G.W. Fellingham, 1982: Enhanced mercury tolerance in marine mussels and relationship to low-molecular-weight, mercury-binding proteins. Mar. Pollut. Bull. 13:250-253.

Stephenson, M.D.; S.L. Coale; M. Martin; D. Smith; E. Armbrust; E. Faurot; B. Allen; L. Cutter; G. Ichikawa; J. Goetzl; and J.H. Martin, 1982: California state mussel watch 1980-81. Trace metals and synthetic organic compounds in mussels from California's coast, bays and estuaries. State Water Resources Control Board, Water Quality Monitoring Report 81-11 TS. Sacramento, CA, pp. 1-72.

White, K.M., 1937: Mytilus. Mem. Liverpool Mar. Biol. Comm. 31.

SCIENTIFIC INFORMATION AND MANAGEMENT POLICY FOR THE DELTA-SAN FRANCISCO BAY ECOSYSTEM

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Abstract

Despite the many attempts to create a useable data base with which to develop management policies for the Delta-Bay ecosystem, there is currently no agreement among scientists, resource managers, dischargers, and the public on a decision-making process that will lead to effective management. This paper proposes a procedure for developing management goals, scientific questions, research programs, conclusions, and recommendations leading to solutions for major estuarine problems based upon the systems analysis approach. The approach is illustrated with a number of systems block diagram examples.

Thus far in this seminar presentation, there has been much discussion about science but little direct mention of management of the resources of San Francisco Bay and the Delta. However, it is important to realize that these earlier presentations have been about resource management because the data that have been presented -- the actual parts per million of pollutants in striped bass and the number of million acre feet of freshwater flowing into San Francisoc Bay from the Delta and rivers (after diverisons) -- are all by-products of management decisions. They are measurements of the effectiveness of the management process.

In fact, most of us believe that the status of the Delta and Bay and their natural resources has been determined to a great extent by prior management decisions. The problem is that we can't prove it. If we could show that the decline in freshwater inflow to the Delta and Bay or level of pollutants in the water caused the radical decline in striped bass, it would be relatively easy to convince resource managers that policies must be changed. The best that we can do is to find significant correlations (associations) between several of those factors (e.g., Rozengurt, Josselyn and Herz, this volume). Convincing resource managers that the findings the sufficient to warrant policy changes requires our developing the most powerful analytical techniques and the best scientific information and communicating it as clearly and concisely as possible in order to assist them with their decision-making.

When one works in the arena of policy and management decision-making, it becomes evident very quickly that scientists and managers view the world, and each other, quite differently. Managers often see scientists as intent on collecting unlimited quantities of irrelevant data over infinite time periods, and as not wanting to state conclusions without significant qualifying language. Perhaps it is this quality that once led Senator Proxmire to lament that he wanted more one-armed scientists, ones who would not say, "But on the other hand......"

On the other hand, scientists view managers (and politicians) as not understanding the need for large data bases collected under standardized conditions over long periods of time before conclusions can be reached with any degree of certainty. They judge the manager's quick decisions, based on what they consider insufficient information to be arrogant guesses, or worse, purse political expediency.

The purpose of this paper is to show that each set of players needs to learn from the other, and that there do exist procedures for maximizing the degree to which decision-making, policy development and resource management can utilize technical information.

This combination of circumstances surrounding the status of ecological information on the River-Delta-Bay-Ocean ecosystem indicates that we have serious problems regarding the adequacy of information on the resources that we are trying to manage. It also indicates that there does not exist an agreed-upon set of management goals for this, the largest estuary on the Pacific coast. Despite the over $3 billion spent on improving Bay water quality since the passage of the Clean Water Act in 1972, and despite the presence of over 75 agencies, academic institutions, and non-profit organizations concerned with the Bay and environmental issues, we have yet to develop a system which established widely accepted management goals. One Bay scientist expressed his concern over this problem as follows (Conomos, 1977):

> In response to environmental concerns during the past few decades, legislative committee have agreed that this estuarine system should be protected against further indiscriminate and unrestrained exploitation. These committees and subsequent Federal and state legislation have mandated that sound plans for long-term intelligent and rational management of this valuable resource be formulated and implemented. There is, unfortunately, little scientific data on which to base these plans. Our knowledge of the complex physical, chemical, biological, and sedimentological estuarine processes is relatively primitive. This is surprising, considering the importance and irreplaceable nature of the system, the magnitude and cost of the public works already built or in the planning stages, and the demands and standards imposed by environmental and regulatory agencies.

On the other hand, there is the view expressed by an industry managers that although you don't have all of the information that you need to make the best management decisions, you must

> ......go ahead and start making some wild guesses based on the information you have. Make your best possible estimates, because if you don't make those estimates, the managers and the decision-makers are going to ignore you and go ahead and decide anyway, in the absence of any data (Adams, 1982).

So the question becomes, how do we chart a course through these troubled waters to find agreement? From the perspective to those concerned with the role of scientific information in the decision-making and management processes, we should begin by developing a set of management goals which are agreed to by managers, scientists, politicians, and the public. From this set of goals, it should then be possible to devise scientific questions which become the basis for a research program designed to produce information and recommendations that support the management goals or lead to their modification to better meet the environmental needs of this estuarine ecosystem. Schematically, the approach is as follows:

RECOMMENDATIONS ←
↓
MANAGEMENT GOALS
↓
SCIENTIFIC QUESTIONS
↓
RESEARCH PROGRAM DESIGN
↓
DATA
↓
CONCLUSIONS

From the earlier discussion, it is obvious that neither the development of the management goals nor the design of the research program should become the exclusive domain of either scientists or managers. Rather, a Management Policy Committee should be created which has representation from both groups as well as from relevant industries and the public. Since research design requires specialized technical knowledge, a Technical Advisory Committee should be formed which consists of a multidisciplinary set of scientists from management agencies (Federal, state, and regional), research institutions, industry, and public oragnizations. Both of these committees should have representation from each of the categories of Bay Area interest groups:

San Francisco Bay Interest Groups

Regulatory Agencies

Environmental Protection Agency
U.S. Army Corps of Engineers
Bureau of Reclamation
U.S. Fish & Wildlife Service
CA Dept. of Water Resources
CA Dept. of Fish and Game
Studies
State Water Resources Control Board
Regional Water Quality Control Bds. (S.F. Bay and Central Regions)
Bay Conservation & Development Commission

Research Organizations

Uni. of California Berkeley
Sanitary Engineering Research Lab
Lawrence Livermore Laboratory
San Francisco State Univ. Tiburon Ctr. for Envir.

U.S. Geological Survey
National Oceanic and Atmospheric Administration
Aquatic Habitat Institute

Non-Profit Organizations

Committee for Water Policy Consensus
Citizens for a Better Environment
Environmental Defense Fund Bay Institute
Oceanic Society
Save San Francisco Assn.
Bay Wetlands Coalition
Audubon Society
Natural Resources Defense Fund

Dischargers

Bay Area Dischargers Assn.
Bay Area League of Industrial Associations

While the management structure is important, the future of the Delta and San Francisco Bay will be determined by whether or not solutions are developed for its problems, many of which have already been identified:

- Decreases in freshwater inflow have resulted in major reductions in flushing activity (increases in renewal time) and reductions in fish stocks to all-time lows (Rozengurt, Josselyn, and Herz, this volume).

- Pollutant loads in some species of fish and wildlife are so high that warnings have been issued to protect public health; these loads may be responsible for reproductive failure and population deterioration (Whipple, this volume).

- Pollutant discharges from industrial and municipal dischargers, agricultural, and non-profit sources are increasing (Nichols, et at. 1986).

- Reduction in wetland habitats has eliminated fish nursery and waterfowl migration and nesting areas (Josselyn, this volume).

One technique for developing an appropriate research program and management scheme for addressing these problems is the systems analysis approach, which has been used successfully in the space prgram. Its procedures are especially useful, since they were designed to analyze the organization and interrelationships among components of complex systems such as those found in natural environments.

Figures 1 and 2 show schematically the processes of formulation and solution of estuarine problems. These, along with decision-making, decision implementation, and analysis of differences between the predicted results and those obtained, are the major parts of system methodology for solving multiple problems. The application of a programmatic approach to organization of complex systems raises a variety of methodological operations related to water resources management and research.

The first category of operations are those which relate to:

1) formulation of problems and objectives, i.e., description of the current conditions or the results of scientific investigations;

2) outlining "the tree of objectives";

3) developing a system of water resources management;

4) creating an operational model of system's functions;

5) establishing a research program designed to achieve the desired objectives; and

6) implementing the research program.

Formulation of the problem is particularly important in a programmatic approach since it determines the development of subsequent investigations. The most appropriate methodology for problem identification is based upon the system analysis approach. According to this methodology, the process of problem formulation represents a chain of consecutive analytical and synthetic operations (Figure 3):

1) evaluation and interpretation of the status of the ecosystem including description of trends in various parameters and their interactions. (Determine objective);

2) identification of problems and undesirable trends;

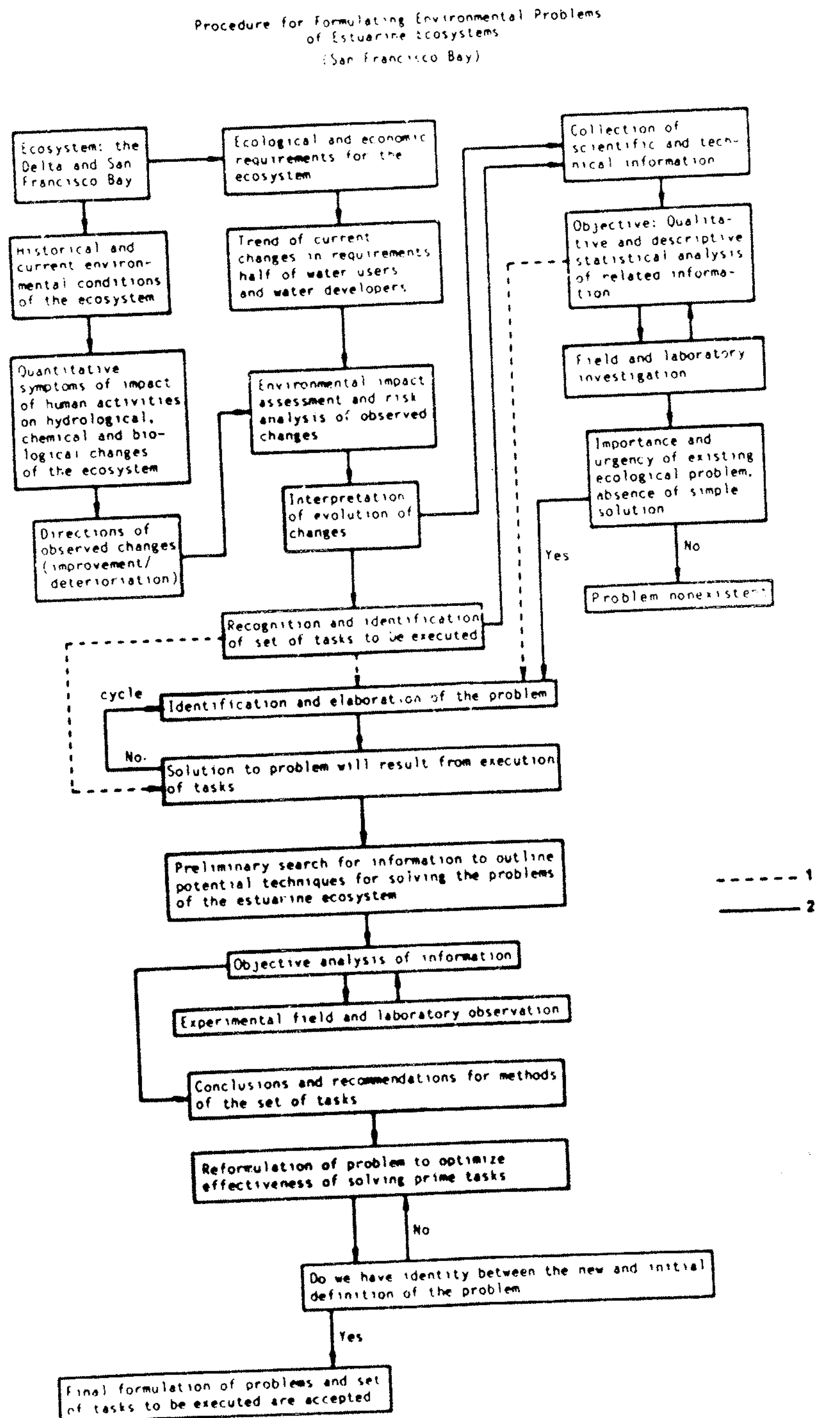

Figure 1. The scheme of the procedure for formulating environmental problems of estuarine ecosystems. (1) flow of information; (2) order of operation and flow of information

Problem Solving Procedure

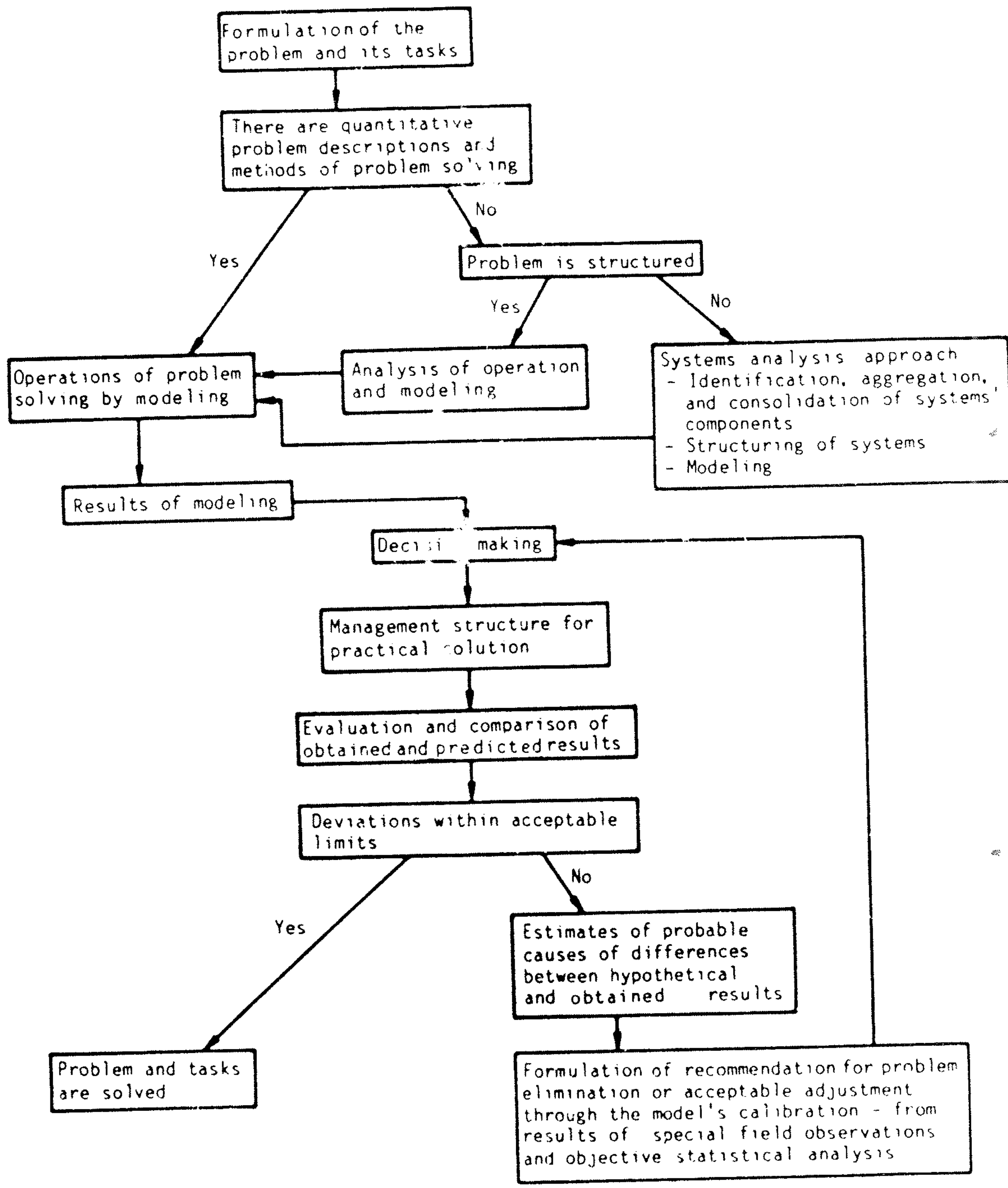

Figure 2. The scheme of systems analysis approach related to solving environmental problems of the Delta-San Francisco Bay Ecosystem.

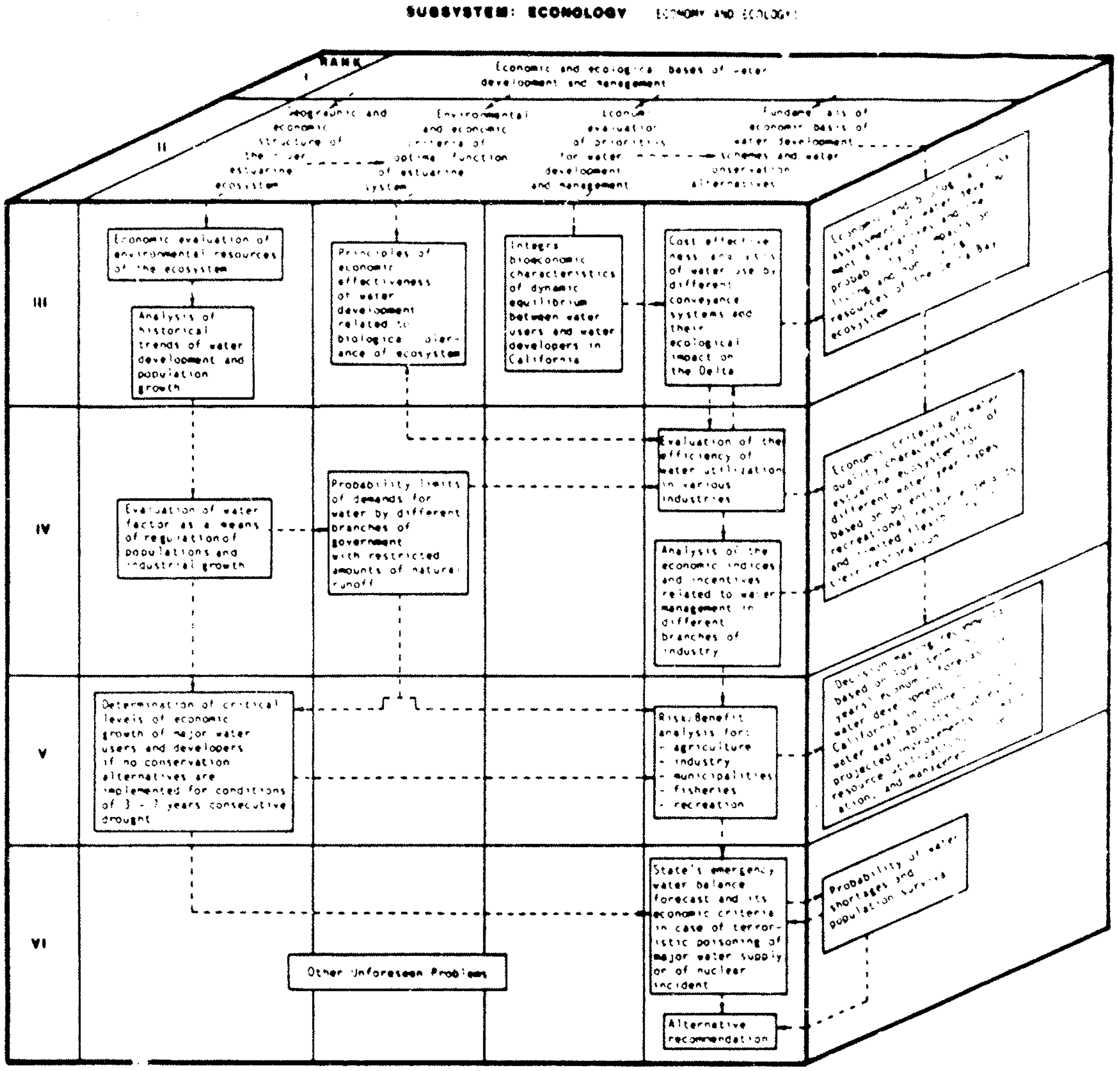

Figure 3. Hierarchy of investigations of the interrelations between ecological and economic indices of development in California under various levels of water supply for the Delta-San Francisco Bay Ecosystem.

3) development of alternative solutions and techniques for modification of negative trends. (Techniques for meeting objectives);

4) assessment of impacts of alternative solutions (Compare with objectives);

5) identification of "best" alternative based on optimal use of environmental resources balanced with needs of the economy.

The process starts with investigations of all water resources of the region, their dynamics (under natural and regulated conditions), quality and biological productivity, as well as their uses, conservation, and restoration. This makes it possible to describe the trends in various dimensions of the ecosystem and to define optimal levels of resources utilization.

Then a long-term forecast begins with water availability studies and analysis of water use by various industries, demographic trends, and recreational needs in this particular region. Based on a variety of projected levels of water use, forecasts are then made of potential impacts of water regulation on the quality of the estuarine ecosystem and its living resources (e.g., fisheries, wildlife, etc.). The main objective of this systems analysis approach is the development of a tentative evaluation of long-term trends in water resources. This should then make it possible to identify the principal factors responsible for these changes and to develop strategies for their mitigation. Decisions regarding alternative strategies will utimately be made through a management system.

The Environmental Protection Agency (EPA) has recently assumed a leadership role in this process to "achieve effective and cooperative management of the Delta-Bay system and to facilitate communication and coordination among and within existing management agencies." Their initial step will be to design a management structure and decision-making process. In order to manage the Delta and San Francisco Bay for the benefit of all the citizens of the area, management goals that are agreed upon by a wide and representative cross-section must be adopted and a research program designed to achieve these goals.

A likely source of information needed for such management is the recently created Aquatic Habitat Institute (AHI) which is governed by a board representing regulatory agencies, dischargers, the academic community and the public, and which was designed to produce a "a comprehensive data base for current and past research, and master plan for future monitoring and research that assures efficient use of the many ongoing programs." It is anticipated that the AHI will work closely with the EPA to address many of the first year priorities agreed upon at EPA's recent San Francisco Bay/Delta Estuarine Management Project meeting: identify, locate, coordinate, and disseminate existing information on the estuary; identify additional data needs; develop quality assurance and quality control measures; initiate long-term monitoring; and develop public participation and education programs focused on policy goals.

Scientist, managers, dischargers, and the public must reach consensus on this management plan and on the scientific questions that need to be answered before the program is undertaken. From our perspective, it is clear that the systems approach described here can play an important role in organizing and understanding this highly complex estuarine system. We are hopeful that the EPA and AHI will use it as part of the planning and management process.

Acknowledgements

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References

Adams, J., 1982: Discussion of "Bioeconomic models and the development of a San Francisco Bay fisheries index." In M. Herz and S.M. Creary, eds., 1982 State of the Bay Conference Proceedings. The Oceanic Society, San Francisco Chapter, p. 181.

Conomos, T., 1977: Introduction. In T. Conomos, ed., San Francisco Bay: The Urbanized Estuary. Pacific Div. Amer. Assoc. for the Advancement of Science. San Francisco, p. 7.

Nichols, F.H., 1987: Benthic ecology and heavy metal accumulation. In San Francisco Bay: Issues, Resources, Status, and Management. NOAA Estuary-of-the-Month Seminar Series No. 6. Washington, D.C., U.S. Department of Commerce, NOAA Estuarine Programs Office, p. 65-67.

Nichols, F.H.; J.E. Cloern; S.N. Luoma; and D.H. Peterson, 1986: The modification of an estuary. Science, 231:567-573.

Rozengurt, M.A.; M.J. Herz; and M. Josselyn, 1987: Impact of water diversions on the river-bay-estuary-sea ecosystems of San Francisco Bay and the Sea of Azov. In San Francisco Bay: Issues, Resources, Status, and Management. NOAA Estuary-of-the-Month Seminar Series No. 6. Washington, D.C., U.S. Department of Commerce, NOAA Estuarine Programs Office, p. 35-62

Whipple, J.A.; R.B. MacFarlane; M.B. Eldridge; and P. Senville, Jr., The impact of estuarine degradation and chronic pollution on populations of anadromous striped bass in the San Francisco Bay-Delta: A summary. In San Francisco Bay: Issues, Resources, Status, and Management. NOAA Estuary-ofthe-Month Seminar Series No. 6. Washington, D.C., U.S. Department of Commerce, NOAA Estuarine Programs Office, p. 77-107

SHORELINE MANAGEMENT

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Bay Conservation and Development Commission

I should first point out that other speakers have covered in one form or another the scientific points about San Francisco Bay that I wanted to make. But, because I am more familiar with coastal management issues than problems faced by scientists, and to avoid repetition, I will focus on how San Francisco Bay is managed. Then I'd like to discuss two recent matters: mitigation policy and diked historic baylands to help show how science does or does not interact well with the coastal manager's needs.

I would like to give you a little more information about the Commission's organization and jurisdiction. The Commission is a state agency, but one with only regional jurisdiction over San Francisco Bay. There are 27 commissioners. The 13 local representatives dominate the Commission's decisions. These locally appointed commissioners are from the 25 cities and 9 counties that control territory in or along the Bay. There are five state commissioners including representatives from the Regional Water Quality Control Board, the State Lands Commission, the State Resource Agency, the State Department of Transportation, and the State Department of Finance. There are five commissioners appointed by the Governor, including the Chairman and Vice-Chairman. One commissioner is appointed by the Speaker of the Assembly and one by the State Senate. There are also two Federal representatives: the District Engineer from the San Francisco District of the U.S. Corps of Engineers and the Regional Administrator for Region 9 of the Environmental Protection Agency. It takes 13 affirmative votes to grant a permit and 18 affirmative votes to adopt or change a policy in the San Francisco Bay Plan.

The McAteer-Petris Act defines the Commission's jurisdiction and authority. The jurisdiction includes all areas of the Bay from a line westerly of the Golden Gate to a line at the Delta that is subject to tidal action, including marshes, salt-ponds, managed wetlands and portions of certain tributaries that flow into the Bay. There is also jurisdiction over the shoreline for the first 100 feet inland from the edge of the Bay. Within this area, permits from the Commission are needed for any filling, extraction of materials, and substantial changes in use. The Commission also has planning responsibilities for the Bay as a regional resource of statewide significance.

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The Act was the first comprehensive coastal management law in the country. In the 20 years it has been in effect, it has worked remarkably well. This law instructs the Commission to balance the need to preserve the natural values of San Francisco Bay with the need to accommodate economic uses of the Bay. However, if there is an unavoidable conflict between those goals, preservation of the Bay predominates.

The San Francisco Bay Plan establishes the policies that govern the Bay. The 1965 version of the Act charges the Commission with preparing a comprehensive plan for the Bay in three years. The resulting planning program involved considerable research summarized in many technical reports. Some titles of these reports may give you some sense of the range of the investigation.

(1) Geology of the Bay;
(2) Mineral Resources of the Bay;
(3) Sedimentation Aspects of the Bay;
(4) Effect of the Bay on Climate;
(5) Ecological Aspects of the Bay;
(6) Tides of the Bay;
(7) Water Pollution and the Bay;
(8) Regional Organization for Bay Conservation and Development;
(9) Municipal, State and Federal Programs Affecting the Bay; and
(10) Air Transportation of the Bay.

This is only a sample -- a number of other reports dealt with ownership, regulatory authority, recreation, public facilities, barrier proposals, safety of fills, surface transportation, waterfront housing, waterfront industry, taxation, funding, and similar matters that affect how the Bay is governed.

Thus, both the McAteer-Petris Act and the Bay Plan address the Bay's resources from a number of points of view. Certainly preserving the Bay is the foremost priority in both the law and the Plan. Because there were several areas where information was lacking and because priorities and values change over time, the Legislature instructed the Commission to make a continuing review of all aspects of the Bay. Since 1969, the Bay Plan has been revised to reflect new information and to adopt new or changed policies. The most important planning efforts since 1970 include the studies that led to the Suisun Marsh Protection Plan, the study on dredging in the Bay, the studies that led to the Richardson Bay Special Area Plan, the diked historic baylands study, and the Seaport Plan. In addition to a well written law and a comprehensive plan for the Bay, the Bay also enjoys strong judicial and public support.

California is fortunate in having legal precedents that support broad regulatory authority -- certainly broader than exist in many other states. The California Supreme Court generally allows government to wield considerable police authority when making land-use decisions. That allows the Commission to be a little more aggressive than other commissions can be when faced with a choice between man's activities in the Bay and the need to preserve the natural values of the Bay.

The "public trust" doctrine also supports better decisions for the Bay. The public trust is a type of public property interest in the tidelands and submerged lands of the Bay. It is held by the state on behalf of the people and is paramount to any private property interests that may also exist. It can be thought of as an easement. The Commission is one of the co-trustees of this public trust. The McAteer-Petris Act is a declaration of the Legislature concerning what the public trust more specifically means for the Bay. When the Commission is acting in its capacity as a co-trustee, it can restrict uses on private lands more completely than it could if it were only using police power. If you use the police power in a way that deprives an owner of his property rights without paying for them, you are subject to a lawsuit that may require the agency to pay for the land affected by the decision. This possibility obviously has a chilling effect on the willingness of government to approach the line of an overly restrictive land-use decision. But if you are applying public trust principles to the land, then you are acting as one of the owners. An owner usually has greater control over property than a regulatory agency.

Public opinion supports an unfilled Bay. There is a fairly broad consensus among the citizens of the Bay Area that the Bay is important, valuable, and deserving of protection. Most Bay Area "leaders" recognize that the Bay Area is at a competitive disadvantage in comparison to most other regions. For example, our ports are disadvantaged in comparison with the deeper watered and richer Ports of Los Angeles, Long Beach, or Seattle. Housing costs in the Bay Area are among the highest in the country -- that discourages new industry. Chip-based technology has been experiencing retrenchment recently due to foreign competition and a maturing marketplace. Education and other public services have been contracting in the wake of Proposition 13, which greatly limits public taxing of property. Transportation is expensive, and roads are jammed and often badly maintained. Sewers need replacement in many areas.

Against these many competitive disadvantages, the Bay provides a great amenity and resource. It defines the area as special; the water creates vast open space and provides spectacular views. It moderates the climate. It is a great sailing Bay. It is a nursery ground for fish. It contains the largest contiguous marsh in California, a stopover for many mitigrating waterfowl. This resource and the region's other environmental advantages are our most important economic asset as well as vital to our continued health and welfare.

Our social and political structure makes it more difficult to govern the Bay as a single, interrelated entity. California divides resource management by subject matter. There is no department of environment or of natural resources. One agency regulates air emissions; another controls discharges into the Bay; a third decides who may take what freshwater where; a fourth regulates fisheries; a fifth administers the state park land-use; and a sixth, the Commission, plans for and regulates land-use in and along the Bay. Add to this 25 cities with councils, administrators, zoning and planning authority and 9 counties with supervisors, administrators, zoning and planning authority. So, special effort must be made in the Bay Area to cooperate to assure balance among the various agencies assigned to protect natural values.

Through the 1966-1970 planning period, science always played an essential role in defining the resources and describing the natural processes. Science has played less of a role recently, particularly in the regulatory decisions of the Commission. This is because scientific information about the Bay is not organized comprehensively, because research on the Bay has not kept up with efforts made for other important estuaries, because some scientific information is readily available in a form that is useful to policy-makers and because some essential data about the Bay has not been gathered. I believe that during the last 10 years or so, science has played less of a role in the decisions about the Bay than law, public opinion, politics, and economics.

Lack of comprehensive information, lack of coordination among various scientists and organizations doing research on the Bay and, failure to provide existing information in a form that is useful to managers are the likely reasons science has played a smaller role than it should when decisions about the Bay are made by the Commission, and I suspect, by other managers of the Bay's resources.

Of course, commissioners vary in their reaction to a situation in which there may be a threat to the natural values but scientists are unable or unwilling to define the extent of the threat clearly. In that situation, some commissioners will ignore unquantified and unspecific threats. That often means that an application is approved or less stringent policy language is adopted. An applicant usually has factual support for this application and is willing to spend the money and effort it takes to produce the scientific information needed. The scientific community is often in that position. Unless scientists can provide reasonable assurance that a specific harm will result unless a restrictive policy is adopted, the Commission may prefer to err on the side of those affected by the restriction.

Recently and frequently for matters before the Commission, scientists have said there is little data relevant to the question before the Commission. Or they state that the data that is available has been brought into question and may not provide a reliable basis for a decision. Or they say that the only scientific opinion available has been extrapolated from other areas which may or may not relate well to the Bay. But commissioners must nevertheless decide. If scientists say they cannot help much and decisions must be made, the Commission is forced to deal with less than a full deck.

As Mike Josselyn has pointed out, coastal managers must have easy access to scientific information. For San Francisco Bay, there is a large number of academic and scientific institutions that do various types of research on various aspects of the Bay. It is not always easy to discover who has what information. We need a clearinghouse or scientific forum that can coordinate the various studies, share information among scientists, and inform managers and the public about research, available data, and new conclusions about the Bay.

As important as providing a clearinghouse, we need scientific information written for the non-scientist. The non-scientists must be able to understand what the information means and must be able to know why the information is important. If the information is presented in a way that is too difficult for the layman to understand, it is unlikely that decision-makers or the public will either appreciate the importance of the research or apply it to the decisions they must make.

Now, I'd like to talk about two specific areas of concern the Commission has been working on where science has played an important part. First, mitigation. Mitigation means many things to different people. For the Commission, mitigation means the addition to or restoration of an area to wetland value. It does not mean buying out of harm that a project could avoid. Nor does it mean that projects that otherwise do not meet the requirements of our policies can be approved if mitigation is provided. A project must first meet the requirements of our law and Plan; it must be designed to have the least possible adverse will, nevertheless, have adverse impacts on natural values of the Bay. Then we require mitigation to offset those unavoidable impacts. Federal agencies often refer to this type of mitigation as compensation.

Now determining the adverse impacts of a small amount of fill in the Bay, particularly if marshes and mudflats are not involved, is very difficult. It is probably impossible to quantify precisely such impacts. However, we can reasonably assume that the cumulative impacts of several small fills, will at some point, affect the natural values of the Bay, even though it is difficult to assess the impacts of each small fill. Nevertheless, the best available environmental information must be provided, preferably in a document that clearly describes the site and project. Certainly biologists, hydrologists, and perhaps other scientific specialists should be involved in obtaining and evaluating that information.

When that information shows that there is an adverse impact that is unavoidable, it should be offset. Usually, this should be done by reopening an area to tidal action or enhancing the wetland values of an area that may not be sufficiently flushed or drained or may not contain as much diversity of habitat as biologists tell us is desirable. We have also found that it is crucial to consult with scientists when reviewing plans to change an area, particularly if areas are to be reopened to tidal action, new wetland vegetation is to be established, or other enhancement actions are to be taken.

Diked historic baylands is another recent study that involved scientific research and opinion. Prior to the Commission's creation, substantial areas of the bay were diked off. Many of these areas were converted to saltponds but many others were used for hay growing, grazing, and similar agricultural purposes. These areas retain some wetland values and are often quite important for waterfowl and other animals that use both the Bay and uplands. Diked baylands are under pressure for urbanization. On the other hand, they present the last opportunity to significantly improve the habitat values of the Bay.

In undertaking the diked historic baylands study, the Commission again turned to the scientific community to discover how these areas functioned and what beneficial changes could occur. We discovered a great deal about the species that now use the areas, about the compatibility of agricultural and wildlife use of many of the areas, about the difficulties of modifying such areas, and about the flood plain and soil values of these areas. Based on the valuable scientific information and opinion, the Commission found that diked historic baylands had great importance as part of the Bay system and adopted findings and policies to use when projects were presented to the Corps.

Both the mitigation and diked historic bayland examples show that governmental regulatory agencies respond well to clear, understandable, and applicable scientific information. When the information is in a form that the average reader can appreciate, there is considerable public and media interest in the Bay Area. There is an increased willingness to take the opportunity to improve the San Francisco Bay, both through mitigation and through increased attention to the diked historic baylands.

REFERENCES

Cloern, J.E., and Nichols, F.H., 1985a: Time Scales and mechanisms of estuarine variability; synthesis from studies of San Francisco Bay. In J.E. Cloern and F.H. Nichols (Eds.) Temporal Dynamics of an Estuary-San Francisco Bay. Dordrecht, Netherlands. Dr. W. Junk Publishers, 229-237.

Cloern, J.E., and Nichols, F.H., 1985b: Temporal Dynamics of an Estuary-San Francisco Bay. Dordrecht, Netherlands. Dr. W. Junk Publishers.

Cronin, L.E. 1967: The role of man in estuarine processes. In: G.H. Lauff. (ed.), Estuaries. Washington, D.C., American Association for the Advancement of Science, Publication No. 83, 667-689.

Cross, R.D., and D.L. Williams, (eds.) 1981: Proceedings of the National Symposium on Freshwater Inflow to Estuarine, Vols. I and II, Fish and Wildlife Service, FWS/OBS-81?04, Washington, D.C., U.S. Dept. of the Interior.

GOIN, 1972: Present and projected water and salt balance of the southern seas of the U.A.S.R. Moscow, U.S.S.R. Transactions of the Government Oceanographic Institute. (GOIN), No.108 (In Russian).

Goldman, E.J., and V.N. Maysky, 197?: Status of Winter Run Chinook Salmon, Onchorhynchus tshawtscha, in the Sacramento River. AFB Office Report. Sacramento, California Department of Fish and Game, Anadromous Fisheries Branch.

Hedgpeth, J.W., 1970. Statement in The Nation's Estuaries: San Francisco Bay and Delta. Subcommittee on Government Operations, House of Representatives , 91st Congress, 2nd Session, 361-386.

Herrgesell, P.L., R.G. Schaffter, and C.J. Larsen, 1983: Effects of Freshwater Outflow on San Francisco Bay Biological Resources, Sacramento, CA, Department of Fish and Game, State of California Technical Report #7.

Kelley, D.W. and W.E. Tippets, 1977: Delta outflow and San Francisco Bay. A report prepared for the Delta Environmental Advisory Committee of the California DWR, 32pp.

Kjelson, M.A., Raquel, P.F., and Fisher, F.W., 1982: Life history of fall-run juvenile Chinook salmon, Ohcorhynchus tshawytscha in the Sacramento-San Joaquin estuary, California. In V.S. Kennedy, (ed.) Estuarine Comparisons, New York, Academic Press, 393-411.

Kockelman, W.T., T.J. Conomos, and A.E. Leviton (eds.) 1982: San Francisco Bay: Use and Protection. San Francisco. Pacific Division of the AAAs.

Krone, R.B., 1979: Sedimentation in the San Francisco Bay system. In T.J. Conomos, (ed.) San Francisco Bay: The Urbanized Estuary. San Francisco. Pacific Division of the AAAs. 85-97.

Lauff, G.H. (Ed.) 1967: Estuaries. Washington, D.C., American Association for the Advancement of Science, Publication No. 83.

L'Vovich, M.I., 1974: World Water Resources and Their Future. Translation, 1979. American Geophysical Union.

Makarov, E.H., V.P. Zakutskij, V.V. Guskov, 1982: The assessment of the stock of the Azov Sea-Blac Sea Medusae and recommendations for their utilization in the national economy. In Biological Productivity in the Azov and Caspian Seas, Ministry of Fisheries of the U.S.S.R., Moscow, VNIRO, 107-113 (In Russian).

Mann, K.H., 1982: Ecology of Coastal Waters, A Systems Approach. Berkeley, CA, University of California Press.

Mancy, K.H., 1979: The Aswan High Dam and Its Environmental Implications. Nairobi, Kenya. Socita Internationalis Limnologiae Workshop on Limnology of African Lakes. December, 1979.

Marti, U.U., and Musatov, A.D., 1973: Management of water regimes is responsible for the success of fisheries. In: The Problems of Regulation and Use of Water Resources. Moscow, Nauka (Science) 179-192.

Meleshkin, M.T., 1981: Ecological Problems of the World Oceans. Moscow, Economics, 279pp.

Meleshkin, M.T., Rozengurt, M.A. and Tolmazin, D.M., 1973: The problems and methods of improving efficiency of use of water resources of the Sea of Azov basin: economic and hydrological aspects. ODESSA Journ. The Problems of the Economy of Sea and the World Ocean, Ac. of Sci., UKSSR V. 2. 3-15.

Meyer Resources, 1985: The Economics Value of Striped Bass, Morone saxatilis, Chinook salmon, Oncorhyncus tshawytscha, and Steelhead Trout, Salmo gairdneri, of the Sacramento and San Joaquin River Systems. Sacramento, CA. Dept. of Fish and Game, Anadromous Fisheries Branch, Administrative Report No. 85-3.

Kockelman, W.T., T.J. Conomos, and A.E. Leviton (eds.) 1982: San Francisco Bay: Use and Protection. San Francisco. Pacific Division of the AAAs.

Krone, R.B., 1979: Sedimentation in the San Francisco Bay system. In T.J. Conomos, (ed.) San Francisco Bay: The Urbanized Estuary. San Francisco. Pacific Division of the AAAs. 85-97.

Lauff, G.H. (Ed.) 1967: Estuaries. Washington, D.C., American Association for the Advancement of Science, Publication No. 83.

L'Vovich, M.I., 1974: World Water Resources and Their Future. Translation, 1979. American Geophysical Union.

Makarov, E.H., V.P. Zakutskij, V.V. Guskov, 1982: The assessment of the stock of the Azov Sea-Black Sea Medusae and recommendations for their utilization in the national economy. In Biological Productivity in the Azov and Caspian Seas, Ministry of Fisheries of the U.S.S.R., Moscow, VNIRO, 107-113 (In Russian).

Mann, K.H., 1982: Ecology of Coastal Waters, A Systems Approach. Berkeley, CA, University of California Press.

Mancy, K.H., 1979: The Aswan High Dam and Its Environmental Implications. Nairobi, Kenya. Socita Internationalis Limnologiae Workshop on Limnology of African Lakes. December, 1979.

Marti, U.U., and Musatov, A.D., 1973: Management of water regimes is responsible for the success of fisheries. In: The Problems of Regulation and Use of Water Resources. Moscow, Nauka (Science) 179-192.

Meleshkin, M.T., 1981: Ecological Problems of the World Oceans. Moscow, Economics, 279pp.

Meleshkin, M.T., Rozengurt, M.A. and Tolmazin, D.M., 1973: The problems and methods of improving efficiency of use of water resources of the Sea of Azov basin: economic and hydrological aspects. ODESSA Journ. The Problems of the Economy of Sea and the World Ocean, Ac. of Sci., UKSSR V. 2. 3-15.

Meyer Resources, 1985: The Economics Value of Striped Bass, Morone saxatilis, Chinook salmon, Oncorhyncus tshawytscha, and Steelhead Trout, Salmo gairdneri, of the Sacramento and San Joaquin River Systems. Sacramento, CA. Dept. of Fish and Game, Anadromous Fisheries Branch, Administrative Report No. 85-3.

Moyle, P.B., 1976: Inland Fishes of California. Berkeley, University of California Press.

Nichols, F.H., J.E. Cloern, S.N. Luoma, and D.H. Peterson, 1986: The modification of an estuary. Science, 231:567-573.

Officer, C.B., 1976: Physical Oceanography of Estuaries (and Associated Coastal Waters). New York, J. Wiley & Sons.

Orlob, G.T., 1977: Impact of upstream storage and diversions on salinity balance in estuaries. Estuarine Processes, V. 2. Ac. Press, 3-17.

Remisova, S.S., 1984a: Water balance of the Sea of Azov. Journal of Water Resources, 1:109-121.

Remisova, S.S., 1984b: Salt balance of the Sea of Azov. Journal of Water Resources, 3:9-14.

Rozengurt, M.A., 1971: Analysis of the impact of the Dniester River regulated runoff on the salt regime of the Dniester Estuary. Kiev, Scientific Thought, Ac. of Sci., U.S.S.R., 132pp. Library of Congress GB2308.B55R69.

Rozengurt, M.A., 1974: Hydrology and prospects of reconstruction of natural resources of the north-western part of the Black Sea estuaries. Kiev. Scientific Thought, Ac. of Sci., U.S.S.R., 224pp. Library of Congress GB2308.B55R69.

Rozengurt, M.A., 1983a: On environmental approach to protecting estuaries from salt intrusion. In O.T. Magoon and H. Converse (eds.) Coastal Zone ,83: Proceedings of the Third Symposium on Coastal and Ocean Management, Vol. III., New York. American Society of Civil Engineers, pp. 2279-2293.

Rozengurt, M.A., 1983b: The Environmental Effect of Extensive Water Withdrawals on the River-Estuary-Sea Ecosystem, Part II. Sacramento, CA, State of California Resource Agency, Department of Water Resources, 157pp.

Rozengurt, M.A. and I. Haydock, 1981: Methods of computation and ecological regulation of the salinity regime in estuaries and shallow seas in connection with water regulation for human requirements. In R.D. Cross and D.L. Williams (Eds.). Proceedings of the National Symposium on Freshwater Inflow to Estuaries, Vol. II. Washington, D.C. U.S. Dept. of Interior, 474-506.

Rozengurt, M.A. and M.J. Herz, 1981: Water, water everywhere, but just so much to drink. Oceans, 14:65-67.

Rozengurt, M.A. and Tolmazin, D.M., 1974: The conflict between energetics and nature. Kiev, Science and Society, No. 10, 6-9.

Skinner, J.E., 1962: An Historical Review of the Fish and Wildlife Resources of the San Francisco Bay Area. Sacramento, CA. Department of Fish and Game, Water Projects Branch, Report #1.

Smith, S.E., and S. Kato, 1979: The fisheries of San Francisco Bay: Past, present, and future. In Conomos, T. (ed.) San Francisco Bay: The Urbanized Estuary, San Francisco. Pacific Division of the AAAs.

Sokolov, A.A. and T.C. Chapman (eds.) 1974: Methods for Water Balance Computations. Paris. UNESCO Press.

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

Striped Bass Working Group, 1982: The Striped Bass Decline in the San Francisco Bay-Delta Estuary. Sacramento, CA. California State Water Resources Control Board.

Sutcliffe, W.H., Drinkwater, K., and Muir, B.S. 1977: Correlations of fish catch and environmental factors in the Gulf of Main J. Fish Res. Bd. Can. 34:19-30.

Therriault, J.C. and Levasseur, M. 1986: Freshwater runoff control of the spatio-temporal distribution of phytoplankton in the lower St. Lawrence Estuary (Canada). 251-260pp.

Skreslet, S. (ed.) The role of freshwater outflow in coastal marine ecosystems. NATO Series G: Ecological Sciencies, Vol. 7. Springer-Verlag, Berlin.

Tolmazin, D.M., 1985: Changing coastal oceanography of the Black Sea. In M.V. Angel and R. Smith (Eds.) Progress in Oceanography, Vol 15. New York, Pergamon Press, 217-276.

THE FEDERAL ROLE IN THE MANAGEMENT OF SAN FRANCISCO BAY

Betsy Coombs
Environmental Protection Agency Region 9

I recently had the opportunity to brief the EPA's new Assistant Administrator for Water on San Francisco Bay. I showed him slides of the Bay, talked about declining fish populations, reviewed the history of fisheries decline, and talked about siltation and long-term degradation of the Bay. During a helicopter tour of the Bay, he turned and said, "The Bay looks so healthy!"

His reaction is not uncommon. Many of us who grew up on the Bay are used to the idea that there are no booming fisheries on the Bay. At one point, San Francisco Bay was the most important fishery on the West Coast.

Despite the lack of visible causes, there are very real problems contributing to the decline on the Bay, many of which have been touched on today. For the first time, there is the real possibility the EPA may receive management funds for what we in the region recognize is a resource of national significance, one that deserves our attention. The budget for such an undertaking may be $12 million, as some members of Congress have sought,...or it may be zero, or somewhere in between. We do not know if our equipment will be a handful of pencils or a Prime computer.

We are at the mercy of The Office of Management and Budget and other people's priorities: the Congress, the State Water Resources Control Board, the Office of Management and Budget and the Reagan Administration. Within the next four to six months, our sense of what the San Francisco Bay Project might be could change by orders of magnitude and in more than one direction, and maybe more than once or twice. But one fact is clear: EPA Region 9 has a commitment to address the problems of San Francisco Bay.

With that introduction, I would like to talk about EPA's statutory role on the Bay, the Agency's relationship with other agencies, and the establishment of EPA's National Estuaries Program through the creation of the Office of Marine and Estuarine Protection.

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Much of EPA's mandated role affecting the Bay is given under the authority of the Clean Water Act of 1972. The Agency is required to respond, case-by-case, to programs outlined in the Act. The following five programs represent the majority of EPA's activity on the Bay:

1) Under specific sections of the Clean Water Act, the EPA is centrally involved in water quality management planning. These activities are at the core of the basic intent of the Act, which is to enhance water quality and protect the public health and welfare. Section 106 allocates funds to the state for water pollution control programs. Section 208 provided areawide water quality management planning, and now Section 205(j) allocates funds for specific studies and specific problems for state water quality planning. These programs provide important information used in setting water quality standards, suggesting needed legislation, and developing basin plans.

2) Under Section 303, EPA requires that the state, through the State Water Resources Control Board, develop water quality standards to protect the beneficial uses of Bay waters. The state and regional boards, with public participation, determine those designated beneficial uses to be attained and maintained. Those uses relevant to the Bay are: municipal and industrial water supplies, habitat for aquatic life, agriculture, and waterways for shipping and recreation. The state has set salinity standards for the delta and delegated the setting of all other standards to the Regional Board. Given that toxic pollution appears to contribute to the declining health of the Bay, new numeric criteria need to be established to augment the existing narrative standards.

   Under Section 301, effluent guidelines are established for all industrial and municipal dischargers based on Best Practicable Technology and are subject to the standards just described.

3) Under Section 402, and subject to EPA approval, the state issues National Pollution Discharge Elimination System (NPDES) permits to all dischargers through the Regional Water Quality Control Board. These permits are the legal basis for requiring dischargers to control the pollutant levels in their effluent. They specify allowable levels and quality of the waste discharge through setting specific effluent guidelines and receiving water standards. Dischargers are monitored to determine whether they are meeting their permit conditions and to ensure that expected water quality improvements are achieved. EPA's role here has

been both carrot and stick; over the past 14 years, the EPA has provided nearly $1.3 billion to San Francisco Bay for construction grants for sewage facilities in the Bay area, granted under Section 201. State and local agencies have provided the 25 percent match.

4) Under Section 404 of the Act, the Army Corps of Engineers, subject to EPA's review, issues dredge and fill permits. A permit must be denied if the request does not meet the series of tests set forth in Section 404.

In regard to San Francisco Bay, 404 activity relates to the protection of seasonal wetlands, most of which are diked. As Michael Josselyn stated earlier, 95 percent of the Bay and Delta wetlands have already been filled or diked. EPA requires that all efforts be made to avoid filling any more wetlands. At the very least, there must be no net loss, meaning that other land may be restored to wetland. A major problem on the Bay, however, is that there is no mitigation land available. The so-called "available land" may be held for $300,000 to $400,000 per acre, clearly an unrealistic option.

5) EPA, under the National Environmental Policy Act (NEPA), must review and comment on all Environmental Impact Statements (EISs) which are required for any agency constructing a Federal project. In contrast to Clean Water Act mandates described above, which are media-specific, NEPA provisions are project-specific where water issues are just one aspect under consideration. On the Bay, EPA's role includes reviewing EISs for construction of municipal sewer facilities, Army Corps of Engineers proposals for navigation improvements, and Bureau of Reclamation projects to develop water supplies.

These five areas, under the Clean Water Act and NEPA, represents EPA's primary responsibility on the Bay. As you have noticed, each of these programs is a site-specific, project-specific response to an action. What is missing is an understanding of the whole -- how all of these pieces fit into a larger context.

Mike Josselyn asked me to speak specifically to the relationship between EPA and other Federal agencies actively involved in the management of the Bay. EPA interacts in a formal capacity with two Federal agencies: the Army Corps of Engineers in the 404 dredge and fill permits process described previously and the U.S Coast Guard on oil and hazardous waste spills through EPA's Emergency Response Team. EPA also reviews EISs submitted by any agency.

In addition, EPA currently works in a joint research venture with the U.S. Fish and Wildlife Service to map the Bay's wetlands. Results from this project will help us to monitor changes in Bay wetlands over time, providing better control and protection over that fragile 5 percent of the Bay's marshes and seasonal wetlands that still remain.

Other agencies have carried out research on the hydrology, chemistry, and biology of the Bay. Dominant among these, the U.S. Geologic Survey has played a most significant role in fleshing out our understanding of the Bay.

In summary, however, the primary responsibility for the management of the Bay has been delegated to the State of California, subject to EPA review under the four Clean Water Act programs just described. Water quality standards, compliance and monitoring, and construction grants are the primary lines of defense for maintaining beneficial uses. As with the EPA, so too must the state respond case-by-case, project-by-project. As the EPA considers a management program for the Bay, it is clear that success will depend on good coordination with state agencies.

At the national level, the Environmental Protection Agency has made a formal commitment to the protection of estuaries and bays through the establishment of the Office of Marine and Estuarine Protection, or OMEP, headed by Tudor Davies. Unlike many other natural features which readily fit together under a single national program, estuaries require a more holistic approach involving the expertise, resources, and commitment of many agencies.

We have all learned a lot today about particular characteristics of the Bay. Any program claiming to address the health problems of this Bay must be carefully designed to meet its unique mix of problems. By creating OMEP, EPA has recognized the multi-disciplinary nature of estuaries, and developed a flexible organizational structure which can be altered to meet the unique needs of each estuary.

Using the Chesapeake Bay Program as a model, OMEP has designed an overall strategy for the implementation of estuarine management programs which may be used for all significant bays. There are five steps in their strategy:

(1) Set up a committee structure to bring in all of the vested interested in the Bay;

(2) Identify and reach consensus on the problems and goals of the program;

(3) Implement a data management program to collect all available data bases in one system and make the results available to all Bay researchers;

(4) Identify data gaps and conduct needed research to develop a comprehensive understanding of the estuary; and

(5) Adopt a management plan for the restoration of the estuary.

It is useful here to note that EPA can undertake this management role successfully with no new legislation; our current authority is sufficient.

Under the leadership and guidance of OMEP, three programs have been started in the east -- Long Island Sound, Narragansett Bay, and Buzzards Bay, as many of you are aware. The program has moved westward in introducing a program on Puget Sound. If given the opportunity, EPA Region 9 stands ready to implement such a program for the San Francisco Bay and Delta Bay, and we would look to OMEP for guidance through their established track record on the five other estuaries.

You have heard a good deal today on the research that has been done to understand specific aspects of the Bay system. Research has revealed problems in the Bay, symptoms that reflect complex interrelationships that have not been well defined. Nowhere is there an overview of the Bay system as a whole. The Bay needs a team effort and the commitment of agencies to work together in understanding their estuarine ecosystem and implementing a management plan to protect it. We at EPA are excited about being a central part of this effort, and we look forward to working with the many agencies and organizations that have played a critical role on the Bay and that have a stake in its future.

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
SAN FRANCISCO BAY REGION

ROGER B. JAMES, EXECUTIVE OFFICER

The State of California's water quality management system is unique, has a relatively long history and frequently amazes those that visit us from other states and countries. The system for managing wastes in the San Francisco Bay Area includes over 100 counties, cities, and special districts responsible for sewerage service with the State providing the regulatory framework for protection of surface and ground waters.

During the mid-1960s, the State undertook a comprehensive study of San Francisco Bay and the Delta systems to develop a long-range plan for management of the Bay Area's municipal and industrial wastes and agricultural drainage from the Central Valley. This study recommended ocean disposal of the Bay Area's wastes after primary treatment at a facility in San Mateo County, numerous studies to assess the biostimulatory and toxic impacts of waste discharges, and a regional agency to implement the long-range plan. Opposition to the plan and concern about the loss of local authority led to 13 subregional planning studies controlled by the agencies responsible for sewerage service. A number of joint power authorities were formed to conduct the studies and construct over $2 billion in treatment facilities and deepwater outfalls into the Bay system.

The California Regional Water Quality Board-San Francisco Bay Region (RWQCB) is the State Agency with the responsibility for the protection of surface and ground water quality in the nine Bay Area counties. The RWQCB has been in operation since 1950 and is one of nine such agencies in the State of California with the authority and responsibility to implement the State Porter-Cologne Water Quality Control Act and the Federal Clean Water Act (FWCA).

The RWQCB operates under statewide policies of the State Water Resources Control Board (SWQCB) which provides budget control, considers appeals of RWQCB actions, adjudicates the State's water rights programs, and administers the Federal construction grant program. The RWQCB implements its responsibliities through four fundamental programs: basin planning, waste discharge requirements including the Federal NPDES permits surveillance and monitoring and enforcement.

The nine members of the RWQCB are appointed by the Governor for staggered four year terms which provides for relative independence and continuity of actions. The RWQCB is supported by a full-time technical staff responsible for implementation of its policies and regulations. The RWQCB's independence combined with a requirement that all planning and regulatory decisions be made in public following quasi-judicial hearings to assure a degree of consistency and predictability and has resulted in a high degree of public acceptance of its decisions.

People living in the San Francisco Bay have a very strong environmental awareness and concern about the pollution of ground water and San Francisco Bay. In spite of earlier testimony at this seminar, the greatest public concern is with ground water contamination problems in the Silicon Valley from leaking underground tanks. In this area, there are 120 sites where solvents have contaminated ground water and over 300 motor fuel tanks with leaking gasoline tanks. The RWQCB regulates over 450 discharges including 43 major municipalities, 19 major industries, and 16 onsite and offsite discharges are non-hazardous waste landfills, smaller municipalities and industries and agricultural operations. In addition to these discharges, there are 115 dairies and 15 wineries regulated through an exempting process.

POLICY AND MANAGEMENT DECISIONS

A number of major policy and management decisions have influenced water quality control and beneficial uses in the Bay area and perhaps the most significant was the political decision in the late 1960s to not form a regional agency with the authority to implement Bay-Delta Plan. The next critical decision influencing the Bay was the 1972 amendments to the FWCA that mandated best available technology for treatment of municipal and industrial wastes. These requirements combined with the availability of State and Federal construction grants up to 87 1/2 percent for local agencies resulted in the consolidation of 82 municipal treatment plants into 49 large systems with upgraded treatment. Over one-third of the total municipal flow now receives tertiary treatment achieving a 70 percent reduction since 1960 in the wasteloading of conventional pollutants such as BOD, SS, and oil and grease in spite of a 100 percent increase in flow. The extreme South Bay has experienced the most dramatic reduction of over 90 percent of these pollutants. The record for major industries is even more impressive with volumes of flow reduced by three-fourths and conventional pollutants reduced by over 95 percent since 1960. Although comparative data is limited, there is evidence that the discharge of toxic pollutants, such as heavy metals and organic chemicals, have been significantly reduced from both industries and municipalities. Heavy metal loadings estimated at 8 million pounds a year in the 1960s have reduced by over 90 percent.

Other major decisions that have affected the protection of San Francisco Bay and the adjacent wetlands have been the formation of the Bay Conservation and Development Commission that limited further filling of the Bay; the RWQCB's support of State and Federal fisheries agencies policies regarding "no net loss of wetlands in the regulation of landfills;" the Citizens for a Better Environment pressure to implement the Federal pretreatment programs to reduce toxic materials discharged to municipal sewerage systems; and the RWQCB's pursuit of best management practices to prevent the spill of petroleum products during vessel transfer operations.

These decisons have resulted in the re-establishment of beneficial uses such as the opening of 1 mile of shoreline in San Mateo County for the public harvesting of shellfish in 1982, 1983, and 1985 for the first time since the 1930s; the consideration of commercial oyster and clam farming along the East Bay shoreline; and, the extreme South Bay, once grossly polluted, now supports a commercial bait shrimp fishery and there are reports of sturgeon and striped bass being caught. Less subtle improvements have been the increased water clarity and reduced bacterial levels along the San Francisco shoreline as a result of the reduction of wet weather raw sewage combined sewer overflows from 80-100 to several each year.

Many of these management decisions were mandated by the FWPCA, were made possible as a result of the availability of sewage construction grants and resulted from the public's concern about gross pollution caused by such incidents as oil spills. Although there have been success stories as a result of these management decisions, there is growing concern about toxic discharges to the Bay; impacts on non-point sources such as urban runoff, dredging, and spoil disposal; agricultural drainage containing selinium and pesticides; and impacts of further diversions of freshwater which is considered to be necessary for the maintenance of a balanced estuarine system.

WATER QUALITY MANAGEMENT NEEDS

The water quality management needs of San Francisco Bay are numerous and varied ranging from completion of the already planned improvements to waste water facilities to basic research on those factors affecting Bay water quality. The City and County of San Francisco need to construct approximately $400 million in sewer system improvements to complete essential elements of its Master Plan and the East Bay Cities are faced with expenditures up to $750 million to upgrade the sewer systems to reduce raw sewage overflows.

The greatest need is to significantly expand and better coordinate the data collection, analysis, long-term monitoring and research conducted on the Bay. An adequate and consistent funding source has been the major problem in meeting this need and the Bay Area citizens must provide this funding source independent of State and Federal funding which are too variable and subject to budget constraints.

The second most important need is to establish an institution with a core of experts doing basic and long-term research on the Bay. It is essential that the institution have the ability to coordinate all research efforts in the Bay as well as maintain a knowledge of current research underway in similar estuaries throughout the world. This institute should be funded and be capable of responding to and investigating the causes of incidents such as the Mesodinium Rubrum blooms that occurred during the late 1960s and the San Pablo Bay Cladophora bloom in 1979. The institute should also provide expert testimony to the SWRCB and RWQCB to assist in their regulatory decisions. The Aquatic Habitat Institute established by the SWRCB is the most viable organization to satisfy this need.

The third major need is to establish a system or mechanism to span the information gap between the research/data collection efforts and the public's knowledge on the condition of the Bay. The Bay Area problems listed water pollution as second only behind transportation. One of the most difficult questions faced by the RWQCB staff is the condition of the Bay and what actions are needed to protect the Bay.

The list of resource management needs are virtually endless and the potential for public harvest of shellfish is just one example of a beneficial use that can be expanded.

The greatest regulatory management need is the development of water quality based standards for species indigenous to the Bay, including the most sensitive. The technology based standards mandated by the FWPCA have been implemented in the Bay Area, yet there is growing evidence that these standards are inadequate to protect beneficial water uses identified by the RWQCB. We must rapidly move forward to develop these standards based on the best available information.

In summary, considerable progress has been made during the past 25 years to reduce pollutants discharged into San Francisco Bay in response to the California Water Code and FCWA; however, there is evidence that the San Francisco Bay system and beneficial uses are stressed and adversely impacted. Toxics in municipals and industrial discharges, non-point source discharges, water diversions, pollutant input from the Delta, dredging, and toxic spills are factors that affect San Francisco Bay.

One major problem in assessing the relative importance of these factors is a fundamental lack of understanding of the complex relationships between pollutant discharges, Delta outflow, and the health of the biological community of San Francisco Bay. This lack of understanding, rather than shortcomings in the law or its implementation, is now the major impediment to the RWQCB in carrying out its mandate to protect the quality of the waters of San Francisco Bay.

The solution to this problem is a sustained program of research on the physical, chemical, and biological processes that affect the Bay.

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