title	SAN FRANCISCO BAY: THE URBANIZED ESTUARY,A SUMMARY
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Subject	ecosystem, ecology, urbanization
Description	PROCESSES AND RELATIONSHIPS, RESEARCH NEEDS, THE FUTURE OF SAN FRANCISCO BAY
Coverage	San Francisco Bay
Temporal	1850-1970
Source	Fifty-eighth Annual Meting of the Pacific Division of the American Association for the Advancement of Science, San Francisco State University, San Francisco, California, June 12-16, 1977
Date	1977-06-12
IsPartOf	SAN FRANCISCO BAY: THE URBANIZED ESTUARY Investigations into the Natural History of San Francisco Bay and Delta With Reference to the Influence of Man (491-499)
Publisher	Pacific Division of the American Association for the Advancement of Science c/o California Academy of Sciences Golden Gate Park San Francisco, California 94118
Issued	1979
Type	text
Format	8-1/2" x 11" bound document
Identifier	ISBN 0-934394-01-6
Language	English
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Abstract

Aboriginal Californians left little evidence of their several thousand years of habitation along San Francisco Bay's shoreline except for piles of shells (middens) located adjacent to their former villages. Modem man, however, began to effect major change to the Bay within 75 years of his first arrival. This change has been unremitting ever since. With the discovery of gold in the mid-19th century, vast quantities of debris from large-scale hydraulic mining destroyed stream courses and agricultural land and silted the upper reaches of the Bay. Transfer of the tidelands to private ownership promoted land speculation and subsequent large-scale reclamation, diking and fdling of the margins. These activities and the addition of large volumes of poorly treated waste waters contributed to the decline, in the late 19th century, of the quality of the Bay environment in general and probably to the decline of large commercial oyster and salmon fisheries in particular. Further increases in agricultural and urban development, during the early 20th century, led to increasing demands for water, and large-scale rivier diversions were begun. These diversions, together with increased waste-water inflows have led to worsening water quality and to the enactment of waterquality control measures.

Today, San Francisco Bay is the focus of continuing studies of the extent to which man can alter an estuarine system without destroying the physical, chemical and biological balances necessary for the survival of that system.

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SAN FRANCISCO BAY: THE URBANIZED ESTUARY
A SUMMARY

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Aboriginal Californians left little evidence of their several thousand years of habitation along San Francisco Bay's shoreline except for piles of shells (middens) located adjacent to their former villages. Modern man, however, began to effect major change to the Bay within 75 years of his first arrival. This change has been unremitting ever since. With the discovery of gold in the mid-19th century, vast quantities of debris from large-scale hydraulic mining destroyed stream courses and agricultural land and silted the upper reaches of the Bay. Transfer of the tidelands to private ownership promoted land speculation and subsequent large-scale reclamation, diking and filling of the margins. These activities and the addition of large volumes of poorly treated waste waters contributed to the decline, in the late 19th century, of the quality of the Bay environment in general and probably to the decline of large commercial oyster and salmon fisheries in particular. Further increases in agricultural and urban development, during the early 20th century, led to increasing demands for water, and large-scale rivier diversions were begun. These diversions, together with increased waste-water inflows have led to worsening water quality and to the enactment of water-quality control measures.

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PROCESSES AND RELATIONSHIPS

Although our knowledge of the natural science of the Bay and Delta has its origins in work done in the early 20th century, it was not until the last few decades that real progress has been made in our understanding of the processes and rates by which water, solutes, sediments and organisms interact. We have learned qualitatively that the water in the system is primarily and continually controlled, in movement and composition, by the shape of the embayments and the interrelated effects of wind, river and waste-water inflows, salt and heat input, and tides. The physical and chemical features of Delta and northern reach waters are dominated by the seasonally varying Delta outflow and to a lesser extent by exchange with the ocean. The waters of the southern reach are affected perennially by exchanges with the ocean and waste-water inflows, and seasonally by intrusions of Delta-derived water and direct inflows from small local streams. Tidal-current circulation is modified significantly in the northern reach by Delta outflow and in the southern reach by wind.

The distribution of biologically reactive water properties such as plant nutrients, carbon, and dissolved oxygen are primarily related to seasonal variations in the supply of these components, to the intensity of water movement and mixing, and to a lesser extent to the amount of available light, which promotes biological activity. In the Delta and northern reach, Delta outflow contributes suspended particles, carbon, dissolved oxygen and plant nutrients. It also generates an estuarine circulation cell and an associated turbidity maximum that are critically important to such biological processes as seasonal migrations of fish and crabs and photosynthesis of water-borne plants. Water properties in the southern reach are most directly affected by the perennial inflow of detritus and nutrient-rich waste water from the southern boundary and by exchange with the

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bottom sediments.

The distributions and abundance of estuarine organisms, many of which are exotic species introduced accidentally or intentionally during the past century from other estuaries, are governed by a unique combination of environmental factors. These factors include residence time, mixing rates, and temperature, salinity and transparency of the waters, the amount and type of nutrients or food available, and the stability of the bottom sediments. All of these factors, in turn, are influenced by the geographic location relative to the Delta and ocean, and the seasonal cycles in weather and Delta outflow. The distributions of benthic plants and animals, for instance, are strongly determined by the physical and chemical interplay between river and ocean waters and by the intermittent disturbance caused by wind waves and tidal currents.

These same factors bear on the distribution of species in the surrounding marshes. Delta marshes, which contain tules, bulrushes and reeds, grade seaward to a salt-marsh assemblage of pickleweed and cordgrass. These marshes, which are quite productive and an important segment of the Bay-Delta ecosystem, exchange an unknown quantity of detritus and nutrients with the open water.

The animals that inhabit Bay waters are the same as or are similar to species that inhabit most temperate latitude estuaries around the world. Because of the relatively high level of productivity in the estuary, large quantities of the common species are found. Some of these species, anadromous (striped bass, king salmon, sturgeon and shad), pelagic (anchovies and herring), bottom (starry flounder and English sole) and coastal marine (perch) fish, shell fish (clams and oysters), shrimp and crabs, at the highest trophic level, are sought by man. But, because of pollution-related concerns and overfishing, this once important group has become primarily a modest sportfishery.

RESEARCH NEEDS

Despite the great progress that has been made in the last two decades in describing and understanding the Bay and Delta, there is still much to learn before we can accurately describe the mechanisms that contribute to the maintenance of the estuary as we know it now, or before we can adequately predict what lies in the future.

For example, our knowledge and understanding of circulation and mixing of estuarine waters is essential for solving problems dealing with water quality and ecology as well as sediment transport and distribution. From these data practical conceptual and numerical models of hydrodynamic processes can be devised and used for predictive purposes.

Closely coupled to the study of the hydrodynamics is a need to quantify the sources and sinks of biologically reactive water properties. As a basis for these activities, our knowledge of the temporal distributions of these properties must be extended into three dimensions of mapping the vast shallow areas of the Bay. The major input of both natural and anthropogenic substances from sewage outfalls, rivers and "nonpoint sources" should be monitored through annual cycles. Further, exchanges across the sediment-water and air-water interfaces should be measured. These factors all bear on the quality and productivity of Bay waters.

Of special interest are continuing studies of the relationship between algal productivity and the success of important fisheries such as striped bass and Dungeness crab. These studies, of necessity, include the intermediate links in the estuarine food web, such as the zooplankton and the benthos. These organisms consume the algae and associated detritus and bacteria and, in turn, are consumed by the fish and crabs. Only by gaining a full understanding of the transfer of organic matter from the producers to the ultimate consumers in the estuary can we begin to appreciate how our own actions will influence these natural processes.

THE FUTURE OF SAN FRANCISCO BAY

Our basic knowledge of the most important processes and rates in the present Bay and Delta is not complete. Yet, human activity continues to result in changes to the physical and ecological framework that we have been attempting to characterize and understand. Recently enacted legislation has stopped the filling and diking of margins, but inputs of municipal, industrial and agricultural waste waters, channel deepening and river diversions will continue into the future.

Diversions of Bay-bound river water continue and will probably increase markedly with population growth and expanded agricultural development throughout California: planned diversions will ultimately lower the average annual Delta outflow to 20% of its natural rates. Although this reduction will undoubtedly change the present ecological balance in the estuary, the potential extent of these changes is unknown. The expected decrease in suspended sediment loads may increase the water transparency, and the supply of biologically reactive substances will diminish. These factors, together with the increase of water residence time and the landward shift of the ocean-river mixing zone may greatly alter the ecosystem, even to the extent of altering or eliminating some exploitable fish and shellfish stocks.

The burgeoning population of the Bay area has resulted in increased industrial and domestic waste-water inflows. Despite large expenditures on larger and improved waste-water treatment plants, the total volume of pollutants is rising and the trend is expected to continue into the 21st century when it will have increased 2- to 3-fold. To this will be added agricultural wastes if a large agricultural drain, planned to carry shallow-lying brackish ground water from the fields in the Great Vally to the northern reach, is built. These waste-water inputs, together with the diminished Delta outflow-modulated flushing, may lead to poorer water quality and increased stress on our present ecological balance.

Routine dredging is a continuing need for the maintenance of shipping channels. But new projects, such as the Stockton Ship Channel, which calls for deepening by 25%, may increase salt intrusion and may create profound changes in the hydrodynamics of the Delta and northern reach.

The pressures to get on with these massive public works are great and there may not be enough time to develop a full understanding of the Bay before these plans are completed. However, in all of these proposals we must be cautious because, while solutions to specific engineering problems are being sought, the synergistic effects of these combined projects are unknown. These combined effects could be profoundly important.

It is apparent that there is a great need for basic research at every level to identify significant estuarine processes and to quantify relationships. Although this knowledge, along with data from economic and social studies, forms the basis upon which important political decisions are made, funding levels for this research are traditionally inadequate. These studies have been undertaken, historically, by governmental agencies at public expense because public interest in the Bay and Delta has been so great and diverse. L. Eugene Cronin, in his eloquent treatise,[1] has suggested, as an alternative, that where the estuary is used for financial profit, some or all of the cost of research on the effect of use be placed where the profit will be realized.

Intelligent management and public education, based on a better scientific understanding of the complex ecosystem, can minimize man's abuses, and perhaps can be used positively and profitably to manipulate the natural system. Such understanding, however, comes only with cooperative, sustained, comprehensive and interdisciplinary study. We feel that we have made a good start.

1 Cronin, L. E. 1967. The role of man in estuarine processes. Pages 667-689 *in* G. H. Lauff, ed. Estuaries. Amer. Assoc. Advance. Sci. Pub. 83.