A SYMPOSIUM ON THE BIOLOGICAL SIGNIFICANCE OF ESTUARIES

ON THE BIOLOGICAL SIGNIFICANCE OF ESTUARIES

Coedited by:

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A SYMPOSIUM ON THE BIOLOGICAL SIGNIFICANCE OF ESTUARIES

Sponsored By The

SPORT FISHING INSTITUTE

in cooperation with the

Sportsmen's Clubs of Texas, Inc.,

and the

National Wildlife Federation

on

FEBRUARY 13, 1970

(First day of a coordinated two-day conference
on Uses of Estuaries)

HOUSTON, TEXAS

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March, 1971

Sport Fishing Institute
719 – 13th St., N.W. (Suite 503)
Washington, D.C. 20005

ACKNOWLEDGMENTS

The Sport Fishing Institute is sincerely grateful to the Symposium participants, who gave of their energies, talents, and time, and endured some unanticipated inconveniences during their presentations. The Institute appreciates the financial support of the Symposium by The National Science Foundation Sea Grant Program (NSF Grant No. H000070).

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FOREWORD

In mid-1969, The Sport Fishing Institute was invited to join forces with the National Wildlife Federation, and its affiliated Sportsmen's Clubs of Texas, Inc., in co-sponsoring a two-day public-oriented conference in Houston, Texas, on Uses of Estuaries. As a result of several inter-staff discussions that ensued, the Sport Fishing Institute agreed to assume full responsibility for organization, conduct, and publication of a one-day scientific Symposium on the Biological Significance of Estuaries. Its purpose was to provide the necessary background and foundation for socio-political discussions of the uses of estuaries, to be undertaken the following day by representatives and guests of the other two co-sponsoring organizations. This Symposium, therefore, occurred on February 13, 1970, in Houston, Texas. It was followed on February 14, 1970, by day-long related sessions on uses of estuaries, chaired and conducted by representatives of the Sportsmen's Clubs of Texas and the National Wildlife Federation.[1]

This publication deals exclusively with the scientific basis for rational socio-political decisions governing the choices among an array of uses to which estuaries may be put. This Symposium is unique in its concept of bringing to laymen, in terms they can understand, a comprehensive insight into why the estuaries of the United States are important, and what American citizens can do to foster the maintenance of estuaries for a multiplicity of uses, in perpetuity. The Institute was fortunate to secure the services of some of the most notable marine scientists to present their views on specific problems of a wide geographic range.

The two session leaders and six speakers, authorities in their field and region, were (in order of their appearances in the program):

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[1] Copies of proceedings during the second day's related sessions February 14, 1970 are not available from the Sport Fishing Institute.

(A) *Morning session*

DR. RICHARD A. GEYER (Session Chairman), Director, Department of Oceanography, Texas A&M University, College Station, Texas.

DR. L. EUGENE CRONIN, Director, Chesapeake Biological Laboratory, Natural Resources Institute of the University of Maryland, Solomons, Maryland.

MR. CHARLES R. CHAPMAN, Bureau of Commercial Fisheries, U.S. Department of the Interior, Washington, D.C.

MR. HAROLD K. CHADWICK, California Department of Fish and Game, Stockton, California.

(B) *Afternoon Session*

MR. JAMES E. SYKES (Session Chairman), Director, St. Petersburg Biological Laboratory, Bureau of Commercial Fisheries, U.S. Department of the Interior, St. Petersburg, Florida.

MR. DAVID H. WALLACE, Director, Division of Marine and Coastal Resources, New York Conservation Department, Ronkonkoma, New York.

DR. ERNEST O. SALO, Fisheries Research Institute, College of Fisheries, University of Washington, Seattle, Washington.

MR. WILLIAM H. MASSMANN, Bureau of Sport Fisheries and Wildlife, U.S. Department of the Interior, Washington, D.C.

The opening paper by Dr. Cronin was especially solicited to serve, in part, as the keynote theme for the Symposium. The closing paper by Mr. Massmann was especially solicited to serve, in part, as a summarization for the inherent theme of the Symposium.

Publication of this Symposium was made possible by means of NSF Grant No. H000070, under the Sea Grant Program of the National Science Foundation.

The Sport Fishing Institute is most grateful to the participants listed above, who gave so generously of their accumulated knowledge, experience, and time to help make this Symposium possible. The Institute is also grateful to the National Science Foundation for providing necessary financial support to the Symposium. The Institute was pleased to cooperate with the National Wildlife Federation and the Sportsmen's Clubs of Texas in providing a solid scientific foundation for their subsequent related sessions on the socio-political considerations in determining appropriate uses of estuaries.

Publication of this Symposium will be of great value in explaining to leadership elements in the interested general public the "whys and wherefores" of estuaries and their biological significance. It is estimated that well over half of the marine fisheries resources of the Continental Shelf adjacent to the U.S. land mass is fully dependent upon estuaries as spawning and/or nursery areas. Moreover, estuaries are critical links in upstream and downstream migration routes of anadromous and catadromous fishes.

There is urgent need to focus national attention on outstanding successes in the management of some of these areas, analyzing how they were achieved, as well as to analyze failures in other areas and reasons for such. The latter will point up the need for research and for application of available knowledge. Our speakers were selected for their exceptional background and capabilities in bringing these facts before a concerned, if poorly informed, public, with examples from the Pacific, Gulf, and Atlantic coasts.

An increasingly rapid decimation of the national heritage represented in estuaries is taking place for purposes of short-term private economic gain, without adequate consideration being given to preserving future multiple-use options for the broad public benefit. Enhanced public comprehension of the biological significance of estuaries, which is the principle objective of this Symposium, should help significantly to bring about more rational and enduring use of the estuarine resource for the benefit of all elements of society.

There is urgent need to improve communications among aquatic scientists, economists, engineers, sociologists, politicians, and planners, as well as concerned lay citizens, in order to achieve this important goal. Hopefully, this Symposium will generate a significant part of the improved public comprehension needed among the many different users of estuaries in order to create an improved climate for solving the problems in maintaining the estuarine environment in a productive condition.

Philip A. Douglas, Executive Secretary
Sport Fishing Institute, Washington, D.C.
Symposium Chairman
December 18, 1970

I. INTRODUCTION TO SYMPOSIUM

INTRODUCTION TO SYMPOSIUM

Richard H. Stroud

Executive Vice President, Sport Fishing Institute, Washington, D.C. 20005

Several nationwide and regional study reports on estuaries have been completed recently. None, however, has adequately emphasized the fundamental biological significance of estuaries. This is the subject of today's symposium, designed to set the stage for subsequent discussion of social, economic, and legal aspects of estuarine use.

At the very outset, therefore, it is important to consider the nature of an estuary. In the first place, an estuary is not a land area, and does not include any land above the high-water mark. An estuary is a body of water at the edge of the sea with special ecological characteristics, being neither wholly fresh nor wholly salt. As generally regarded:

> "An estuary is a semi-enclosed coastal body of water having a free connection with the open sea and within which the sea water is measurably diluted with fresh water deriving from land drainage" (Cameron and Pritchard, 1963).

Thus, estuaries are zones of ecological transition between fresh water and salt water—the coastal brackish water areas. Closely associated with estuaries are the tidal freshwater habitats that occur immediately above the upper limits of saltwater intrusion. These are vitally important as nursery and spawning areas for many anadromous species. Seaward from the estuary, beyond the semi-encompassing headland features, measurable dilution of sea water by land drainage can be traced for considerable distances offshore in some ocean surface waters. Moreover, considerable acreages of coastal salt meadow and salt marsh customarily occur in close ecological relationship to estuaries. Together with the estuaries, themselves, these important transition zones encompass the entire estuarine-associated environment, which may be usefully regarded as the "estuarine zone." As generally accepted:

> "The estuarine zone is an environmental system consisting of the estuary and those transitional areas consistently influenced or affected by water from the estuary" (Smith, 1966).

This symposium, today, is concerned with the estuaries as the key environments within the estuarine zone. Since all estuaries (by definition) lie adjacent to salt water, the mouths of rivers tributary to the Great Lakes are not considered here. However important otherwise, they do not qualify as estuaries regardless of repeated propaganda to that effect for purposes of temporary expedience.

According to data supplied to the Congress by the U.S. Department of the Interior, the United States presently possesses 26,364,800 acres of estuarine waters (Cain, 1967). Of this total, 8,342,600 acres occur along the Atlantic Coast south of Alaska, and 11,022,800 acres along the coast of Alaska. Of the total, about 7,734,400 acres (29.4%) is water less than six feet deep, most vulnerable to filling, as well as especially productive of fish, shellfish, and wildlife. At least 564,500 acres (6.8%) of the latter have been obliterated through filling, mostly in the last fifty years. This obliteration has proceeded most rapidly on the West Coast below Alaska—35 percent loss of original shallow areas (40% in California, largely San Francisco Bay), and on the Atlantic Coast—4.2 percent loss of the original productive shallow areas.

One of the broad expanses of Continental Shelf (out to the 200m depth contour) occurs adjacent to the Atlantic Coast estuaries. This broad Shelf area encompasses about 166,656,000 acres of readily accessible ocean bottom. In 1967, the total weight of fish and shellfish harvested from the Atlantic Continental Shelf area was at least 6,610 million pounds.[1] Thus, the yield from this area of Continental Shelf averages about 40 pounds per acre, the finfish fraction (about 37 pounds) being equivalent to about 22 percent of an estimated standing crop of 168 pounds of finfish per acre. The finfish yields appear already to be close to, at, or beyond the level of optimum sustained natural yields for many species (Edwards, 1968).

Based on findings by the Sport Fishing Institute, resulting from a recent survey of selected estuarine fisheries biologists, unanimity of opinion is lacking

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[1] Includes U.S. angler-catch of edible finfish = 400 million pounds, U.S. domestic commercial harvest of all fish and shellfish (about equally divided) = 1,100 million pounds, and known catches of finfish by foreign nationals = 5,110 million pounds.

Table 1. **Identification of Estuarine-Dependent Marine Fishes Common to U.S. Coastal Waters**

Species[1] / Estuarine Fisheries Biologists	Working Locations of Biologists														
	Atlantic Coast								Gulf Coast	Pacific Coast				At Large	
	Northeast				Middle			South							
	Cole	Alperin	Saila	Wallace	Daiber	Massmann	Hassler	deSylva	Chapman	Chadwick	Loeffel	Lasater	Noerenberg	Smith	McHugh[2]
Barracudas															
Bass, Black Sea			X			X		X							X
Basses, Pacific															
Bluefish		X		X				X	X					X	
Bonitos								*							
Cabezon and Pacific Sculpins															
California corbina															
California sheephead															
Catfishes								?	X						X
Cobia						X	?	?							
Cods, Atlantic															
Cods, Pacific															
Croakers	X	X		X	X	X	X	X	X					X	X
Cunner	?		X												
Dolphins															
Drum, Black	X	X			X	X	?	X	X					X	X
Drum, Red	X	X		X	X	X	X	X	X					X	X
Eel, American	X	X	X	X	X	X	X	X	X					X	X
Flounder, Pacific									*						
Flounder, summer		X		X	X	X	X	X	X					X	X
Flounder, winter	X	X	X	X	X	X	X	X	X					X	X
Gar															
Groupers								*							
Grunts									X						
Haddock															
Hake, silver															
Hake, spotted						X									
Hake, squirrel															
Halibut, California															
Herrings, Atlantic							X	X							
Jacks								*							
Jack Mackerel															
Kingfishes		*				X	?		X						
Ladyfish								X							
Lingcod				X											
Mackerel, Atlantic															
Mackerel, King															
Mackerel, Pacific															

Table 1. Identification of Estuarine-Dependent Marine Fishes Common to U.S. Coastal Waters (cont'd)

Species[1] \ Estuarine Fisheries Biologists	Working Locations of Biologists														
	Atlantic Coast								Gulf Coast	Pacific Coast				At Large	
	Northeast				Middle			South							
	Cole	Alperin	Saila	Wallace	Daiber	Massmann	Hassler	deSylva	Chapman	Chadwick	Loeffel	Lasater	Noerenberg	Smith	McHugh[2]
Mackerel, Spanish				X				X							
Mullets	X	X			X	X	X	X	X					X	
Ocean Whitefish															
Opaleye															
Perch, white		X	X	X		A	X	X	X					X	X
Perch, yellow			X	X											X
Pigfish						X		X	X						
Pollock															
Pompanos														X	X
Porgies		X		X				X							X
Puffers		X		X		X		X						X	X
Rockfishes															
Sablefish															
Salmon, chinook		X		X	X	A	X	X	X	X	X	X	X	X	X
Salmon, coho		X		X	X	A	X	X	X	X	X	X	X	X	X
Salmon, pink		X		X	X	A	X	X	X	X	X	X	X	X	X
Seabass, white															
Searobins					X										X
Seatrout, sand		X		X	X		X	?	X					X	
Seatrout, spotted	X	X		X	X	X	X	X	X					X	
Seatrout, white		X		X	X	X	X	?	X					X	X
Shad, American	X	X	X	X	X	A	X	X	X	X	X	X		X	X
Shad, hickory	X	X	X	X	X	A	X	X	X					X	X
Sharks								*						?	
Sharks, dogfish															
Silversides		X		X	X	X	X	X	X					X	X
Smelts	X	X	X	X	X	X		X	X	*	X	*		X	X
Snapper, gray								X							
Snapper, red															
Snapper, yellowtail															
Snook						X		X	X					X	
Spadefish, Atlantic						X	?	?							
Spot		X		X	X	X	X	X	X					X	X
Steelhead				X	X	A	X	X	X	X	X	X	X	X	X
Striped bass	X	X	X	X	X	A	X	X	X	X	X			X	X
Sturgeon		X	X	X	X	A	X	*	X	X	X	X		X	X
Surfperches															

Table 1. **Identification of Estuarine-Dependent Marine Fishes Common to U.S. Coastal Waters (cont'd)**

Species[1] \ Estuarine Fisheries Biologists	Working Locations of Biologists														
	Atlantic Coast								Gulf Coast	Pacific Coast				At Large	
	Northeast				Middle			South							
	Cole	Alperin	Saila	Wallace	Daiber	Massmann	Hassler	deSylva	Chapman	Chadwick	Loeffel	Lasater	Noerenberg	Smith	McHugh[2]
Tarpon						X	X	X	X					X	
Tautog	?		X	X										X	X
Tenpounder															X
Toadfish			X	X	X	X		?							
Trout, cutthroat						A					*	*	*		
Trout, Dolly Varden						A					*	*	*		
Tunas															
Weakfish		X		X	X	X	X	X	X					X	X
Yellowtail, California															

NB: * designates "some species only"; A designates anadromous nature.

[1]List of Species (Species groups) from—Deuel, D. G. and J. R. Clark. 1968. The 1965 Salt Water Angling Survey. Bur. Sp. Fish. and Wildlife. Res. Pub. No. 67. 51 pp.

[2]McHugh, J. L. 1966. Management of Estuarine Fisheries—A Symposium of Estuarine Fishes. Amer. Fish. Soc., Sp. Pub. No. 3:133-154.

about which species or species groups of marine fishes commonly found in coastal waters are in fact estuarine-dependent at some critical stage(s) of their life histories (Table 1). This serves to illustrate the poorly-appreciated fact that much essential elementary biological information about many of these species remains to be acquired. In terms of their landed values, however, nearly two-thirds (63%) of the commercial catch on the Atlantic Coast is made up of species believed to be estuarine-dependent (McHugh 1966). Assuming that this applies equally to the combined catches by foreign nationals as to the U.S. domestic catch, the fisheries yield from the U.S. Atlantic Continental Shelf, at present levels of development of the fisheries, is equivalent to about 535 pounds per acre of estuaries.

Thus, for each acre of estuary obliterated through filling, or otherwise destroyed, there could be a corresponding annual loss in yield (at present levels of resource development) of about 535 pounds of fisheries products on the Continental Shelf. (Whether some compensatory increase might occur in production of other species is a matter of speculation.) Similarly, general overall reductions of productivity of the estuaries by pollution (or other factors), say by

20, 40, 60, or 80 percent, etc., would cause corresponding reductions in Shelf yields. On the other hand, given intensive management of the estuaries for optimum fisheries yields, it is already certain that Shelf yields could be substantially increased, especially for high-value sessile shellfish and selected species of finfish.

The Sport Fishing Institute takes great pleasure in welcoming all the contributors, distinguished guests, and other participants to today's Symposium. Its purpose is to help demonstrate the great biological significance of those unique brackish-water ecosystems—the estuaries—that occupy the vital aquatic transitional zones at the edge of the sea. It may not be too extreme to predict that what present civilization does to or with these irreplaceable limited resources over the next few decades may have such a decisive ecological impact as to critically affect the future history of human society in America.

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II. MORNING SESSION

OPENING REMARKS BY SESSION CHAIRMAN

Richard A. Geyer

Department of Oceanography, Texas A&M University,
College Station, Texas 77843

There is an ever increasing intensification of the use of the Coastal Zone as the expanding population of the United States moves into this area.

Currently, seventy percent of the nation lives within an hour's drive of the sea coast, if the Great Lakes are included. A decent concern to preserve life's amenities, as well as economic considerations, demand that more adequate provision be made for recreational use of the Nation's crowded Coastal Zone.

This Zone is a region of transition between two environments–the land and the sea. It may be defined as that part of the land affected by its proximity to the sea, and it includes a total of 1631 statute miles along the Gulf Coast. The associated estuarine areas along the Gulf of Mexico include 3,837 square miles. This area is based on a definition of an *estuarian zone*, as an environmental system consisting of an estuary and those transitional areas consistently influenced or affected by water from an estuary, such as, but not limited to, salt marshes, coastal and intertidal areas, bays, harbors, lagoons, inshore waters, and channels. The estuary, itself, is part of the mouth of a navigable or interstate river or stream or other body of water having unimpaired natural connections with open sea and within which the sea water is measurably diluted with fresh water derived from land drainage.

The total shoreline of the Gulf of Mexico includes 17,500 statute miles. Of this some 4,000 miles have been categorized as recreation shoreline, of which only 121 meet the criteria of public recreation shoreline. Of the slightly more than a thousand miles of recreation shoreline of the state of Texas, 301 miles are designated as beach, 421 miles as bluffs, and 359 miles as marsh. For Louisiana, with a comparable total shoreline, 257 miles are designated as beach and the remaining 819 as marsh. All but two miles of the entire 1,076 in Louisiana are privately owned. Of the total of 203 miles of shoreline for Mississippi, 134 are categorized as beach, 69 as marsh, and 178 miles are privately owned.

Currently Federal, State, and local governments, including intrastate and municipal coastal and harbor authorities, are funding coastal zone facilities through revenues derived by taxation of citizens and industries situated in this area. Consequently, they also share the responsibility to develop a plan for the coastal zone which reconciles, or if necessary must make decisions to choose among, competing interests and protect both long and short term values. Effective management to date has been thwarted by:

1. the variety of government jurisdictions from all categories involved,
2. the low priority afforded marine matters by State governments,
3. the diffusion of responsibilities among State agencies, and
4. the failure of State agencies to develop and implement long range plans.

Current coordination at the Federal level is through the Committee on Multiple Use of the Coastal Zone of the Marine Council. It considers the broad aspects of coastal management and seeks effective and consistent Federal policies. In addition, the Water Resources Council, a Cabinet level coordinating and planning group analogous to the Marine Council but chaired by the Secretary of the Interior, also has an interest in the Coastal Zone. However, its work is primarily directed to inland waters; but neither committee is concerned with the detailed management of specific coastal areas. This diffusion and fragmentation of responsibility is reflected within State governments within which individual agencies deal directly with their counterparts at the Federal level. Too often States lack plans of their own based on an appraisal of all State interests. They also lack sound scientific knowledge in developing and maintaining their coastal resources. Frequently, in these cases, States have tended only to react to Federal plans.

On a State Government level, the States are frequently subjected to intense pressures from the county and municipal levels because coastal management often directly affects local responsibilities and interests. Hence, local knowledge frequently is necessary to reach rational management decisions at the State level. These decisions in turn should be reflected at the Federal level. It is necessary to reflect the interests of local governments in accommodating competitive needs.

The President's Commission on Marine Engineering and Resources has given considerable thought to the problem of Coastal Zone Management. It recognized the tremendous significance of this problem by designating a panel to study it specifically during its two-year tenure. In fact, of the many recommendations made by the Commission to accelerate the development of marine resources, the closest program considered for the possible category of a crash program was that of Coastal Zone Management. This is necessary because of the rapidly accelerating rate at which existing coastal zone areas are being consumed for a variety of purposes, without any long term planning. Recognition of the legitimate needs of competing uses, both industrial and sociological, is often lacking. As a result of the studies of this Commission Panel, as well as of the entire membership, a number of specific recommendations have been made. Some of the major ones include:

1. A Coastal Management Act be inacted to provide policies and objectives for the Coastal Zone, and authorize Federal grants-in-aid to facilitate establishing State Coastal Zone authorities empowered to manage the Coastal waters and its adjacent land.
2. Federal legislation to aid States to establish Coastal Zone authorities should not impose any particular form of organization. But it should require that approval of each grant be contingent on showing that the proposed organization has the necessary powers to accomplish its purposes, has broad representation, and provide adequate opportunities to hear all viewpoints, before adopting or modifying its coastal development plans.
3. The land and water conservation fund be more fully utilized to acquire wet lands and potential coastal recreation lands. Enact legislation authorizing Federal guarantees of State bonds for wetland acquisition when necessary to implement the Coastal Management Plan.
4. Estuarine studies should be conducted by the Department of Interior to identify areas to be set aside as sanctuaries to provide natural laboratories for ecological investigations.
5. Federal and State agencies with Coastal Zone responsibilities should provide more adequate support for scientific and engineering research on coastal problems. This includes making an inventory of the multiple resources in this area.
6. Universities affiliated with coastal laboratories should be encouraged to provide aid to State officials on coastal issues and for their training.

It is not too soon to start implementing the many recommendations made by the Commission for the Coastal Zone of the United States–the nation's most valuable geographic feature–if the Coastal Zone is to be developed in an optimum manner for all concerned. Yet, it must be done in a manner compatible with the best short and long term interests of the diversified segments of the industrial and sociological components of our society. Otherwise it will not be possible to cope successfully with the myriad of problems involved in this area.

THE BIOLOGY OF THE ESTUARY[1]

L. Eugene Cronin and Alice J. Mansueti

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An estuary is a mixture of a river and the sea. More exactly, it is a semi-enclosed body of water which has a free connection with the open sea and within which sea water is measurably diluted by fresh water from land drainage.[2] Each estuary is a site of vigorous interaction among land, sea and air. The symposium cover shows a diagram of one principal type, the drowned valley or coastal plain estuary which is found in many coastal areas.

There is enormous variation among the nearly 900 estuaries along the coasts of the United States. The Atlantic Coast includes many of them; among these, the Chesapeake and Delaware Bays (Fig. 1) are large and excellent examples of drowned valleys and have received much research attention. Such coastal plain estuaries are the prototypes for most of the characteristics and examples presented in this discussion.

Other types of estuaries, and those in regions other than the Atlantic Coast, differ from this summary to varying degrees. It is not possible or appropriate to reduce all estuaries to a single characterization. Each, in reality, is an individual ecosystem with its own interesting identity, reflecting the highly local effects of river, sea, land and air.

Glacier-gouged fjords, such as occur in Norway and the Pacific Northwest, are

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[1]Contribution No. 421 from the Chesapeake Biological Laboratory. The Senior author is Director of the Laboratory and the second author is a Research Associate.

[2]Definition of Dr. Donald W. Pritchard.

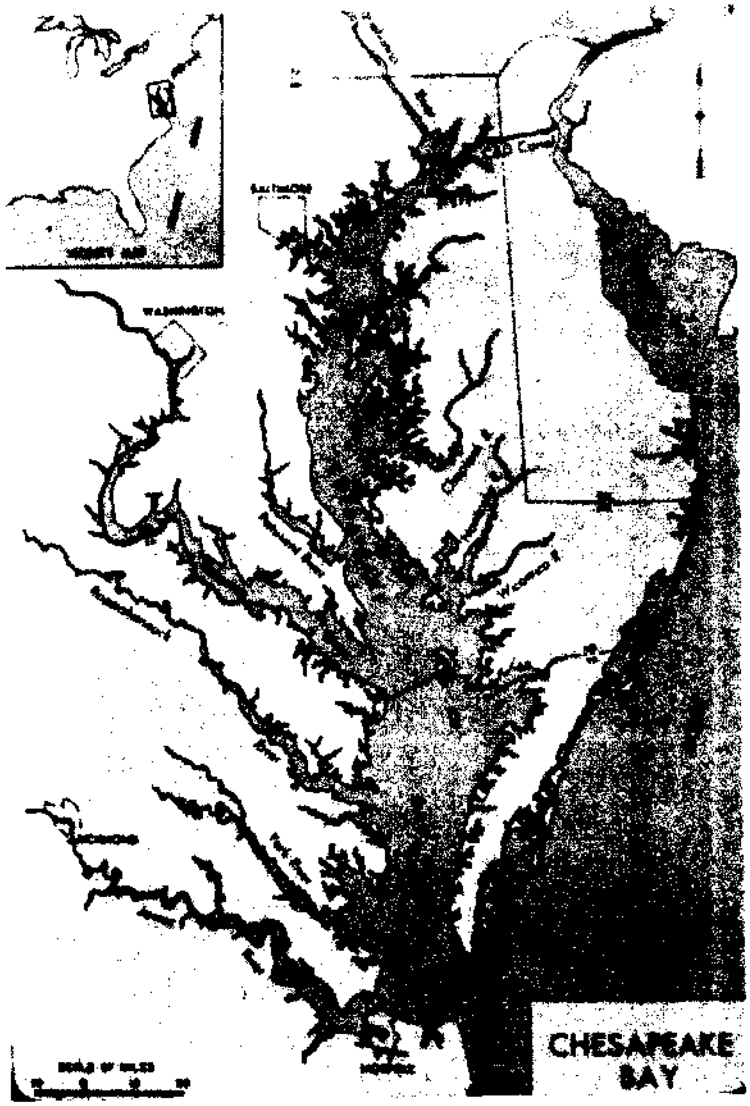

Figure 1

one kind of estuary (Fig. 2). Earthquakes, land shifts and other violent actions created estuaries such as San Francisco Bay. Barrier beaches have slowly developed to enclose Biscayne Bay in Florida and the lagoon behind Ocean City, Maryland (Fig. 3), and scores of comparable coastal lagoons, especially along the Gulf Coast. Some estuaries contain a mixture of oceanic and land-sourced water but are not easily classified, such as the area in Florida around Ten Thousand Islands and at Cape Sable.

SOME PHYSICAL, CHEMICAL AND GEOLOGICAL CHARACTERISTICS

There are, however, characteristics which appear to be common to many estuaries. As shown by a section along the center of a simplified model (Fig. 4),

Figure 2

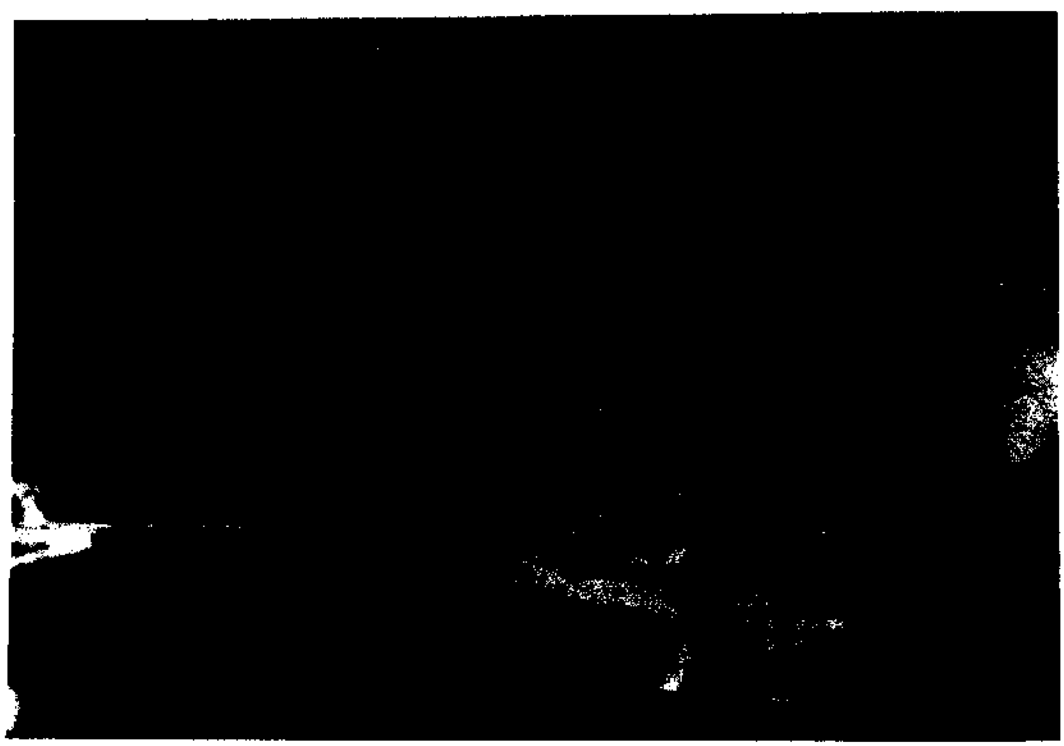

Figure 3

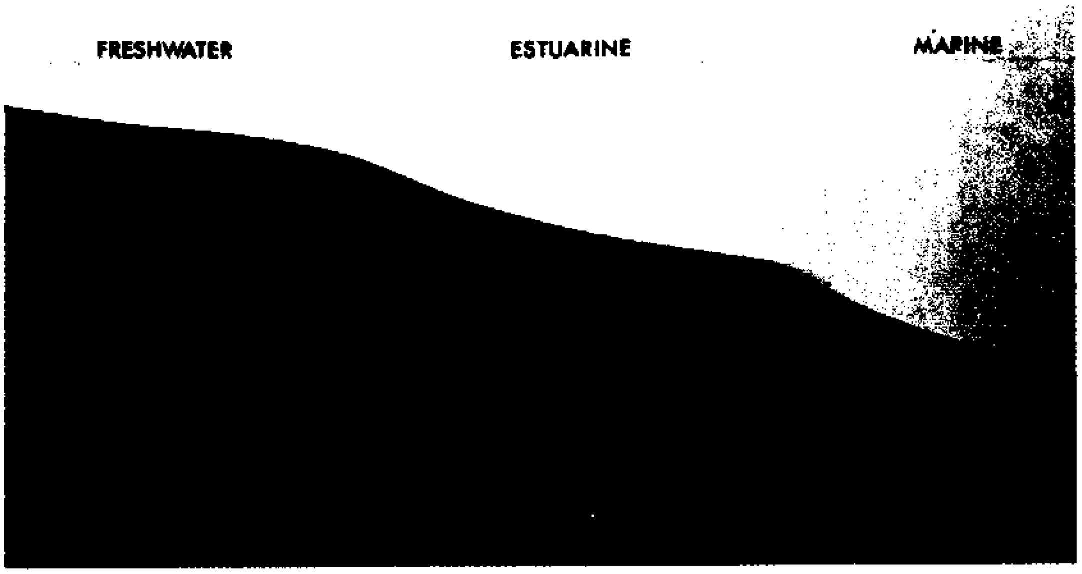

Figure 4

Courtesy U.S. Army Corps of Engineers

Figure 5

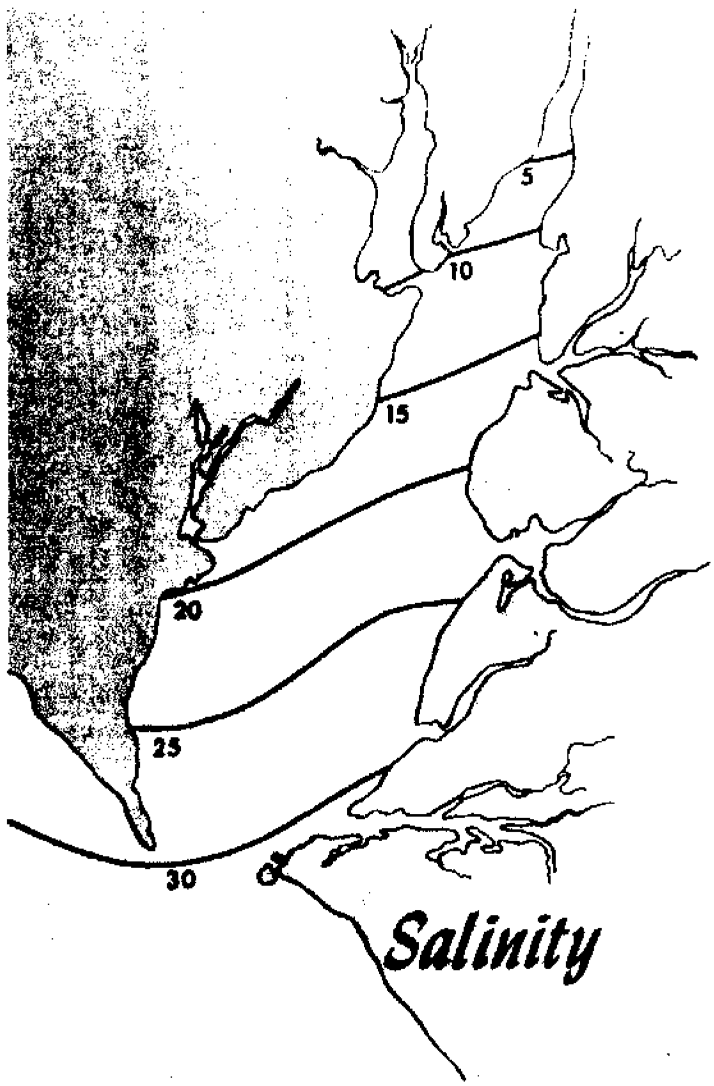

Figure 6

there is fresh water at the river end, oceanic conditions at the other, with the mixing system called the estuary located between. The river influence may originate far inland, and the oceanic influence may derive far beyond the continental shelf (Fig. 5) or the edge of the open sea.

In most estuaries, there is a gradient in salt content from high values of 30 to 35 parts of salt per thousand parts of water at the ocean end to zero salinity at the river end. Isohaline lines following the same salinity value, however, do not usually run straight across the estuary. The earth's rotation causes these lines to be higher on the right-hand side facing upstream in the northern hemisphere (Fig. 6) and on the left-hand side in the southern hemisphere. Sampling also reveals that deeper waters are usually saltier than surface waters and that the ebb

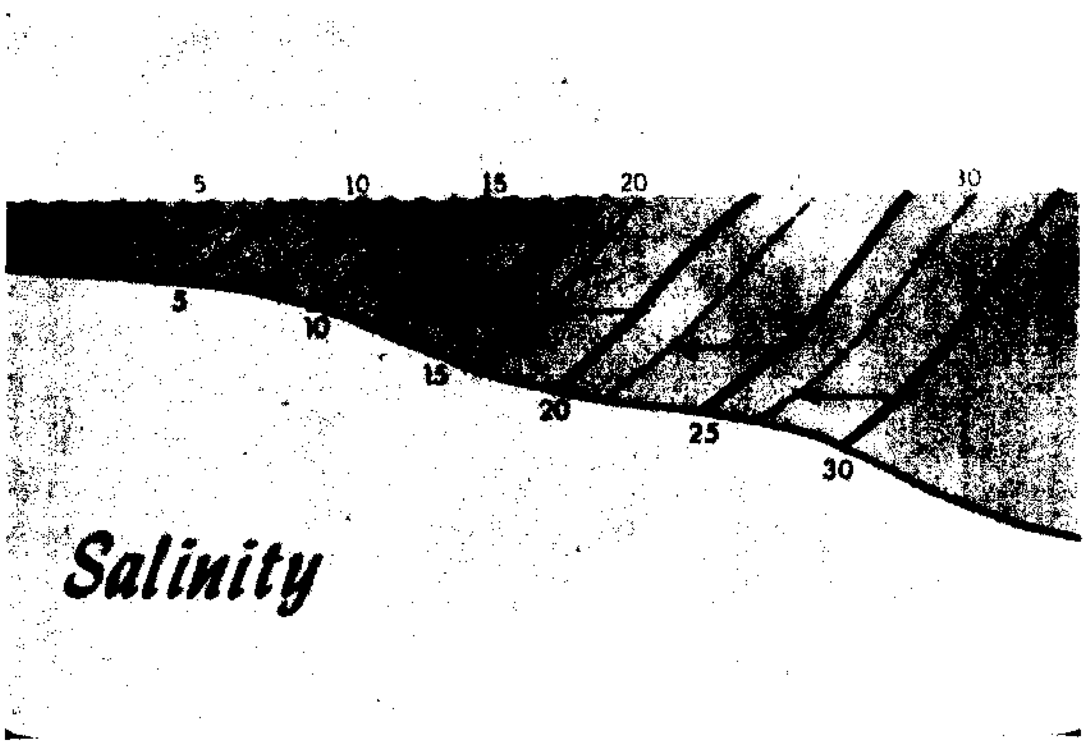

Figure 7

and flow of the tide carry the isohalines up and down the estuary (Fig. 7). These lines of uniform salt content are also driven downstream when the river flow is high and upstream during the periods of low flow from the land. Since high-flow runoff is often several hundred times as great as low-flow runoff, seasonal salinity variation may be very large at one location.

Many of the coastal plain estuaries contain a two-layered system of circulation which is of unique importance to the species which live there. This circulation pattern is the result of the intrusion of heavier salt water from the ocean under less saline and lighter water from the river. Particles of water near the surface undergo a net downstream movement, whereas water particles near the bottom are carried toward the upper end of the system (Fig. 8). This creates a stratified system, with a distinctive estuarine pattern of circulation (Fig. 9) that results in transportation of organisms in the surface water toward the sea and of organisms in the bottom water toward the river.

The total quantity of water flowing past each point of land increases enormously toward the ocean. In a diagrammatic representation to suggest the increase, 1*R* can equal the flow from the river and the quantity at various locations may be shown in multiples of *R* (Fig. 10). It is clear that far greater volumes of river water are available for dilution of wastes (if that is desired) in the seaward portion of the estuary.

River water contains sediments which are washed down from the river or eroded from the shore. The constant input of this solid material eventually fills

Figure 8

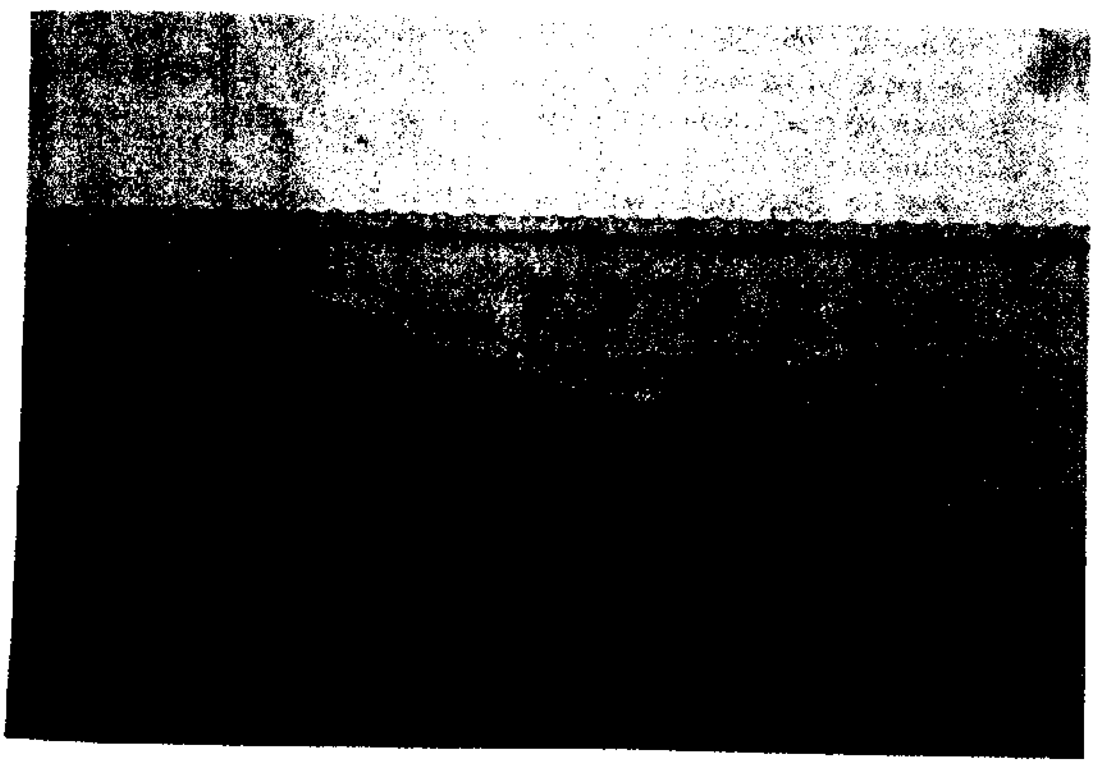

Figure 9

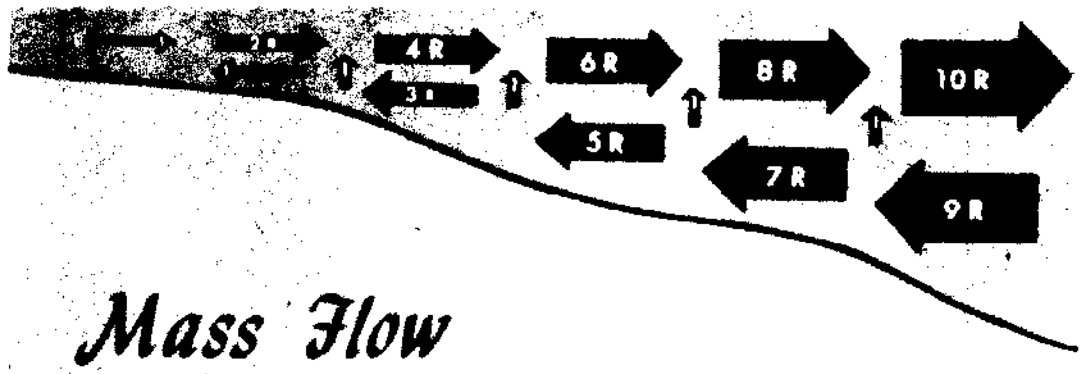

Figure 10

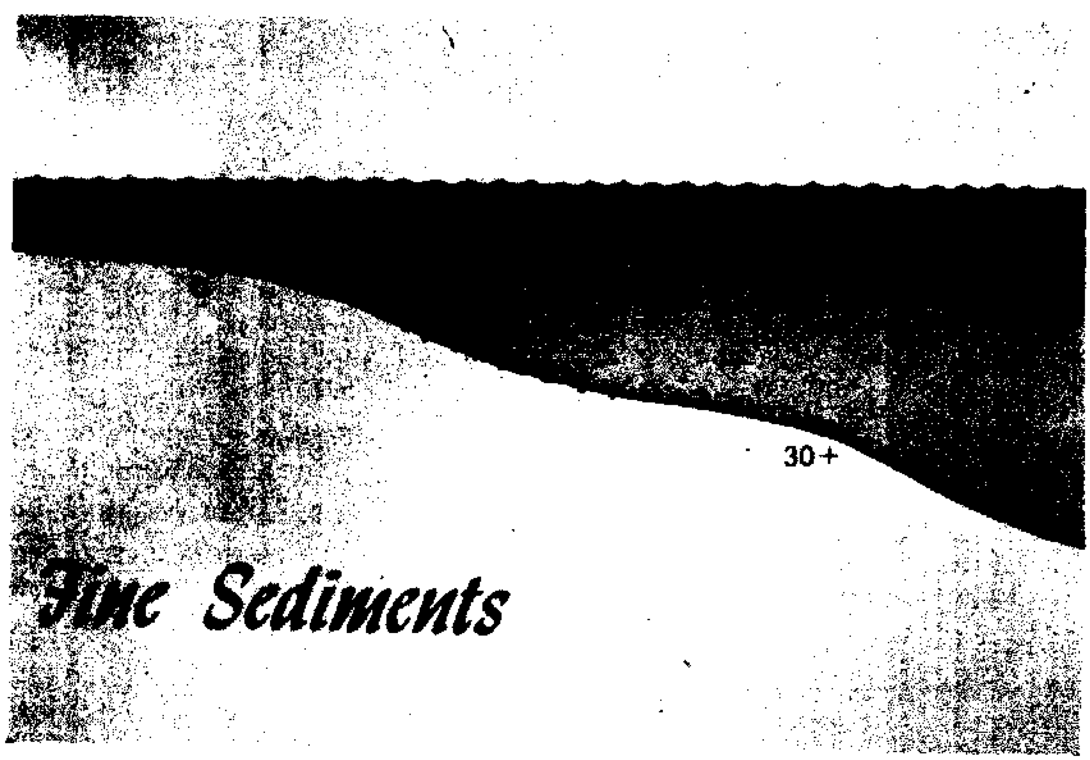

Figure 11

Figure 12

each basin or builds a delta out into the sea. In large estuaries, the highest concentration of suspended sediment is usually found in the low salinity portion (Fig. 11). This is where flocculation occurs, where the broadening of the bay permits sediment to settle, and where currents from wind and waves frequently resuspend and redistribute sediments. Permanent accumulation occurs in the deeper channels (Fig. 12), where compact deposits of fine particles may be over a hundred feet deep. The sediments absorb many chemicals and remove them from the water unless dredging or stirring releases them or biological activity removes the chemicals from the deposit.

Physically, estuaries are influenced principally by variations in river flow, density differences between water masses, tidal movements, the physical shape of the basin, the earth's rotation, and friction. Because they are relatively shallow, estuaries are more affected than the open sea by wind, changes in air temperature, and sunlight. Man's effects on the physical parameters are rapidly increasing. Flow rates, temperatures and vertical stratification all change seasonally; also, there are short-term variations in all physical conditions.

The chemical composition of estuarine water at one site is usually the quantitative resultant of the mixture of seawater (with stable inorganic ratios and more variable organic components) with land-sourced water (chemically related to the river basin). The form and chemical activity of elements and compounds in estuaries are only partially understood. Chemicals may enter physical association with the abundant silts and microorganisms, interact chemically with the great variety of other elements and compounds present, or enter the biochemical processes of the diverse biota. Addition of such substances as nutrient salts from treated sewage, trace metals or other compounds from industrial waste, pesticides, or other materials from specific points of origin, will produce patterns which are not the simple resultants of admixture of ocean and river water.

All of these geological, physical, and chemical patterns create the environment of the living organisms which are so frequently abundant in estuaries. They produce a dynamic, variable, and highly stressful environment for life, and they have many important effects on the selection and abundance of successful plant and animal species.

THE BIOLOGICAL PATTERNS

Bacteria are ubiquitous and abundant in estuaries. Many surfaces and the water mass itself are rich in bacterial flora. As "little bags of enzymes" they are important to many chemical cycling and recycling processes. They are also important to the health of estuarine species and people and there is urgent need for increased comprehension of their roles in estuaries.

The only food factories in estuaries, as on the rest of the earth, are plants. They use nutrients and carbon dioxide in the photosynthetic processes to create organic materials. Drifting one-celled or colonial phytoplankton are frequently present in quantities of millions of organisms per liter of water. Measurement of phytoplankton and of its rates of production are not easy; therefore, use is made of indirect techniques such as comparing oxygen production in light and dark bottles placed in stable conditions of temperature and light for fixed periods of time. Such studies show that phytoplankton, in summer, is often most dense near the surface and in the low salinity areas (Fig. 13). In winter, the crop is smaller and more uniformly distributed (Fig. 14), but food production continues.

Planktonic plants are the only important plants in the open sea, but the rooted aquatic plants are of enormous importance in the shallow waters of estuaries at the edge of the land. These form two kinds of communities—

Figure 13

Figure 14

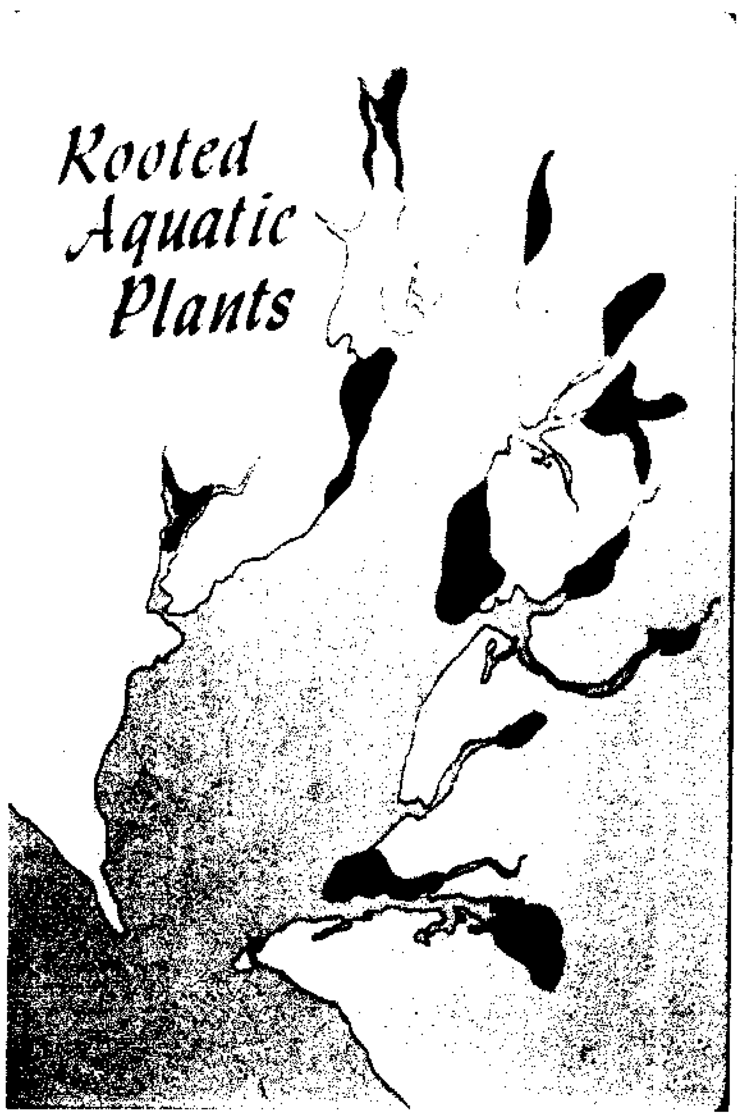

Figure 15

submerged beds and marshes (Fig. 15). Subsurface rooted plants (in which the "root" is more accurately called a hold-fast) capture nutrients which are built into plant tissues during their growing season. These beds are excellent habitats for many fish, crustacea and other species. In temperate climates, these beds die back during fall and winter, releasing organic detritus. Films or beds of algae on the bottom are sometimes highly productive.

Marshlands (Fig. 16) vary, especially in relation to salinity, the available substrate, and longitude. Recent research has helped to clarify their complex and unique roles in coastal systems. Briefly, they are organic factories, traps for sediments, reservoirs for nutrients and other chemicals, and the productive and essential habitat for a large number of invertebrates, fish, reptiles, birds and mammals. Annual plant growth and decay, providing continuing large quantities

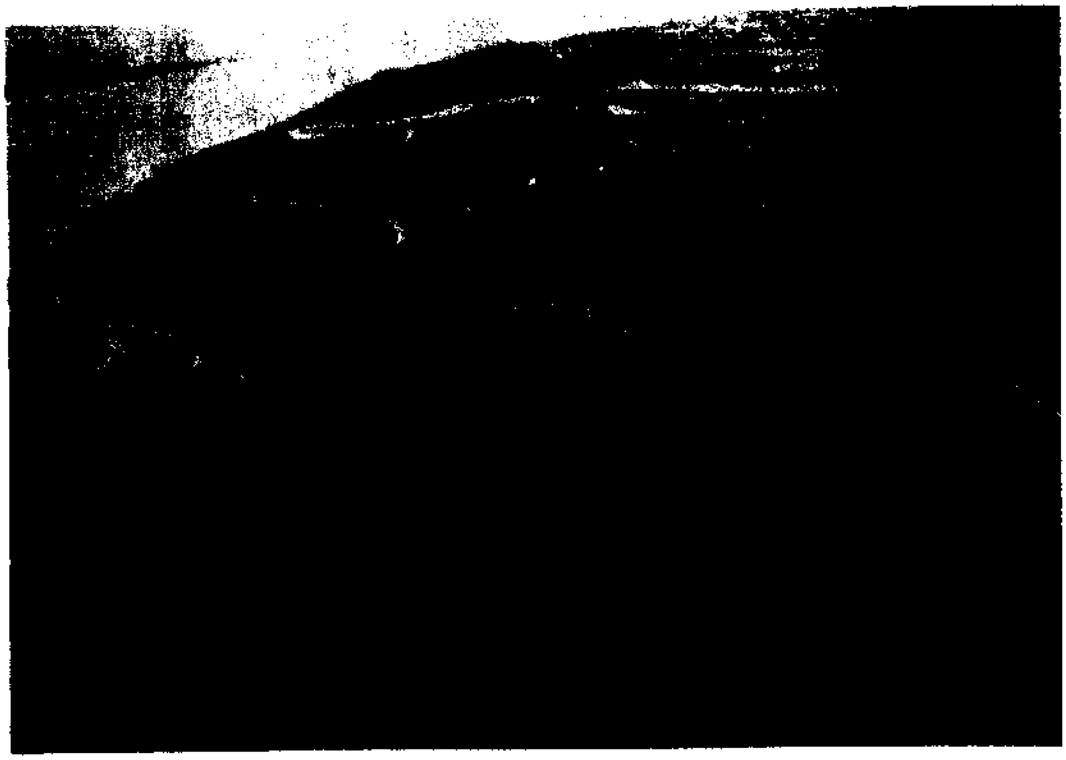

Figure 16

of organic detritus, is one of the major components of the cycling of nutrients in estuaries.

A portion of the plant material is consumed by animals. The zooplankton includes abundant copepods, shrimplike species (Fig. 17), larvae of almost all of the animals which live in estuaries (Fig. 18), jellyfishes, and other drifting species. Many of these consume phytoplankton or browse on larger plants, but some ingest detritus, strip off the bacterial film which has developed, and evacuate the detritus to act again as a substrate. Zooplankters, like all other estuarine species, reveal behavioral patterns which permit them to be successful in the specific environment of the estuary. A diurnal migration cycle has been observed in many species (Fig. 19). In the ocean, this would involve only vertical movement. In the water circulation pattern of a two-layered estuary (Fig. 8), however, this vertical movement translates into upbay movement during the day, and downbay transport at night - resulting in a roughly circular motion which retains the species near its optimal salinity range. Other interesting mechanisms are known to exist which prevent zooplankton populations from being washed out to sea, and there are probably undiscovered adaptations which assist the species.

The bottom species, collectively called the benthos, are usually more abundant and valuable in estuaries than in fresh water or the ocean. The species are highly diverse, including many annelid worms, a variety of crustacea, molluscs, and associated fish and invertebrates. Many feed by various filtering

From Sir Alistair Hardy's The Open Sea–by permission Houghton Mifflin Co., Philadelphia

Figure 17

processes, and this continuous removal of phytoplankters and other food particles is an effective trapping of nutrients flowing through the estuary.

The rich shellfish beds of Chesapeake Bay and many other bays on all coasts are vivid examples of captured food incorporated into sessile and harvestable animals. Shellfish beds are widely dispersed in estuaries, with each species in its own optimal habitat. Oysters of various species are found on all coasts of the United States, but several of the most successful species occur only in estuarine environments. Soft-shell clams are more northern in distribution and range from low to high salinities. Some of the densest clam beds are in the Chesapeake, near the southern edge of their range (Fig. 20). The bottom sediments of many estuarine areas contain a varied and abundant mixture of species which is revealed only by sieving and washing (Fig. 21).

From *Nature Adrift* by James Fraser

Figure 18

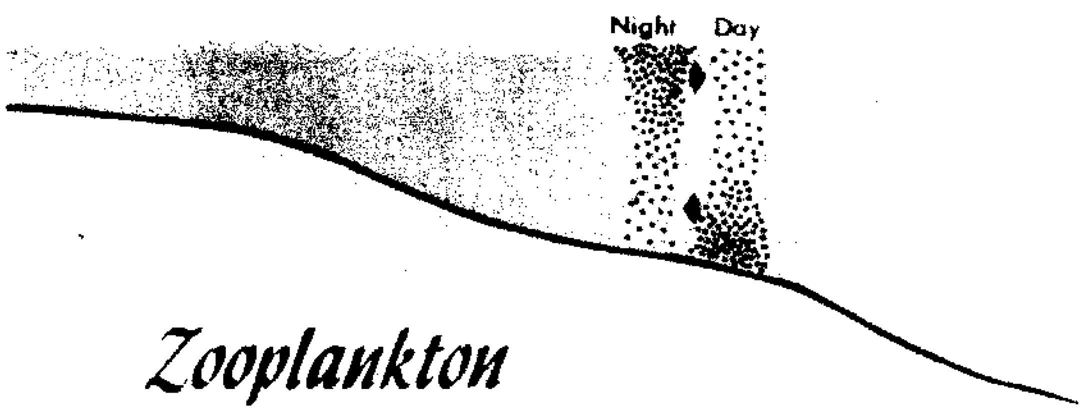

Figure 19

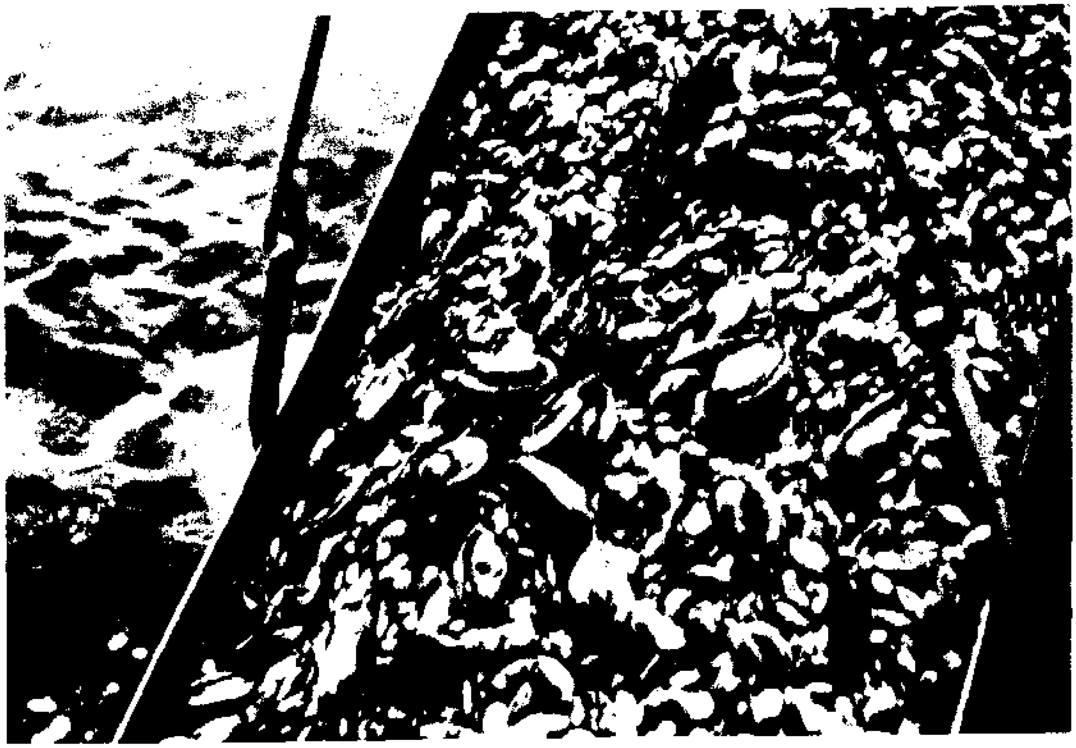

Figure 20

Figure 21

Figure 22

Along the length of the estuary, the benthic populations range from fresh to marine environments, but the densest beds are often near the center of the system. Each community is complex (Fig. 22) and greatly affected by the surrounding biological community and abiotic environmental conditions. The oyster, for instance, is notable for its ability to tolerate high sediment concentrations, temperature variations from near freezing to summer heat, and salinities from about five parts per thousand to oceanic concentrations. The real distribution of oysters, however, is frequently controlled by three factors. The upstream limit is set by the maximum flow of fresh water from the river. The downstream limit is set by predators and parasites (boring snails, starfish, fish, and microscopic organisms) which occur only in high salinities. Its lateral spread is limited by the too-soft sediments of many channels, so that the oyster (and other molluscs) are most abundant on the shoal, firm channel shoulders (Fig. 23).

The sessile benthic estuarine species possess unique advantages and offer some of the greatest opportunities for aquaculture. They occur close to shore and are accessible, they are sessile and can be owned by the culturist, and they have high commercial value. Especially significant is the fact that they feed very near the beginning of the food chain, where the quantities of available food are greatest. Some species can also be reared in hatcheries, making it possible to breed superior strains for fast growth or other desirable characteristics.

The aquatic species which can swim faster than usual water currents, and can

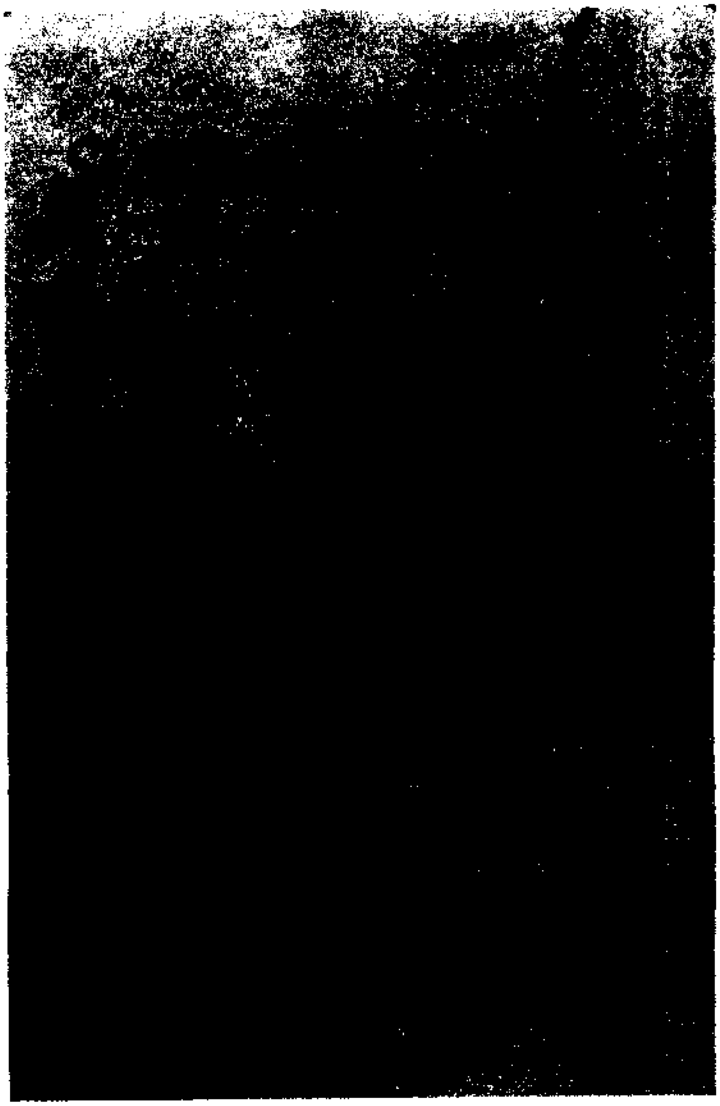

Figure 23

therefore control their distribution and movements, are called nekton. Most of these are fish, and most of the valuable coastal species are totally or partially dependent upon the estuaries. Some fish are herbivores, feeding on microscopic plants by filtration or on larger plants. Others are carnivores, which catch smaller animals. Some of the finest game fish are super-carnivores, pursuing and capturing other fish. Most species, in fact, change their feeding habits drastically as they grow from tiny larvae to post-larvae to juveniles to adult fish. A striped bass might depend in turn on phytoplankton, copepods, possum shrimp and, eventually, a mixture of fish and larger invertebrates. Fish use estuarine waters in several different ways, and typical species illustrate those uses.

The striped bass is one of the great estuarine species of the world, providing excellent fishing for both food and pleasure. In many bays and rivers, it spawns near the interface of fresh and low salinity water (Fig. 24). (Some move farther

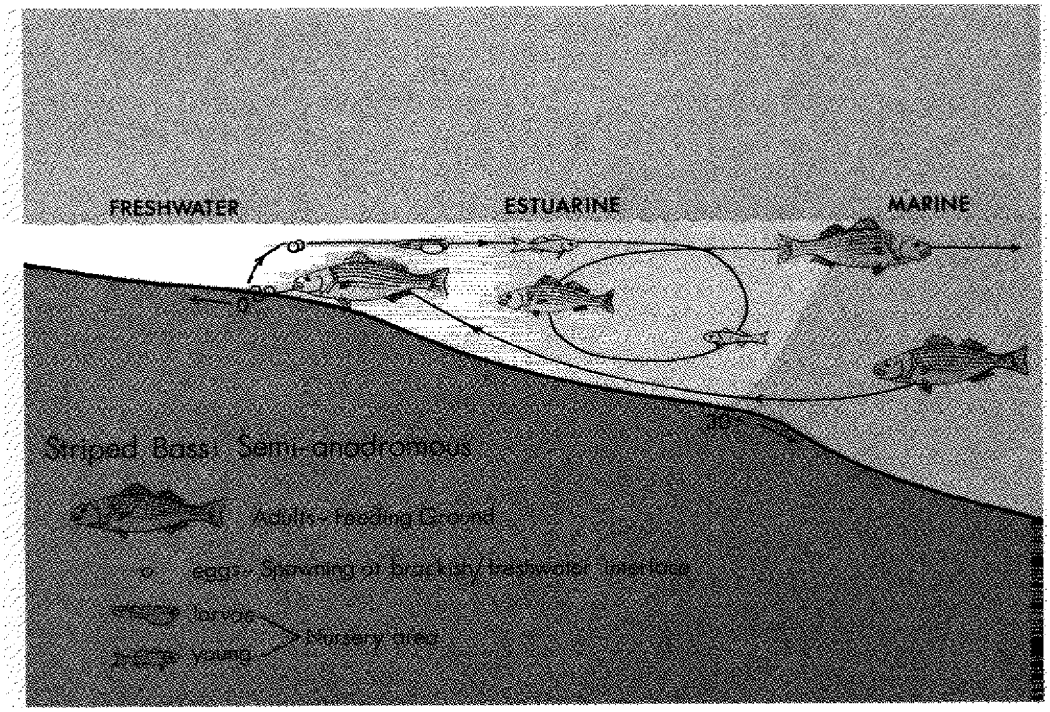

Figure 24

into rivers, and a few striped bass populations are adapted to fresh water.) In the estuary, the eggs and larvae drift downstream (past the area of heaviest silt) and the developing fish feed throughout the system until they reach maturity and repeat the cycle. There are several subpatterns, involving movement of small fish to shoals, winter congregation in deeper water, summer dispersion, and coastal migration by part of the population. Each demonstrates the remarkable compatability of the estuary and this species. There is even some suggestion that the early effects of enrichment of estuaries by human waste disposal may have been beneficial to this species. The white perch, a member of the same family of fishes, follows a similar pattern (Fig. 25), except that populations do not range as far in the large estuarine systems. Both of these are semi-anadromous fish, which move from saline water to, or almost to, fresh water for spawning.

Anadromous species are well exemplified by the herrings, the salmons, and the shads. The American shad spawns only in fresh water, the young browse in the estuary during their first summer and the next 3 to 4 years are spent in the open ocean (Fig. 26). Utilizing sensory systems which are almost incredibly selective (and very poorly understood), most return to their river of origin for spawning. For such species, it is obvious that the environmental quality of the entire estuarine system must be within the tolerance of the species, or the life cycle will be broken. The homing instinct is almost certainly guided by extremely small quantities of chemical substances in the water. Therefore, it is conceivable that one or more of the many exotic chemicals now seeping and

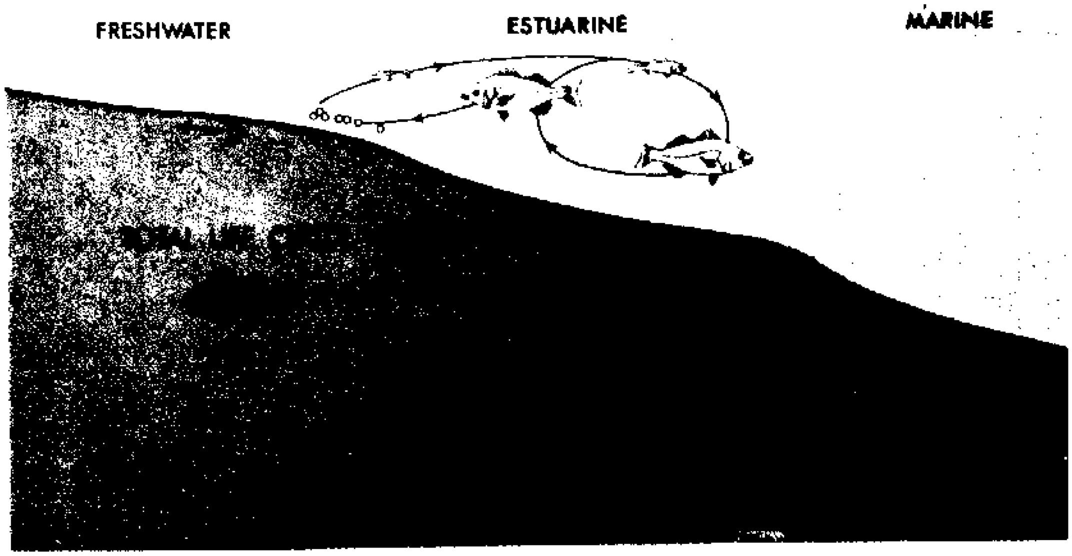

Figure 25

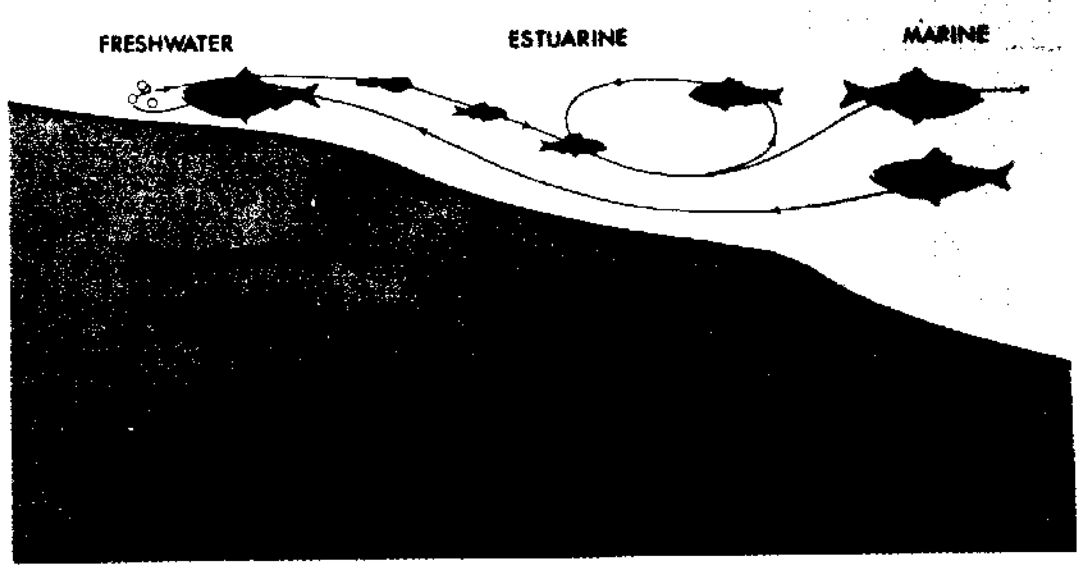

Figure 26

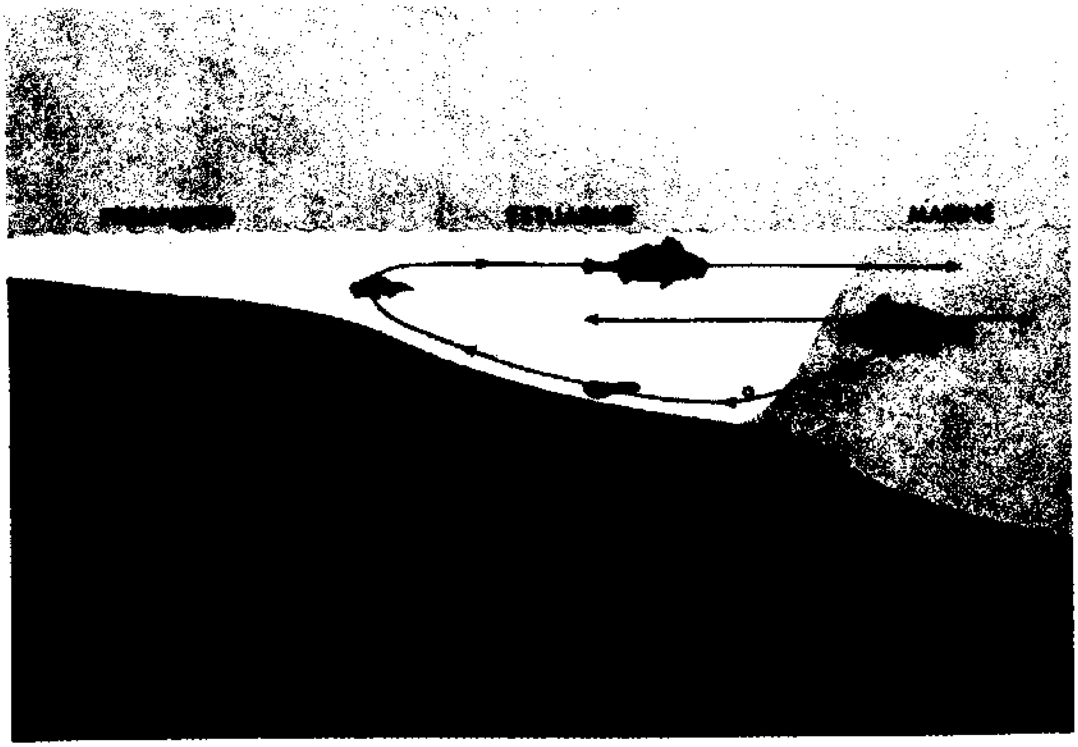

Figure 27

dripping into estuaries may interfere with the delicate sensory systems or mislead or confuse the fish on their urgent migration to the spawning grounds. Such a subtle sequence could destroy a population with very little chance that the cause could or would be detected.

Another group of fish regularly utilizes the complex circulation system of the estuary by spawning at the entrance to estuaries. The croaker is an example on the Atlantic coast. The young are rather rapidly transported upstream in the saltier deep water to reach the plankton-rich low salinity area (Fig. 27). Several members of the drum family, the menhaden, and other species use the inherent movement of water in this way.

Many of the species which live in the open ocean or over the continental shelf, such as bluefish, move into the estuaries to feed on the abundant biological crops that occur there (Fig. 28). In fact, most oceanic species occasionally enter estuaries, and some undertake regular seasonal feeding forays into them.

All of these patterns of use exist simultaneously as each species follows its own seasonal sequence. The resulting complexity of movement (Fig. 29) may include the regular or occasional presence of up to several hundred species. Many of these species are dependent both on the estuary, itself, and upon availability of clean water and a favorable environment in all of the areas they utilize.

The low salinity portion of many estuaries is a region of exceptional value to fish. This region receives fish eggs, larvae, and young from freshwater spawners,

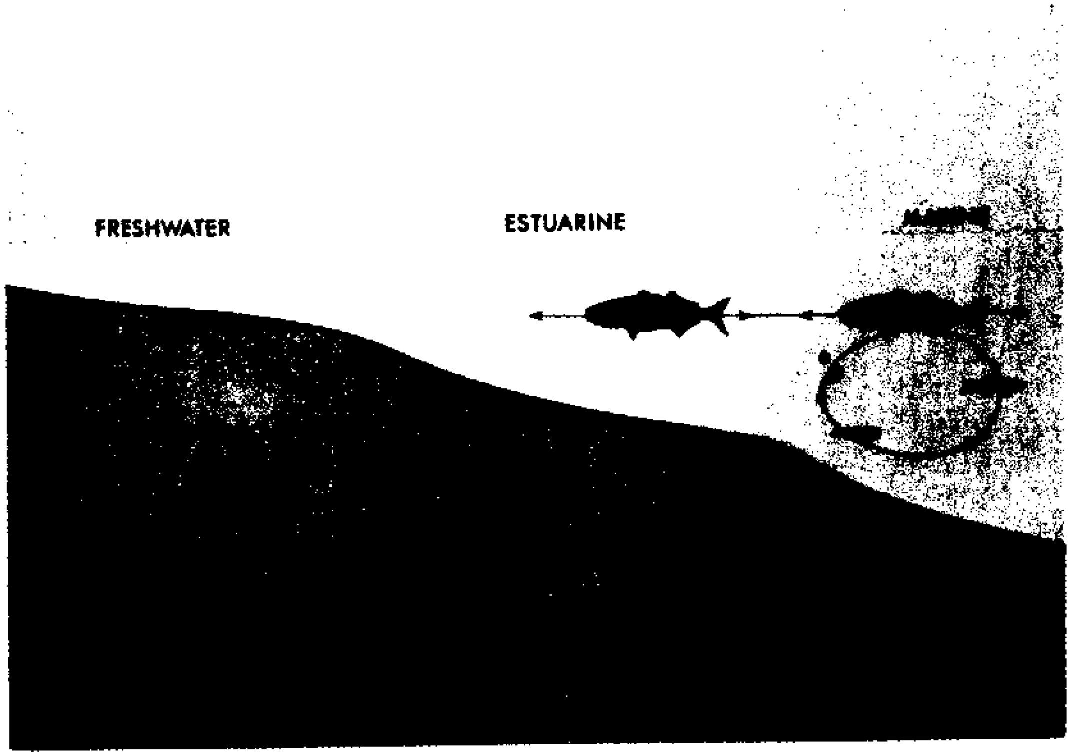

Figure 28

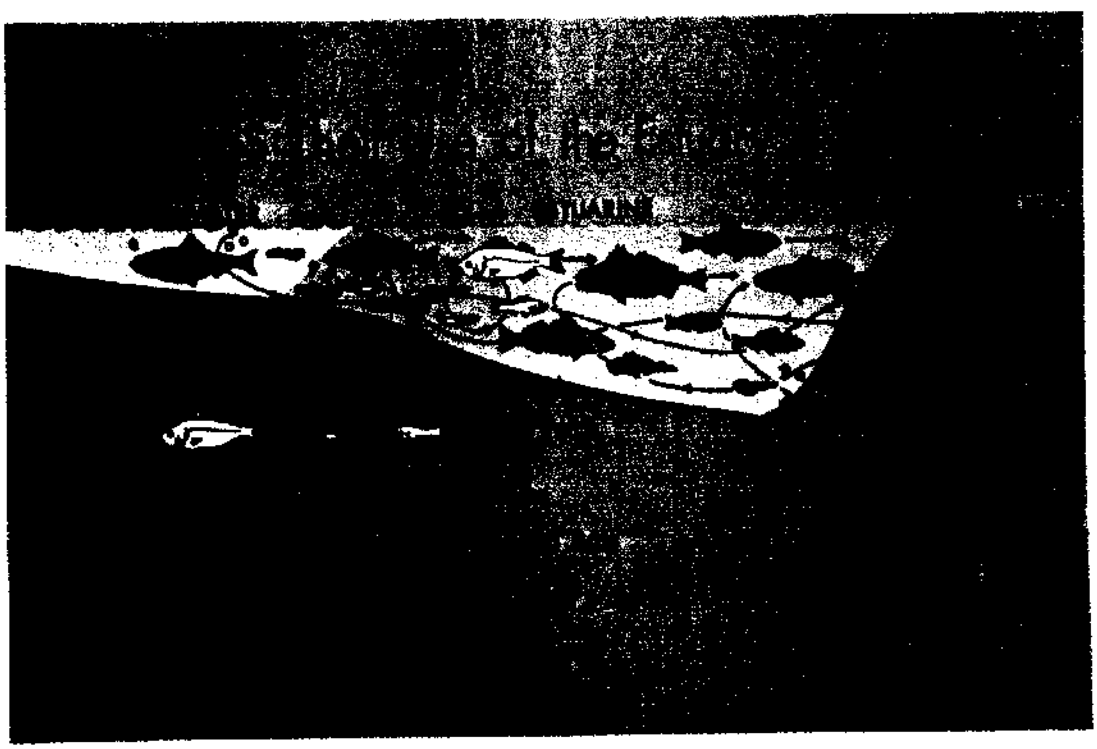

Figure 29

Figure 30

semi-anadromous and anadromous fish, estuarine spawners, and some of those that spawn in the lower estuary or ocean (Fig. 30). This region therefore becomes a resource of unique importance. Its high value is not obvious, however, since these stages in the life history are not visible to anyone except those who employ the highly specialized collecting gear (Fig. 31) that is required to reveal the diversity and abundance of young fish and their food. These rich fish nurseries that are the estuaries merit special care and protection; it is a threatening coincidence that many cities are located near these regions close to the head of navigable deep water.

The species which have successfully adapted to estuarine circumstances are not numerous in comparison with tropical or oceanic species. When they are well adapted, however, they are often exceptionally abundant. Within the groups briefly discussed, copepods, jellyfishes, oysters, clams, worms, striped bass, white perch, anchovies, herring, and many others provide examples of remarkably high population densities.

Among those species which are exceptionally well fitted for the estuarine environment is the blue crab, which spawns near the ocean to produce planktonic zoea larvae (Fig. 32). The megalops, or second stage larva, settles to the bottom and subsequent post-larval stages are widely dispersed by the *upstream* deepwater drift. The juvenile crabs semi-hibernate during cold weather

Figure 31

Figure 32

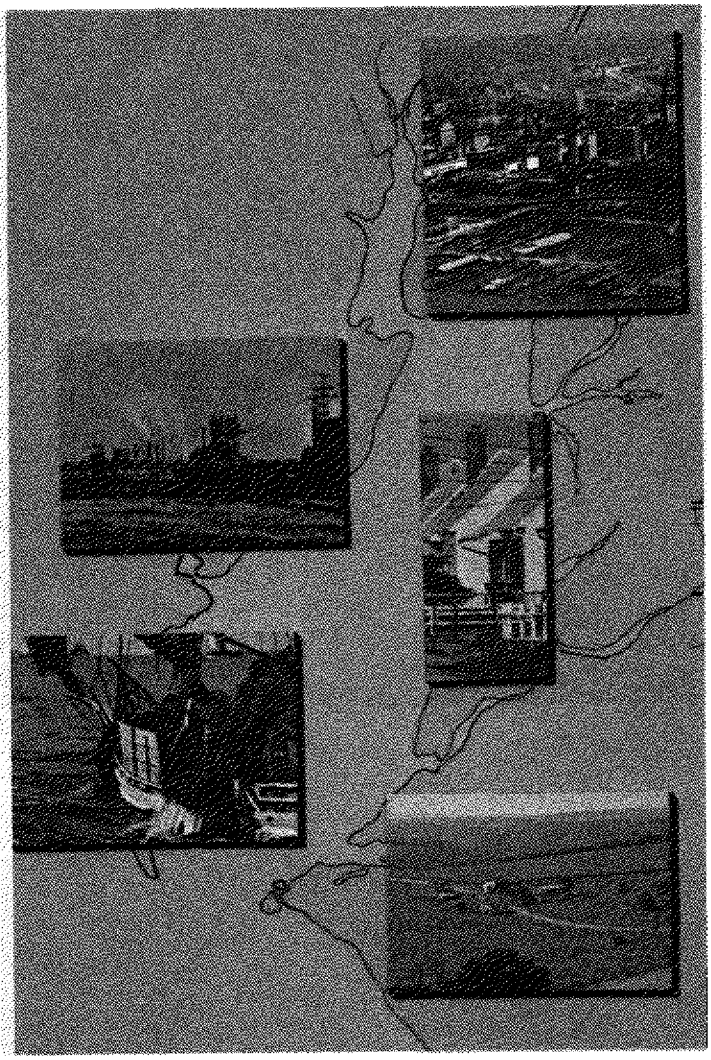

Figure 33

(north of the Carolinas, not south) and continue to shed their exoskeletons and grow. Mating occurs in middle and low salinities and the females move rapidly back to the spawning grounds, perhaps gaining some advantage from the net *downstream* drift of surface water. Here is a composite example of use of the circulation patterns, dispersion to rich feeding areas, dependence on the integrity of the entire system, and high (though widely variable) abundance. Perhaps the blue crab is an appropriate biological symbol of the estuary.

IN CLOSING

These features of the physics, chemistry, geology, and biology of many American estuaries existed when this continent was first discovered by people from other land masses. Subsequent migration, population expansion, and dramatic technological development have rather suddenly placed enormous additional stress on many useful but fragile estuaries (Fig. 33). Perhaps this brief summary of the rich biological systems involved can assist rational and effective efforts to live in enduring harmony with the complex and sensitive ecosystems of these valuable but vulnerable bodies of water.

ACKNOWLEDGMENTS

We wish to express our special appreciation to Dr. Donald W. Pritchard and his associates at the Chesapeake Bay Institute of The John Hopkins University for their excellent contributions to knowledge of the physical and chemical nature of estuaries. The summary and illustrations presented here for salinity distribution, stratification, patterns of water movement, and other environmental features are based in large part on their research and publications.

The staff of the Chesapeake Biological Laboratory has provided more assistance and encouragement than we can possibly cite. Most of the photographs are by the senior author, but some were taken by others and "loaned," to disappear in his collection. Mr. Michael J. Reber has been exceptionally imaginative in assistance with the diagrams. Other colleagues have been kind enough to review the manuscript and offer constructive suggestions for reducing a complex body of incomplete scientific knowledge to a communicable general description.

If thanks can be given to an atmosphere, we express our appreciation to the informal and stimulating spirit of the Atlantic Estuarine Research Society, where so many ideas about estuaries have been presented and discussed until they were either matured or abandoned.

THE TEXAS WATER PLAN AND ITS EFFECT ON ESTUARIES

Charles R. Chapman

Bureau of Commercial Fisheries, U.S. Department of the Interior, Washington, D.C.

The Texas Water Plan (Fig. 1) is a complex, flexible guide for long-range development of water resources to meet the needs for water throughout Texas for all purposes through 2020.

The Texas Water System is that part of the Texas Water Plan comprising reservoirs, canals, pipelines, distribution facilities, pumping stations, etc., which will be necessary to move and manage water resources of basins in Texas with interim or long-term surpluses, to provide for intrabasin needs, to make surpluses available for conveyance to areas of deficiency, and to provide for and manage water imported from out of State.

The State has concluded that if its economy is to be maintained and continue to expand it is essential to make the best use of available water for municipal and industrial uses, irrigated agriculture, mining, recreation and other essential uses.

Thus, the Texas Water Development Board first defined long-range requirements for water in all parts of the State, and water resources in the State which could be utilized to meet these requirements. It soon became apparent that if the Texas population continued to grow and its economy to expand at the present rate, water supplies within the State would not be adequate to meet the projected needs over the next 50 years. The Board concluded that water from out of State must be obtained, and several alternatives were examined. The conclusion was reached that surplus water from the lower Mississippi River

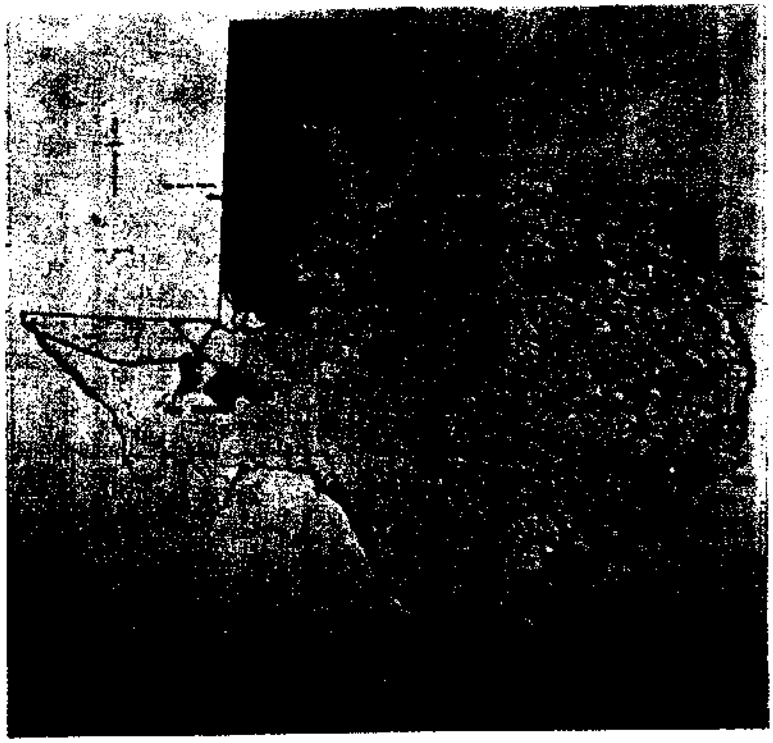

Figure 1

appeared to offer the greatest promise. The Texas Water Plan, therefore, is based on the assumptions:

1. that the water resources of Texas will be fully committed by 2020
2. that 12 to 13 million acre-feet of surplus water annually will be available for export from the lower Mississippi River.

WATER SUPPLY AND DEMAND

The water supply problem in Texas is compounded by the fact that annual supplies vary greatly and the amount of water flowing in Texas streams ranges widely from east to west, as does precipitation. About 3/4 of the total average annual runoff occurs in the eastern 1/4 of the State. During a series of wet years (1940-1946) total runoff averaged about 59 million acre-feet annually but during a dry cycle (1950-1956) only 24 million acre-feet of runoff resulted.

In 1960, Texas industry, agriculture and municipalities used more than 15.0 million acre-feet of fresh water, supplied mostly by ground water (Table 1). It is estimated that with population projected to increase from 9.6 million people in 1960 to 30.5 million people in 2020, together with attendant industrial and agriculture expansion, Texas will require more than 29.0 million acre-feet of fresh water annually for municipalities, industry and agriculture. These are in addition to fresh water needs for mining, navigation, pollution control, the estuaries, and to replace evaporation losses. Since ground water supplies are diminishing, most of the future fresh water needs must be supplied by surface water and almost half of this will have to be imported from out of State.

Table 1. Total Estimated Fresh Water Requirements for Texas, Exclusive of Estuaries (Millions of Acre-Feet)

Uses	1960			2020[1]		
	Total	Ground	Surface	Total	Ground	Surface
Irrigation	12.5	10.4	2.1	16.9	3.0	13.9
Municipal and Industrial	2.6	1.5	1.1	12.2	2.2	10.0
Mining	.1	.1	0	.1	.1	0
Navigation	0	0	0	.4	0	.4
Estuaries and Refuges[2]	0	0	0	2.5	0	2.5
Evaporation Losses From Texas Water System	0	0	0	1.4	0	1.4
Total	15.2	12.0	3.2	33.6	5.3	28.2

[1] Includes 13.0 million acre-feet of surface water needed from out of state.

[2] Partial replacement for upstream divisions; not total estuarine fresh water requirements.

Source: Publication, "The Texas Water Plan," by the Texas Water Development Board, November, 1968.

Much of the water diverted from streams for municipal and industrial purposes is returned to the stream as sewage and industrial waste. Part of the water used for irrigation also returns to streams or estuaries as agriculture return flows containing fertilizers, pesticides, and herbicides.

Municipal and industrial return flows now total about 0.8 and 1.3 million acre-feet, respectively, each year. About 0.5 million acre-feet of the industrial return flows are saline water from the estuaries. Thus about 1.6 million acre-feet of fresh water are diverted from streams, used, and returned to the streams and estuaries as domestic sewage and industrial waste. There is little if any information on the quantity and quality of agricultural return flows.

Almost 30 percent of all municipal and industrial return flows derived from fresh water originate in the Houston area and most is discharged into Galveston Bay. An additional 15 percent of the return flows originate in Dallas-Fort Worth and also reach Galveston Bay via the Trinity River. Municipal and industrial return flows will increase tremendously, with 30.5 million people in Texas, reaching an estimated 6.1 million acre-feet per year by 2020. Much of this waste water will reach the estuaries. The amount of future agricultural return flows is not known but would be considerably greater with expanded irrigation. The estimated amount of municipal and industrial return flows now reaching the estuaries, and flows expected by 2020, are shown in Table 2.

Table 2. Estimated Change in Annual Municipal and Industrial Return Flows to the Texas Estuaries (Millions of Acre-Feet)

Estuary	Historic (1960)	Future (2020)
Sabine Lake[1]	.049	.56
Galveston Bay	.202	1.50
East Matagorda Bay	0	0
Matagorda Bay	.004	0
San Antonio Bay	.011	.30
Aransas Bay	.011	.15
Corpus Christi Bay	.022	.20
Total	.299	3.01

[1] Future return flows estimated to 2010 only.

Source: *Historic* and Sabine Lake 2010 from the Bureau of Reclamation.

Future, excluding Sabine Lake, from the Texas Water Development Board report, "The Texas Water Plan," of November 1968.

At present the Texas estuaries, including Sabine Lake, receive an average of 26.5 million acre-feet of fresh water from major tributary runoff. This has varied between about 6.0 and 52.0 million acre-feet depending if the particular year was extremely wet or dry. Much of this water must be considered as part of Texas' water requirement if the ecology of its estuaries is not to be disrupted.

In its present form the Texas Water Plan does provide for considerable amounts of fresh water for the estuaries to partially replace that which will be diverted by local upstream developments. In fact, about 2.45 million acre-feet would be delivered to the estuaries each year. I will discuss this aspect of the Texas Water Plan later. First, however, I would like to acquaint you with the major features of the Texas Water System.

Virtually all of the information and statistics I am presenting was obtained from publications of the Texas Water Development Board and from records, reports, and publications of the Bureau of Reclamation, United States Fish and Wildlife Service, and Texas Parks and Wildlife Department (*cf.* General Source References, following Conclusion) pertaining to the earlier Texas Basins Project.

The latter has been incorporated virtually intact into the plan for the Texas Water System.

DESCRIPTION OF THE PROJECT

I will not attempt to discuss inland areas which might be modified or influenced by the Texas Water System as this is not the purpose of this symposium. Even so, I can at best discuss only some of the highlights of the Texas Water System as it relates to estuaries. It would take years of study by a large group of specialists and many days of discussion to describe all of the ramifications and impacts of this proposed system on the estuaries and their associated fish and wildlife resources.

The coastal area which would be influenced by the Texas Water System includes all of the estuaries, coastal lagoons, and brackish and salt marshes in Louisiana and Texas. They total about 9.6 million acres.

Texas presently has existing or under construction 157 reservoirs of 5,000 acre-feet or larger capacity; the total combined conservation storage is 28.6 million acre-feet. The Texas Water Plan proposes 67 additional major storage or regulating reservoirs with conservation storage of 32.1 million acre-feet. Hundreds of miles of canals and pipelines would be required. The actual length of such conveyance facilities is not known because final alignments are not definite. In any event, waters from east Texas would have to be lifted 2,700 feet to the terminus in the high plains. This would require about 5 million kilowatts of electrical energy annually for pumping. When fully operational, the Texas Water System would require almost 7 million kilowatt-hours of electrical energy each year, or 37 percent of the present generating capacity of the entire State. This does not include the energy which would be required to pump Mississippi River waters to Texas.

The physical facilities of reservoirs and conveyance channels, pipeline, etc., comprising the Texas Water System are grouped into (1) the Trans-Texas Division, (2) the Coastal Division, (3) the Eastern Division, and (4) the Interstate System (Fig. 2).

Trans-Texas Division

The Trans-Texas Division includes the storage and regulating reservoirs and interconnecting conduits and pumping plants in the northeast Texas river basins, the Trans-Texas Canal, and the terminal reservoirs and water distribution systems in west Texas, the panhandle and eastern New Mexico.

The Trans-Texas Division would supply water for all municipal, industrial, and irrigation requirements in northeast Texas and the Dallas-Fort Worth area. It

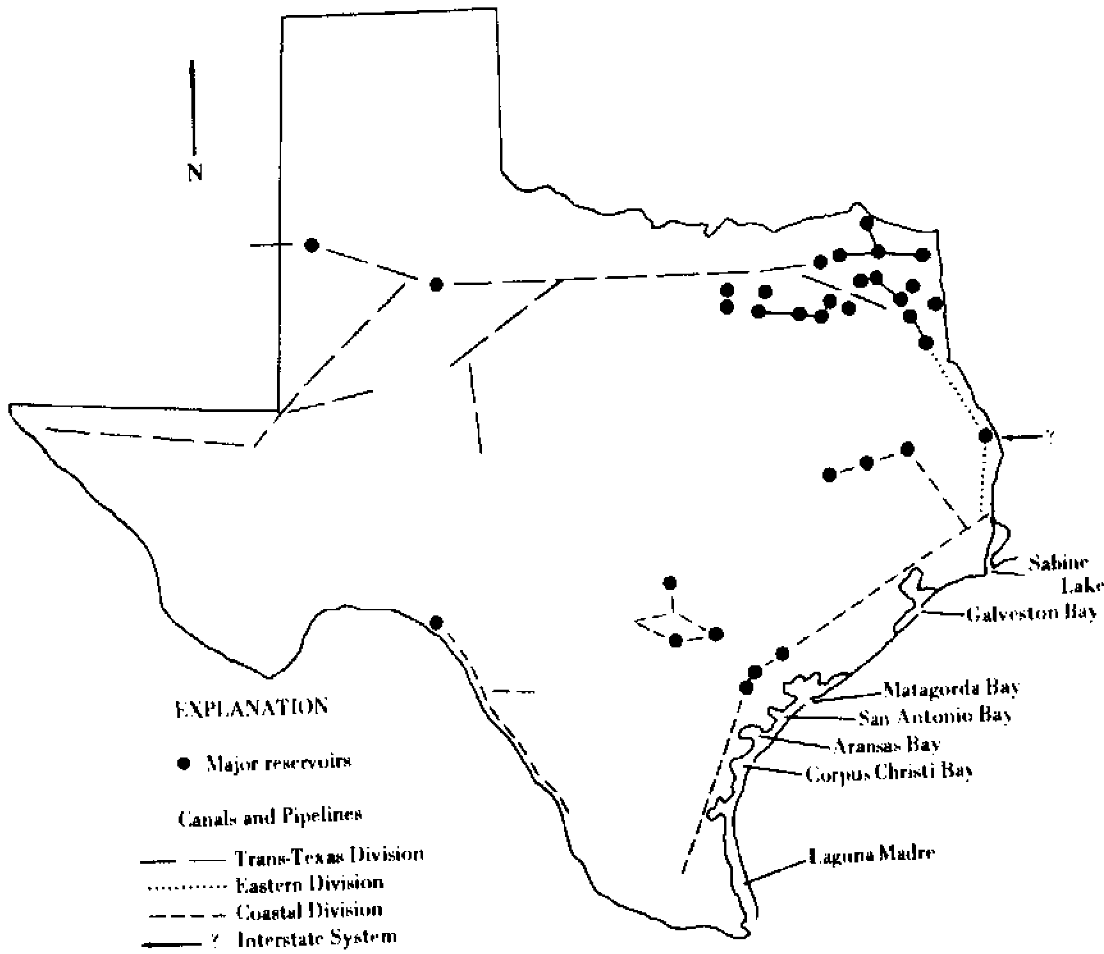

Figure 2. Schematic Diagram of the Texas Water Plan's Major Facilities and the Texas Estuaries.

would deliver water through the Trans-Texas Canal to north central Texas, the high plains, and eastern New Mexico and by pipeline from the high plains to west Texas.

Water to be transported through the Trans-Texas Canal includes:

Use	*Acre-Feet Per Year*
Municipal and Industrial	950,000
Irrigation	7,584,000
New Mexico	1,500,000
Operating Loss (Evaporation)	947,000
Total	10,981,000[1]

[1] About 8.4 million acre-feet of this total would be supplied from the Mississippi River.

The Trans-Texas Division is far removed from the coast and could not be expected to effect estuaries directly except that it would carry considerable volumes of water which otherwise would reach the estuaries.

The Eastern Division

The Eastern Division includes the conveyance facilities, regulating reservoirs and pumping facilities in eastern Texas to move imported water from the Mississippi River north to the Trans-Texas Division and south to the Coastal Division as required. Since final decision has not been reached as to where imported waters (if any) would reach Texas, the plan for the Eastern Division remains flexible enough to accommodate either southern, northern, or mid-state delivery.

The Coastal Division

The Coastal Division is comprised of the Coastal Canal with storage and regulating reservoirs, storage and conveyance facilities required to supply water to the city of Houston, and diversion, storage and conveyance facilities to supply irrigation waters to the southwest and Rio Grande Valley. The Coastal Division would provide water for municipal and industrial uses, irrigation, the estuaries, and wildlife refuges as follows:

Use	*Acre-Feet Per Year*
Irrigation	1,817,000
Municipal and Industrial	518,000
Bays and Estuaries	2,450,000
Wildlife Refuges	60,000
Operating Loss (Evaporation)	455,000
Total	5,300,000[1]

[1] Does not include water for Houston and San Antonio which can be provided from several sources.

About 4.1 million acre-feet of water for the Coastal Division would be supplied by the Mississippi River.

The Coastal Canal would parallel the coast from the Sabine River of eastern Texas to the lower Rio Grande Valley, a distance of about 400 miles. The alignment is similar to that proposed by the Bureau of Reclamation for the Texas Basins Project.

The Coastal Canal would divert surplus water from only three river basins along the Gulf Coast—the Sabine and Neches Rivers that flow into the Sabine Lake estuary, and the Guadalupe River that is a tributary to San Antonio Bay. Water would not be diverted by the Coastal Canal from the other major rivers which terminate in the estuaries. Instead, the water of these rivers, which include the Trinity, San Jacinto, Brazos, Colorado, Lavaco and Navidad, Mission, Aransas and Nueces, would be developed, diverted and used by local interests so that flows reaching the estuaries nonetheless would be reduced in quantity and quality.

The Coastal Division through the Coastal Canal would augment freshwater flows to Galveston, Matagorda, Aransas and Corpus Christi estuaries to partially replace local diversions and to San Antonio Bay to replace (in part) diverted project flows from the Guadalupe River.

The Interstate System

The Interstate System includes the facilities such as canals, regulating structures, siphons, and pumps to move 12-13 million acre-feet of water each year from the Mississippi River to Texas. Many routes are being considered but final selection must await a determination that surplus waters are indeed present in the Mississippi River for export. Studies now are under way which should settle this question. In any event, the route which is receiving the most attention is one which essentially would follow the Gulf Intracoastal Waterway and intersect the Mississippi River below New Orleans.

Stages of Construction

Prerequisite to construction of any conveyance unit would have to be the assurance that out of State water is available for Texas. This is absolutely essential to avoid expenditure of huge sums of money only to end up with a dry ditch.

After imported water supplies have been assured, the Texas Water Development Board has proposed that schedules for study, authorization, design, and construction of the Texas Water System and Interstate System proceed as follows:

1. Feasibility studies completed by the end of 1973
2. Authorization for construction by mid-1974
3. Funding for design in late 1974
4. Complete the design for the Coastal Division in mid-1976
5. Complete the design for the Trans-Texas Division in mid-1977
6. Complete the design for the Interstate System in mid-1980

Timing of these developments would be critical, particularly for the high plains where ground water supplies for irrigation will be considerably reduced by 1985.

Construction would start immediately after completion of design so the first delivery of water through the Coastal Canal to the Rio Grande Valley would occur in 1980; delivery of water from northeast Texas through the Trans-Texas Canal to the high plains would be achieved in 1985; and first delivery of Mississippi River water through the Coastal and Trans-Texas Canals would be expected in 1988.

Cost

The Texas Water Plan is the largest, most complex and costly water plan ever conceived. Estimated total cost, exclusive of local irrigation distribution systems, based on 1967 prices, is about $10 billion. Local irrigation distribution systems would cost about $250-$300 per acre. The State portion of the estimated $10 billion cost would be about $3 billion. At 3½ percent discount rate it would cost about $120 million in capital costs to supply 2.45 million acre-feet of replacement water to the Texas estuaries. This is about 1.2 percent of the total cost of the Texas Water Plan—a real bargain.

FISHERIES RESOURCES

A significant part of the United States commercial fishing industry is located in the Gulf of Mexico region. From 1950 to 1968 the relative contribution of Gulf landings to the total United States commercial fisheries harvest rose from 12 to 31 percent. The Gulf of Mexico in 1968 contributed 1.3 billion pounds of fish and shellfish, worth $125 million to the fisherman. Most of this harvest consisted of species dependent on estuaries.

The coastal area to be influenced by the Texas Water Plan (Louisiana and Texas) in 1968 contributed 22 percent of the total volume of 4.1 billion pounds of fish and shellfish caught by United States fishermen. This catch contributed 18 percent of the total income to our fishermen (Table 3).

Virtually the entire catch from Louisiana and Texas is comprised of species dependent on estuaries. Species contributing to this commercial harvest include the brown, white and pink shrimps, menhaden, spot, Atlantic croaker, striped mullet, black drum and red drum. All of these species spawn in the Gulf of Mexico, but their young move into the estuaries to complete their juvenile growth before returning to the ocean. Other species which contribute significantly to the commercial catch of Texas and Louisiana are the American oyster, a permanent resident of the estuaries, and the blue crab and spotted sea trout.

Both of these species normally spend most of their lives in estuaries, but occasionally may venture into the shallow, near-shore waters of the Gulf. Without the estuarine nursery habitat, or suitable estuarine conditions, it is doubtful if any of these species could survive in commercial quantities.

Table 3. Comparison of 1968 Commercial Fishery Catches from the Project Area (Louisiana and Texas) with Total Catches from the Gulf of Mexico and from the United States (In Millions)

Area of Capture	1968 Commercial Catch	
	Volume	Value to Fishermen
	Pounds	$
Alabama	32.3	9.8
Florida West Coast	103.8	22.1
Mississippi	242.4	8.7
Project Area Total	896.5	84.5
(Louisiana)	(747.5)	(40.6)
(Texas)	(149.0)	(44.2)
Total Gulf of Mexico	1,275.0	125.4
Total United States	4,116.1	471.5
Percent project area contributes to United States Total	22%	18%

Source: Bureau of Commercial Fisheries publication, "Fisheries of the United States–1968," C.F.S. No. 5000.

In addition to commercial fishing, most of these same species now support about 16 million man-days of sport fishing in Louisiana and Texas. If population projections are anywhere near correct, the coastal project area (Louisiana and Texas) will be called on to provide more than 35 million man-days of sport fishing annually by 2020.

Even though the project area estuaries and marshes contribute so much to the total United States commercial fish catch, their potential to contribute more is considerable. Many species are not now being harvested to capacity and others are not caught at all. As the human populations increase, there will be more and more demand for commercial fisheries products, as well as for more fish to support recreational fishing. It is entirely possible that the catch of estuarine-dependent species can be increased several-fold in Texas and Louisiana if the integrity of the estuaries and coastal marshes can be maintained.

PROJECT AREA ESTUARIES

The Gulf of Mexico is richly endowed with estuaries and coastal marshes. The most recent figures available indicate there are 12.7 million acres of estuaries and coastal marshes in the five States bordering the Gulf of Mexico. The ratio of tidal shoreline to marsh area of 0.54 is the greatest of any coastal region in the United States. Two-thirds of our coastal marshes and more than 1/3 of our estuarine water area is located adjacent to the Gulf of Mexico. It is this tremendous area of coastal marsh and shallow estuaries that makes the Gulf of Mexico so productive of fisheries resources.

The combined estuarine areas of Louisiana and Texas (the project area) include 4.8 million acres of estuaries and lagoons and 4.5 million acres of coastal marsh. This represents about 68 percent of the entire estuarine acreage of the Gulf of Mexico and almost 80 percent of its coastal marshes. Even more significant, the project area contains 24.0 percent of the total estuarine area and 55 percent of the coastal marshes of the entire contiguous United States. Stated another way, Louisiana and Texas contain almost one-third of the total estuarine-coastal marsh complex of the contiguous 48 States (Table 4).

The project area estuaries are unique also for another reason. They are extremely shallow, being only a few feet deep, have very small tides of only one or two feet and, for the most part, are relatively turbid naturally. This is because

Table 4. Comparison of Marsh and Estuarine Acreage in the Project Area (Louisiana and Texas) with that of the Gulf of Mexico and the Contiguous 48 States (Millions of Acres)

Habitat	Project Area[1]			Gulf of Mexico	United States
	Total	Louisiana	Texas		
Coastal Marshes	4.5	3.9	.6	5.7	8.2
Estuaries and Lagoons .	4.8	3.4	1.4	7.0	20.1
Total	9.3	7.3	2.0	12.7	28.3

[1]Does not include 350,000 acres of salt-flats in Texas.

Source: *United States and Gulf of Mexico* from the Federal Water Pollution Control Administration's report on, "The National Estuarine Pollution Study," of November 3, 1969.

Louisiana from the Louisiana Wildlife and Fisheries Commission's Gulf of Mexico Estuarine Inventory Federal Aid 88-309 study.

Texas from data developed by the United States Fish and Wildlife Service for the Texas Basin Project.

of the great volumes of tributary fresh water received which carry fine sediments from the uplands. Waters of the central and western Texas estuaries, however, are relatively clear because much less tributary runoff occurs.

Because the project area estuaries contain relatively small volumes of water in relation to their surface areas and because tidal exchange is small they are very susceptible to pollution and physical alterations caused by man, including modification or reduction of tributary fresh water.

The project area estuaries provide suitable habitat for most species that contribute to commercial and sport fisheries. Many of these species require somewhat different environmental conditions during various stages of their development. Typical estuaries in the project area possess a well-defined salinity gradient between headwater and tidal pass. They thus are characterized by a broad spectrum of conditions and habitats throughout which many species can be accommodated, many of them simultaneously.

The amount of fresh water discharging into or reaching the estuaries controls these conditions to a very large extent and literally can be considered the life blood of the system. Without sufficient fresh water, hypersaline conditions develop in regions of high evaporation, such as in southwest Texas. The estuary then becomes a hypersaline coastal lagoon. The Laguna Madre is such a system and Corpus Christi estuary frequently exhibits such hypersaline characteristics because its freshwater supplies are being reduced by upstream development.

Reduction of fresh water also has a profound effect on coastal marshes of the project area. Salinities in coastal Louisiana have been increasing during recent decades, causing a conversion of fresh and brackish marsh to salt marsh with an accompanying accelerated rate of marsh erosion. Louisiana now is loosing thousands of acres of marsh each year by erosion. This has been well documented by current studies of the Coastal Studies Institute of Louisiana State University whose preliminary figures indicate Louisiana now is loosing through erosion more than 10,000 acres of coastal marsh each year.

Tributary fresh water also is essential to assist the estuaries to dilute and flush pollution into the ocean. In addition, many species depend on lowered salinity to exclude predators. Perhaps most important is that tributary fresh water carries nutrients derived from land drainage to the estuaries. Nutrients from the land then mix with minerals from the sea, to create one of the most naturally productive environments in the world.

FRESH WATER AND THE ESTUARIES

The report on the Texas Water Plan attempts to describe how much fresh water each of the Texas estuaries will receive in the future. Totals of tabular data indicate that the estuaries would receive as much fresh water in 50 years as they do now. This, however, is misleading and not correct because:

1. The report does not consider the amount of tributary fresh water that would be developed and diverted by local interests in many of the major rivers.
2. The report considers only averaged flows, not the minimums or maximums.
3. The report includes return flows (sewage and industrial wastes), as part of the total fresh water supply.
4. Historic average volumes reaching Corpus Christi estuary as used in the report already have been much reduced. This may be a problem for other estuaries as well, because 13 years have elapsed since the 1941-1957 period of record used to establish historic base conditions.
5. Sabine Lake, the easternmost estuary which receives the largest volume of tributary fresh water, was not included in the report.

The plan properly includes direct rainfall on each estuary and coastal or local drainage as part of the total freshwater supply.

Such supplies, however, remain relatively fixed. The rainfall cannot be captured and local runoff cannot be developed economically. The citing of annual average rainfall and local runoff volumes, however, only complicates the problems associated with extremely dry years, when little or no fresh water is received from such sources.

A real problem, however, is evident when we consider the volumes of tributary fresh water received by each estuary as opposed to the flows expected in the future. Even with the 2.45 million acre-feet of fresh water which the Texas Water System would deliver, the total amounts reaching the estuaries would be much reduced (Table 5). The entire water requirement—water supply picture needs to be studied in considerably greater detail. Fortunately the Texas Water Development Board is doing just that.

Historically, the Texas estuaries receive on the average about 26.69 million acre-feet of tributary fresh water each year from major streams (Table 5). As little as 5.8 million acre-feet, however, has been recorded during an extremely dry year and as much as 52.2 million acre-feet during a very wet year. More than half of this supply discharges into the Sabine Lake estuary from the Sabine and Neches Rivers. Thus, on an average about 12.3 million acre-feet are available for the rest of the State's estuaries. During a dry year less than 2 million acre-feet would be available.

Under 2020 conditions, the Texas Water Development Board estimates that, on the average about 11.0 million acre-feet of fresh water would be available for the estuaries west of Sabine Lake each year. The volumes of water which would be developed and diverted by local interests, however, have not been deducted from this amount. The 11.0 million acre-feet figure does include direct rainfall on the estuaries and local runoff but does not include water to be supplied by the Texas Water System.

Table 5. Projected Changes in Estimated Average Annual Major Tributary Fresh Water Flow to the Texas Estuaries (Millions of Acre-Feet)

Estuaries	Historic Average (1941-57)	2020 with Texas Water System but not local Diversions[1]	2010 with Local Diversion only; does not include Texas Water System
Sabine Lake	14.36	8.99 (0)	10.95
Galveston Bay	9.07	6.60 (1.50)	5.14
East Matagorda Bay .	.20	.20 (0)	.20
Matagorda Bay	.68	.67 (.30)	.50
San Antonio Bay ...	1.55	.70 (.30)	1.08
Aransas Bay	.23	.47 (.15)	.15
Corpus Christi Bay ..	.60	.47 (.20)	.26
Total	26.69	18.10 (2.45)	18.28

Note: Figures do not include direct rainfall on estuaries, local runoff, or return flows.

[1] Includes water proposed for delivery by the Texas Water System (also shown in parenthesis).

Source: *Historic and 2010 with Local Diversion Only* from the Bureau of Reclamation and from the publication, "The Texas Basins Project," by Charles R. Chapman, in Special Publication No. 3, 1966, by the American Fisheries Society.

2020 with Texas Water System but not Local Diversions from the Texas Water Development Board report, "The Texas Water Plan," of November 1968.

Direct rainfall would average about 3.4 million acre-feet and local runoff an estimated 1.3 million acre-feet. Therefore about 6.4 million acre-feet of tributary runoff, exclusive of local diversions would be received. Tributary fresh water thus would be cut in half. The Texas Water System, however, would deliver 2.45 million acre-feet of water to these estuaries. Thus, almost 9.0 million acre-feet (exclusive of local diversion, direct rainfall, and local runoff) might be expected. These, however, are average flow figures. How much fresh water would be received in a dry year? Obviously much less. It appears that local diversion will present the most critical problem.

The Bureau of Reclamation during its study of the Texas Basin Project did develop an estimate of the volume of water which might be diverted by local interests. I would like to explore these estimates for a moment. Exclusive of Sabine Lake, local interests might develop and divert about 5 million acre-feet or about 40 percent of the stream flow on the average that now reaches the estuaries (Table 5). During a dry year only 500 thousand acre-feet would remain.

I do not know how much of this estimated local development has been included in the Texas Water Plan; therefore, it is impossible to quote a truly reliable future figure. Several very important conclusions, however, can be drawn. During extremely dry years, the only firm source of fresh water for the Texas estuaries would be from the Texas Water System. During dry years the Texas estuaries would receive as much sewage and industrial waste as they would fresh water. Even during years of normal runoff the total supply of tributary fresh water to the Texas estuaries would be much curtailed.

WHAT THE TEXAS WATER PLAN WOULD NOT DO

The Texas Water Plan provides water for municipal and industrial uses, irrigated agriculture, mining, navigation and the estuaries. The plan also incorporates flood control benefits, salinity control projects, and guarantees water for coastal wildlife refuges. The Texas Water Plan is described as a flexible guide for the development of water resources of the State. The stated goal is to provide in the most effective and economic manner the water supplies and other benefits necessary to meet the needs of Texas for all purposes throughout the State as the population grows and the economy expands. The Texas Water Plan, however, does not provide for the orderly development and management of all of the State's water resources. Most of the rivers which discharge into the estuaries would not be included in the Texas Water Plan, at least in their lower reaches. Instead, their water supplies would be developed piecemeal by local interests with little or no regard for estuarine requirements. The Texas Water Plan would replace in part such diverted supplies with water of different quality and claim a project benefit for doing so. Further, water for the estuaries to be delivered by the Texas Water System would come from the Mississippi River. If water from the Mississippi River cannot be obtained, then what?

The Texas Water Plan objective is to provide water for a growing populace and expanding economy; a populace and economy that are growing much faster than the national average. The plan, itself, by providing water that is not available now, will contribute and control to a large degree how long this period of accelerated growth will continue in Texas and where it will occur. This is an excellent example of a water development project that, for the most part, is not needed at this time, but is dependent on future growth that could not take place if the project were not built. To quote Dr. Daniel Willard of the University of Texas, "In short, this sort of thinking is a classic example of cause and effect reversal. We should be thinking more of increasing the quality of living rather than the quantity of living."

And after 2020 what? Water supplies will be totally committed and imported supplies wrung dry. Will Texas' booming economy and population growth then slow down and stabilize? The Texas Water Plan does not consider the inevitable that some day this will happen.

Though the Texas Water Plan would provide water for more than 30 million people, its price tag of $10 billion does not include the cost of providing recreation for these masses, particularly coastal recreation. Why not? The need for recreation is directly related to the increases in population which the plan would make possible. Can you imagine the impact of 7 million people in the Greater Houston area? There just will not be enough coastal recreation space available. Such urbanized centers need to be spread out, decentralized to smaller units, if there is to be a coastal environment left to support fish and wildlife and recreation needs.

The Texas Water Plan could, in part, plan for such a distribution--but it does not. The Plan would provide the necessary water for more than 30 million people and it does acknowledge the growing problem of providing water for the estuaries, but it does not plan for the environmental impact of 20 million more people in Texas. It does not consider the environmental impact on Galveston Bay of 7 million people in the greater Houston complex, or of more than 1 million people in Corpus Christi on Corpus Christi Bay, or of more than 1 million people in Port Arthur and Beaumont on Sabine Lake.

The Plan does acknowledge that 30.5 million people, with associated industrial complexes (which the water will provide for), will generate more than 6.0 million acre-feet of sewage and industrial waste, much of it to be discharged into the estuaries. The Plan does discuss the need to treat these pollutants but does not include a comprehensive program, or funds to do so.

The space requirement alone for the millions of people projected for the coastal areas would be a major disrupting factor on Sabine Lake, Galveston Bay, and Corpus Christi Bay. Add the tremendous amount of sewage and industrial wastes to be generated by these millions and the destruction of these estuaries is virtually guaranteed. The Texas Water Plan does not consider or provide for such a crisis.

What else does the Texas Water Plan not do? It does not consider the impact on the Louisiana estuaries of diverting Mississippi River waters to Texas. True, this problem is being studied by several agencies but this does not guarantee a solution. It is certain, however, that if the Louisiana marshes and estuaries are further deprived of fresh water marsh destruction will accelerate. As the marshes are destroyed the productiveness of the estuaries declines, which poses a direct threat to dependent fishery resources, both sport and commercial. Merely dumping millions of acre-feet of water into the estuaries of Louisiana and Texas might not work; the Plan does not provide for such an eventuality, or the alternative decisions that would be required.

Fortunately, the Texas Water Plan does not ignore the Texas estuaries. This is much to the credit of the people who planned it, and it must be considered a triumph of sorts. The Plan, however, does not go far enough. Piecemeal development by local interests of the water resources of many of the State's major rivers is now causing and will continue to cause severe degradation of the estuaries. Total planning and management of all of the State's water resources is essential if the estuaries are to survive. If the Texas estuaries continue to be altered, polluted, and deprived of tributary fresh water, the fishery resources they harbor will be destroyed and the recreation they provide will be lost. The Texas Water Development Board is now restudying the Plan to improve it. Hopefully, the revision will provide total planning to assure that the estuaries receive sufficient high quality water.

CONCLUSION

The Texas Water Plan acknowledges that many problems remain and must be solved. Particularly, the Plan recognizes the need to learn more about the estuaries and estuarine fresh water requirements.

I would like to quote from the Texas Water Plan Summary prepared by the Texas Water Development Board, viz:

> "The Board is aware of an impact from changes in volumes of water from streams entering the bays resulting from upstream reservoir development and water utilization, continually increasing return flows, and changing conditions of surrounding land development on water quality in the bays and estuaries along the Texas Gulf Coast.
>
> "The economic urgency for finding meaningful solution to these problems is demonstrated by the increasing value of commercial and sports fishing in the estuarial environment, now estimated at more than $150 million annually, more than 99 percent of which is derived from the catch of species dependent on the estuarine environment at some point in their life cycle. The related economic return to the State from Tourism attracted to the bay areas is estimated at $300 million annually. All of this can be lost to the State if some solution for preserving the ecology and aesthetic quality of the bays is not found."

I believe the Texas Water Development Board has stated the problem very well.

The State of Texas took a big step forward this past year by establishing by law an Interagency Natural Resources Council. The Council is charged with developing a Comprehensive Coastal Resources Plan to provide for the management and development of the human and natural resources of the urbanizing Texas Gulf Coast Region. The Governor's Office will provide program coordination to mesh the activities of eight State agencies dealing with estuarine activities into a single united effort through the Interagency Natural Resources Council.

Ultimately, that part of the Texas Water Plan which would effect the estuaries must be compatible with the Comprehensive Coastal Resources Plan. Hopefully, the effort Texas is making to save its estuaries and coastal resources will be successful.

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STRIPED BASS AND WATER DEVELOPMENT IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

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INTRODUCTION

Anadromous fisheries resources in California are affected directly by ecological changes in rivers and estuaries as a result of water development. The intent of this paper is to illustrate how water development affects fisheries resources in the Sacramento-San Joaquin estuary by describing the effect of water development on ecological requirements of striped bass. Programs to alleviate potential adverse effects are also discussed.

The discussion is limited to effects associated with water storage and distribution. Effects of pollution, dredging and filling are important but are excluded from the discussion.

Striped bass are strictly sport fish in California, now, and they support the most valuable fishery in the Sacramento-San Joaquin estuary. It has been predicted that the net economic value of the sport fishery in 1970 will be about 7.5 million dollars (Altouney et al., 1966).

Annual harvest rates during the past 10 years have varied from about 15 to 35 percent of the adult population (Chadwick, 1968 and unpublished data). This is well within safe limits, so the primary resource maintenance problem is environmental protection.

WATER DEVELOPMENT PROGRAMS

One major threat to suitable environmental conditions is water development. Most of California is semi-arid or arid, and annual rainfall is much greater in the north than in the south. As a result, virtually all agriculture depends on irrigation, and much water must be developed for municipal and industrial use, as well. Reservoirs throughout the State store water for all uses, and water is commonly transported hundreds of miles from its point of origin to the place where it is used. The vast water development projects constructed to supply water needs have often affected ecological conditions drastically.

Portions of the two largest projects, the Federal Central Valley Project and the State Water Project, are having a major impact on the Sacramento-San Joaquin estuary. Both projects transport water from northern California to the San Joaquin Valley, and the State project will also transport water to the Los Angeles-San Diego area (Fig. 1).

The present operation of both projects consists basically of releasing stored water down the Sacramento River, moving it by gravity flow across the Sacramento-San Joaquin Delta, and pumping it into canals at the southwest corner of the Delta. Because of this basic similarity, the effects of the two projects cannot be separated.

The projects affect ecological conditions in the estuary in two basic ways. One is by the transport of large amounts of water across the Delta. This causes higher than normal rates of flow in many Delta channels, causes water to move in a net upstream direction in some channels, and causes the water in the San Joaquin portion of the Delta to be largely Sacramento rather than San Joaquin water.

The second basic effect is to reduce and redistribute seasonally the water flows out of the Delta toward the Pacific Ocean. Reduced outflow increases both retention time in the system and intrusion of ocean salinity. Because of flow redistribution, late summer minimum flows will be about the same or slightly greater than historical flows. These minimum flows, however, will exist for longer and longer periods as exports increase. Hence, maximum salinity intrusion will be about the same, but the whole system will become more stable.

Both of these effects are most important in the eastern portion of the estuary, because tidal flows far exceed freshwater flows in the western estuary. This generalization may change 30 to 50 years from now, when water development programs reach the point where flows can be controlled year-round in dry years.

Past and predicted future changes in water flows indicate the degree of change which is occurring and the relative importance of upstream and export development programs. The historic median Delta outflow was about 29 million acre-feet annually. The present median outflow is about 15 million acre-feet, and this is expected to decrease to about 5.5 million acre-feet by 1990 (FWPCA, 1967). Current exports are about 3.7 million acre-feet annually, and they are expected to increase to about 10 million acre-feet by 1990 (Kaiser Engineers, 1969). Thus, most past development is due to upstream use and diversion and to

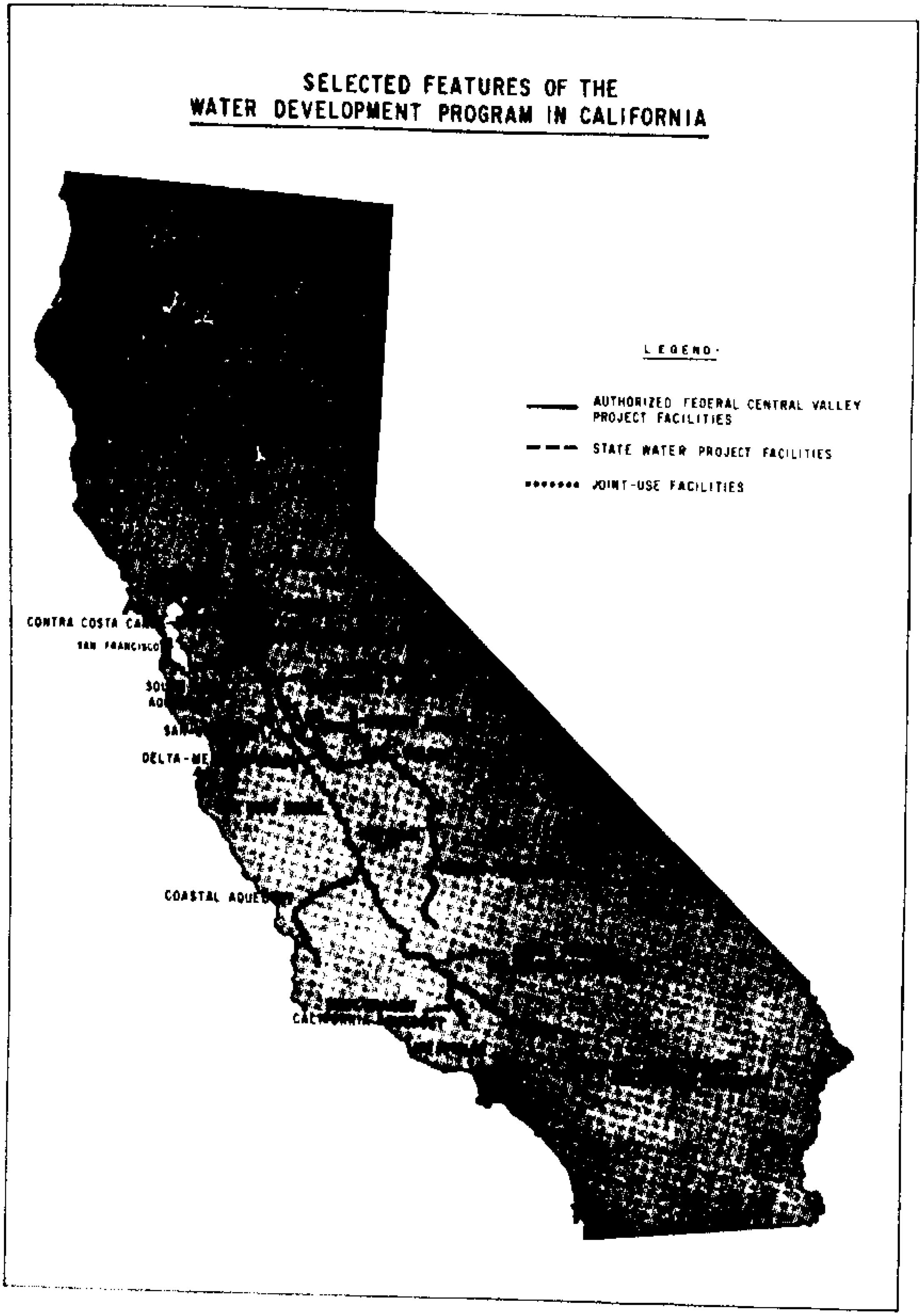

Figure 1. Map of the Sacramento San Joaquin Delta. Clifton Court Forebay, the pumping plants and export canals near Tracy are in operation. The Peripheral Canal is a schematic representation of this proposed project.

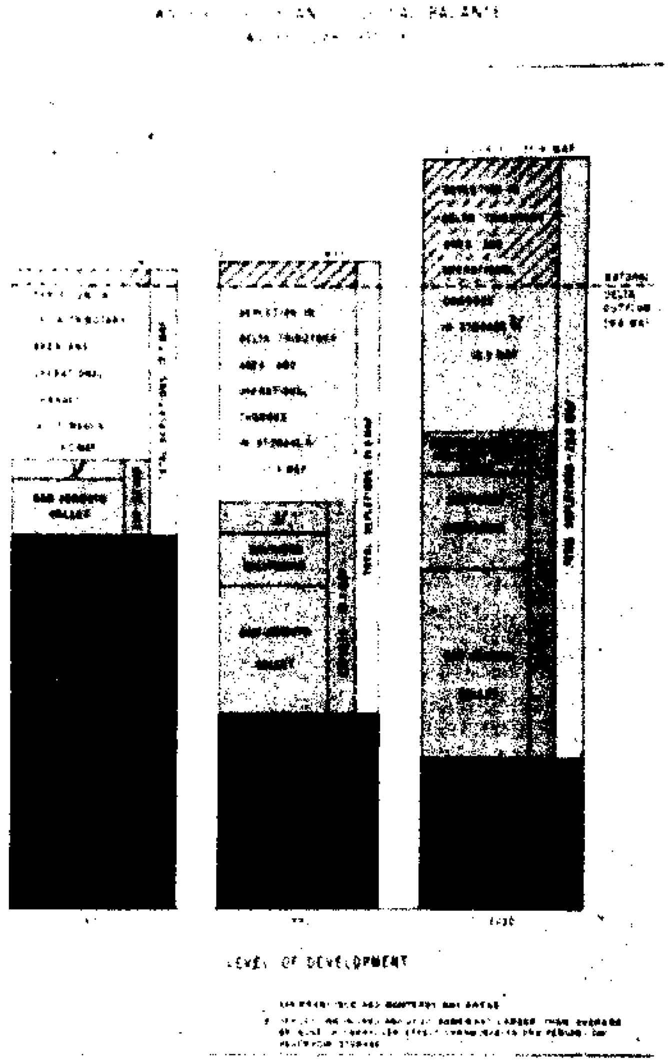

Figure 2

use in the Delta, while most future development will be exports from the Delta (Fig. 2).

BILOGICAL EFFECTS

Cross Delta Transport Problems

Striped bass eggs and larvae are pelagic. Millions of them are carried to the export pumps by the water flowing across the Delta and are pumped into the canals (Fig. 3). With the present plan of operation and increasing exports, over 50 percent of the eggs and larvae could be lost in this way (Delta Fish and Wildlife Protection Study, 1964).

Figure 3

The intake canals to the pumps have louver screens which are reasonably effective in removing fish large enough to swim well. However, about 10 to 50 percent of the bass 1/2 to 1-1/2 inches long are still lost. To give an indication of the magnitude of this problem, an estimated 41 million bass, mostly less than 2 inches long, were saved at the Bureau of Reclamation screens in 1966. Losses in other years have been smaller.

A second problem area associated with cross Delta transport is a reduction in zooplankton and benthos populations in Delta channels. These reductions presumably result from dispersal of zooplankton and unfavorable bottom conditions caused by the high net flows.

A final area of concern is related to the downstream migration of adults after spawning. The export canals are far from the major migration pathways. Small numbers of adult bass now find their way to the trash racks across the canal intakes and fight the current until they die of exhaustion. As the flows toward the pumps increase, we are concerned that this loss may become serious. The extent of this loss will depend on the importance of the direction of water flow in guiding migrations. This is not known.

Reduced Flow

The location of striped bass spawning in the San Joaquin River is restricted to a small section, apparently, primarily by salinity conditions. Bass seldom spawn farther downstream than where the salinity is about 600 ppm TDS. Above this, salinities fall to about 150 to 200 ppm TDS because of Sacramento River water moving across the Delta. Upstream, salinity increases again in dry years, because of low quality water coming down the San Joaquin River. Bass generally refuse to continue moving upstream beyond the point where salinity reaches about 350 ppm TDS (Radtke and Turner, 1967). Laboratory studies indicate no adverse effects of salinity on egg survival up to about 1,000 ppm TDS (Turner and Farley, Ms), so this is apparently a behavioral characteristic. Probably, a larger and larger percentage of the bass population has spawned in the Sacramento River as San Joaquin River water quality has deteriorated. The spawning area would presumably be reduced further by continued reductions in flow.

A second problem area related to flows through the Delta is that from 1959 through 1968 the number of young bass surviving in midsummer has been directly correlated with water flows (Turner and Chadwick, Ms). The correlation coefficient is 0.95 for the relationship between the number of bass surviving when their mean length is 1.5 inches and the mean June-July outflow from the Delta. While this high correlation coefficient obviously indicates that some parameter related to flow is controlling survival, we cannot identify this parameter. The relationship is so striking though that it has probably created more concern than any other factor. Hence, I will review some of the possible mechanisms.

This relationship may reflect losses in water diversions from the Delta, because a higher percentage of water is diverted when flows are low. The correlation coefficient for the relationship between the percentage of inflowing water diverted and bass survival is about the same as the outflow-survival correlation. However, fish distribution patterns we have observed early in some seasons indicate that this is probably not the primary mechanism.

The other potential mechanisms which have been identified all involve direct effects of flows on the Delta environment. The most obvious potential mechanism of this type is the effect of density on survival. In low flow years, young bass occur farther upstream than they do in high flow years (Chadwick, 1964). Because water volume decreases rapidly as one proceeds upstream, density-dependent mortality could cause lower survival. However, density in the central portion of the bass' range is greatest when flows are high, indicating that this is not an important factor.

A second potential mechanism is food production. Recent information on zooplankton standing crops in the Sacramento-San Joaquin estuary indicates that they are negatively related to water flows. While this negative relationship may reflect the effects of grazing by young bass rather than differences in production, relationships between zooplankton abundance and net flows and nutrients within the Delta (Turner, 1966) make this improbable. Hence, zooplankton production is unlikely to explain bass survival.

A more probable food supply relationship concerns the opossum shrimp, *Neomysis awatschensis.* The evidence indicating this is that *Neomysis* distribution largely coincides with that of young bass, and the stomachs of larval bass contain more shrimp in high flow years than in low flow years (Stevens, unpublished data).

Another factor which may be involved in the relationship is that bass spawn later when water flows are high than they do when flows are low. This appears to be quite significant because in all years when we have measured survival of larval bass during the spring, survival has been poor until late spring (Stevens, unpublished data). This could be another indication that food is important since invertebrate food supplies generally increase during the spring.

At any rate, the combined effects of spawning time and *Neomysis* abundance appear to be the most promising explanations at the moment for the flow-survival relationship.

An important consideration regarding the potential importance of the relationship controlling the survival of young bass is that the recruitment of adults to the population may not be directly related to the early survival of young. While evidence relative to this is very inadequate, the available evidence suggests that recruitment of year classes from the early 1960's was in fact not related to early survival.

A final problem related to reduced flows is that they may cause reduced turbidity in the future on occasions when minimum flows occur for a long time (Krone, 1966). This is of concern for several reasons. First, light penetration into the water is the primary factor limiting algal growth now, and nutrient concentrations are relatively high, so a potential exists for excessive algae blooms. This could, of course, lead to oxygen depletion. In addition, turbidity probably provides the primary shelter for young fish now, and light limits the distribution of *Neomysis,* the primary food of young bass and many other fishes, so that reduced turbidity may decrease young fish survival.

THE PROPOSED SOLUTION

A possible solution would be to eliminate water exports, and thereby provide sufficient outflow. Considering the 18-year history of water exports, the degree of present construction programs and contract commitments, and water needs, I believe this solution is politically impossible.

If export is to continue, an element of an acceptable solution must be the elimination of cross Delta flows, since many detrimental effects are associated with them. This could be accomplished either by additional levee construction to isolate a pathway of natural Delta channels from the remaining channels or by extending the export canals around the Delta, so that the point of diversion is on the Sacramento River above the Delta.

The latter approach is preferable, from a biological standpoint, because it avoids eliminating a significant portion of the present Delta, and because it provides an opportunity to control flows more efficiently. This premise has been accepted by biologists and engineers and has been termed the Peripheral Canal concept (Fig. 4).

The canal would not solve all problems. Young fish migrating down the Sacramento River must be protected from diversion, and enough water must be released to solve the problems associated with water flows. No solution has been assured yet for these requirements, but solutions compatible with the Peripheral Canal concept are available. Formulation of administrative procedures which will establish the basis for the solution of these remaining problems is a top priority task of the agencies involved. Current hearings before the State Water Resources Control Board, and the Federal authorizing legislation, should provide the necessary administrative framework.

The State has authority to construct the canal, but Congress has not authorized Federal participation. Progress toward congressional authorization has been hindered by strong opposition to canal construction by various local groups. Hence, it is entirely possible that the canal may never be built. In this event, a biologically unsatisfactory solution to water supply problems would probably be implemented by default.

The present status of the program has several aspects of general interest. From the biological standpoint, a critical review of the problems identified indicates that none necessarily causes a reduction in fishable populations. For example, no one knows how important the loss of some spawning area or the diversion of many eggs and larvae is to striped bass. In a fish as prolific as striped bass, substantial losses of this type might well not affect adult abundance.

Such uncertainties make both the detriments of the present situation and the benefits of the Peripheral Canal subject to question from the biological standpoint. Yet, considering the number of potentially adverse conditions, the likelihood of detriment is probably great. Certainly, past management actions have often been based on less complete understanding, and I believe that most conservation agencies would not hesitate to use such evidence to justify management actions.

Nevertheless, these uncertainties contribute to the controversies over justification for the canal and implementation of management actions to solve problems the canal does not solve automatically. At present, most groups accept the biological justification for the canal but disagree over those pertaining to canal operations or, in other words, to those concerning amounts of water allowed to flow through the Detla.

The California Department of Fish and Game wants the water agencies to meet a set of tentative flow conditions whenever this can be done at little cost. More importantly, however, we believe that continuing studies are imperative, with the intention that firm criteria be established as soon as need is clearly demonstrated. I believe the foregoing is clearly the most reasonable course of

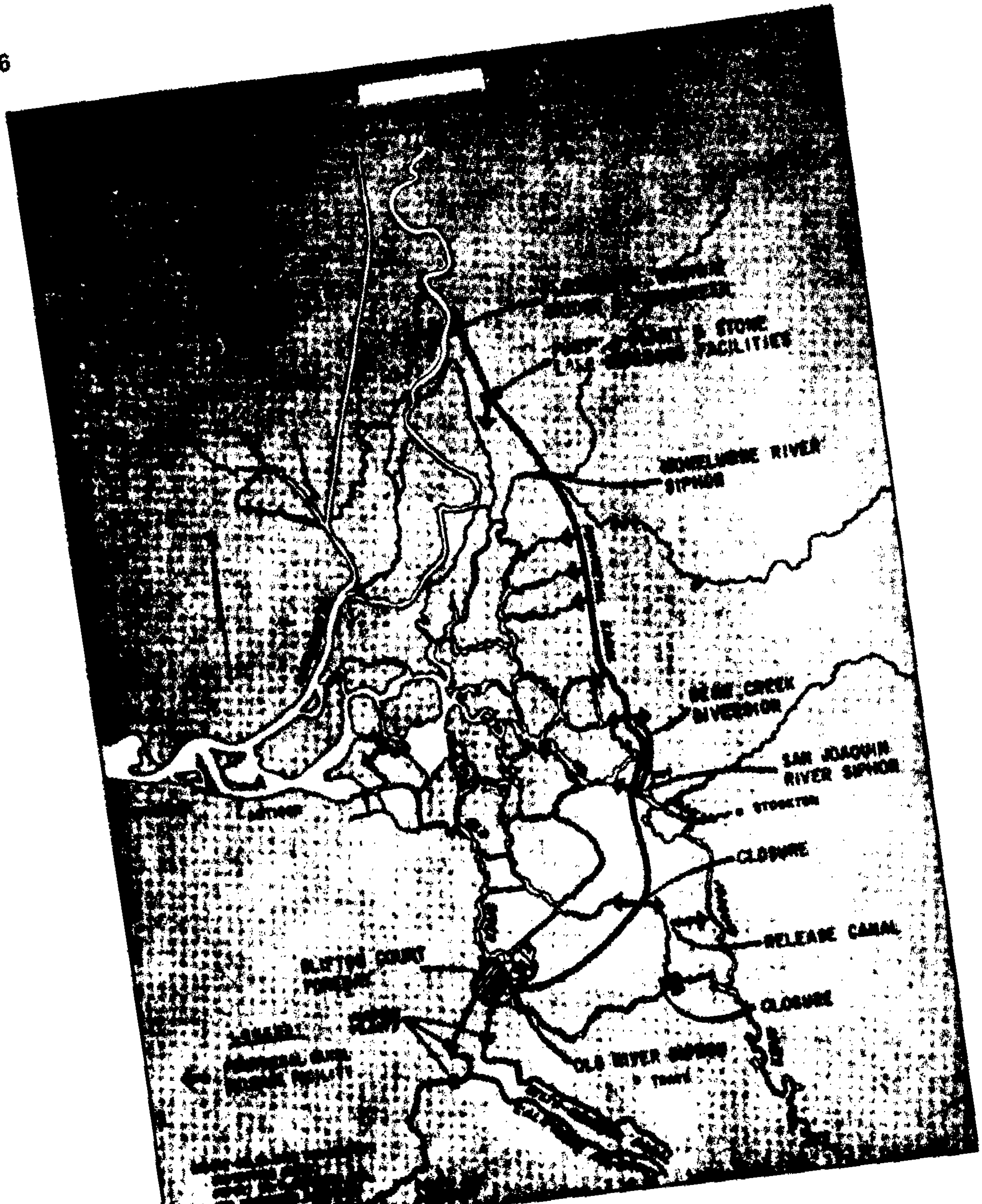

Figure 4

action, provided that an administrative framework can be established to assure a high probability of taking adequate corrective action. Important considerations in this judgment are: a) no drastic changes in flows will occur in the immediate future, b) irreversible biological consequences appear extremely unlikely, c) most management options prior to canal construction are unlikely to be very effective, and d) the degree of uncertainty in the biological relationships.

As might be anticipated, this position has placed us squarely in the middle. Many in the development agencies consider our position to be reasonable, but the tentative requirements we have identified have caused considerable concern about their potential impact on water supply commitments. Also, the developers are concerned about the use and misuse of information we have developed by opponents to development.

Much opposition to the program as a whole and also to the Peripheral Canal has been based on ecological considerations supported by our findings. Many conservationists are members of the opposition, because they question whether the canal will be operated in a manner compatible with biological requirements. Some past actions by water development agencies and the lack of a clear administrative framework for solving problems encourage this attitude. Many of these conservationists consider our position to be either naive or subservient to the water developers.

A real dilemma is that constructive opposition will help assure adequate considerations for biological needs and may, in fact, be necessary to get such considerations. Yet, such opposition could easily get out of control and be used by others with different political motivations to prevent canal construction. This would result in continued degradation of the system by increased exports.

The Department of Fish and Game's present position has obvious inherent dangers. Essentially, the position is based on the premises that mutually acceptable solutions are available and that all parties concerned will act in good faith in trying to implement such solutions. Its success depends on biologists and engineers recognizing and solving problems facing both groups. We are encouraged in this approach by generally being able to communicate effectively with many engineers in our Water Resources Department while seeking mutually acceptable solutions. Important failures still occur in our dealings with Water Resources and other agencies; however, I submit that this is the most responsible and rational course for reaching acceptable solutions to resource problems.

Hopefully, the present concern over environmental deterioration will create a climate more conducive to this approach. One ingredient essential to success will probably always be an informed and interested public reviewing management proposals and decisions. This, of course, is an important role for the public groups participating in this conference.

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CLOSING REMARKS BY SESSION CHAIRMAN

Richard A. Geyer

Dr. Cronin's definition of an estuary is much more concise than the one I suggested at the outset of this session. The fact that almost a thousand estuaries have been identified along the U.S. Coast is indicative of the myriad of natural complexities associated with the origin and characteristics of these coastal phenomena. Therefore, it is not surprising to find them affected to varying degrees by the activities of man, as well as their affecting him over a wide spectrum of scientific, technologic, industrial, political, legal, economic, and sociological activities. He has also emphasized the tenuous state of the natural equilibrium in which the ecosystem exists in estuaries and how deleterious many of the effects of man's activities can be in maintaining this precarious balance. The eight basic characteristics of the ecosystem of estuaries which he listed represent the major common-denominator factors that must be considered in studying specific estuaries wherever they might exist.

Mr. Chapman's paper dramatically highlights the critical problems occurring from the intense competition for natural resources. This is brought about by the ever-increasing economic and sociologic demands caused by a burgeoning population. Not only would the important Texas Water Plan have a direct, perhaps irreversible, effect on some portions of the estuaries; the indirect effects on those areas must also be considered. These result from what might be called the by-products of the expected major increase in population in Texas, in the form of industrial and human waste disposal and the simultaneous need for more coastal recreational and living areas. Here again, wise objective and cooperative research and planning on the part of scientific and regulatory agencies at all government levels, including Federal, State and municipal, discussed in some detail in my opening remarks, are imperative if viable solutions are to be achieved.

The needs and demands of all the people, those living inland as well as those living on the coast and in interstate as well as intrastate areas, must all be considered in reaching decisions resulting in an equitable solution for all segments of our society.

It is encouraging from Mr. Chadwick's talk, in some ways, to see that Texas is not the only State requiring extensive long-range water development plans to be able to cope effectively with its future population needs. Also, Mr. Chadwick was able to demonstrate specifically and quantitatively some of the actual hydrologic, biologic, and geologic effects resulting from the proposed changes. The data presented, for example, on the effects of increasing salinity on the migration patterns and mortality of striped bass are particularly significant. They represent the type of specific scientific information required on which objective regulatory measures can be based and adopted. They demonstrate the need for surveys of this type as well as calibration, inventory and monitoring varieties; only then can sound Coastal Zone Management decisions and predictions be made—on the basis of facts rather than intentions, subjective analysis or, worst of all, emotional reactions only. Unfortunately, the latter criterion is used much too often in the promulgation of decisions pertaining to conservation practices and subsequent regulatory action.

Communication, coordination, cooperation—these three C's constitute the cornerstone on which certain segments of our society such as science, industry, government, and citizens must build to attain a viable solution to the multi-user problems involved in equitable and effective Coastal Zone Management. We stand on the threshold of decision. Procrastination is no longer either profitable or possible. These problems must be solved soon or Society as we know it today will not even continue to exist, much less flourish.

III. AFTERNOON SESSION

OPENING REMARKS BY SESSION CHAIRMAN

James E. Sykes

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If we think back over a 20-year period, we can probably recall several biological research programs centered in estuaries of the United States coasts two decades ago. Those among us who do remember these early efforts are aware that they were primarily species-oriented and provided little accompanying information useful in protecting or managing the environment. At that time there seemed to be no great fear that the environment was deteriorating.

As the 1950's wore on, there were pleas from professionals that something be done to protect the Nation's estuaries from further industrialization and pollution—but, to the best of my memory, very little was done. The biologist's voice was too weak to be heard; funds were not appropriated; and research designed to show how the estuary could best serve humanity did not come about.

More can be said about coastal environmental research of the 60's than about that of the 50's. Those later years were characterized by some progress in research, some progress in management, considerable competition between agencies in quest of funds—and very little funding. Nevertheless, courses seem to have been charted that will have an impact on coastal resources in the future.

By way of progress in the 60's, there occurred the first Congressional appropriation to a Federal agency that bore the label, Estuarine Research Funds. The appropriation occurred after some 6 to 8 years of effort spent in seeking it. I recall this well, because our BCF (Bureau of Commercial Fisheries) Laboratory in Florida was given access to one-half of those funds and has been supported by them ever since. They were among the first funds to produce results that went to court. The findings were used frequently in public hearings and legislative hearings concerning estuarine modification. Moreover, they were responsible for winning several cases for conservation. The most prominent court action was the Zabel-Russell case in Florida in which the Corps of Engineers, for the first time, denied a dredge-fill permit on the basis of fish and wildlife values.[1] These values were documented and supplied by research biologists.

Then, some progress in other funding has been noted, for example, in Federal grant-in-aid programs or P.L. 88-309 matching funds for fisheries. These are putting $1.8 million annually into research and development in south Atlantic and Gulf estuaries. A significant outgrowth of that funding has been the Gulf of Mexico Cooperative Estuarine Inventory. This was sponsored by the Gulf States Marine Fisheries Commission, operated cooperatively by the Gulf States and the Bureau of Commercial Fisheries, and funded under P.L. 88-309. It began producing a multistate base line of estuarine information—descriptive, sedimentological, hydrological, and biological. Atlases resulting from this study are now in preparation for each State involved.

Although it is possible to identify some funds appropriated for research and management in the 60's, it was pitifully small progress in relation to the needs. Perhaps there were several reasons: space programs, the war, inappropriate political timing, etc. It would be unfair, however, if government agencies did not accept some of the blame, themselves. Research and conservation agencies have not planned together except in a few instances. Many programs have been initiated by separate agencies without regard to plans or existing activities of others. Scientists, teachers, and administrators have shifted their allegiance, alternately, from oceanography to coastal ecology, depending upon the direction of political winds. Now, most attention has been redirected to the coast where the action seems to be.

It appears that a great amount of emphasis will be placed upon pollution problems in the 70's and it is indicated, at this early point in the decade, that most funds for coastal research and management may be stimulated through concern over pollution. I cannot much quarrel with that approach because pollution is one of the serious threats to the coastal environment. I am inclined to caution, however: (1) that there are other serious threats to the environment; (2) that through genuine cooperation and coordination, such as I have observed between agencies working on the Gulf of Mexico Estuarine Inventory, I am positive that an inter-agency approach to mutual problems draws more support, and results in a finer product, than a single-agency approach; and (3) if we are to preserve a major portion of the coast, our investigations must be largely mission-oriented.

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[1] *Editor's Note*: This significant case was carried in subsequent actions to the U.S. Court of Appeals, where the principle involved and related action in denial of permit was upheld.

I am also inclined to voice an impression that pollution problems, although fearsome in our environment, should be thought of and worked with in the proper perspective. Some of us devote most of our time to research and management of natural products of the coastal zone–fish: those types found in food chains, those offering protein for the human diet, and those providing recreation. In the 70's, it would be advantageous to plan together in accordance with an outline of agency responsibility–considering that fishery organizations should conduct studies on the effects of pollution on fish, shellfish, and their food organisms; considering that pollution agencies should conduct studies on the effect of pollution on human health and on esthetic qualities of the environment.

The speakers in this afternoon's session are in a position to provide us with considerable insight into the biological significance of estuaries and some of the serious problems that we face in maintaining their productivity. These three gentlemen know more about estuaries than most; they share a combined wealth of experience in research, research administration, and teaching. If we can heed the type of guidance that these three can offer, we shall be able to manage most estuarine problems that confront us in the foreseeable future.

THE BIOLOGICAL EFFECTS OF ESTUARIES ON SHELLFISH OF THE MIDDLE ATLANTIC

David H. Wallace

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A confrontation is taking place in the waters of the Middle Atlantic area. This confrontation is the impact of man's activities and actions on the estuarine waters. Some 17 million people live in and around New York City, adjacent to the shores of bays and rivers. The interface between man and the marine waters is at the shoreline. The coastal environment has been losing as man's uses of the waters have increased. An informed and aroused public wants an all-out effort toward pollution abatement and control. However, the tasks of meeting life needs and, at the same time, preserving the marine waters so that they can remain productive for food and recreation are appallingly complex. For example, over 4 million cubic yards of sewage sludge and other solid wastes are discharged annually in the New York Bight. Effluents from sewage plants amount to over 2 billion gallons of primary and secondary wastes charged with nitrates, phosphates, and fecal type bacteria. Control of these conditions is not in sight without massive injections of money and man's energy. And yet we must solve these problems quickly, if our marine waters are to remain suitable for use by man.

New York has taken some major steps to meet this challenge. A bond issue of $1.7 billion was sponsored by the Governor and overwhelmingly approved by the voters in 1965 as the foundation of a Pure Waters Program. Subsequent large appropriations have been passed to accelerate pollution abatement, but it is doubtful that even these amounts are sufficient to do the job. In some ways, New York has become a testing ground. The lessons learned here may be helpful in other areas where current conditions are not so acute.

Pollution from sewage and chemicals and physical alterations of our marine environment are, in my opinion, the greatest threats to our coastal waters. For many years, the receptacle for wastes was the nearest stream or lake. As man observed the disastrous effects of these actions, he turned his eyes to the estuaries and coastal waters. The capacity of these waters to absorb wastes appeared unlimited. We know now that this conclusion was erroneous. Drastic steps are necessary to correct these errors.

POLLUTION AND SHELLFISH

The shellfish industry was one of the first marine industries to feel the pressure from pollution. The natural habitat of oysters is in estuarine waters where the salinity ranges from 7 to 30 parts of salt per 1000 parts of water. These conditions are found in the lower estuaries and our cities have developed in precisely these areas. Before the turn of the century, one of the centers of the oyster industry was in Raritan Bay, adjacent to New York City. As the population grew and the waters became polluted, the oyster industry was forced to migrate easterly on Long Island. This shift of oyster cultivation away from populated centers has been repeated in Connecticut, Rhode Island, Massachusetts and New Jersey.

It is necessary to know something of the life history of the oyster to understand the cause and effect relationship between pollution and shellfish. Oysters reach sexual maturity in the Middle Atlantic area in most cases in the second or third year of their life. Oysters spawn when the temperature of the water reaches about 70°F in the summer. The eggs are shed into the water and fertilization takes place there. The fertilized egg develops into a free-swimming larval stage. After two to three weeks, the tiny larval form must find a solid object for attachment. Otherwise it sinks to the bottom and dies. After attachment, the oyster is sedentary unless moved by storms or by man. Since the waters in the Middle Atlantic are relatively cold in winter, the period of growth is only 8 to 9 months of the year. Some 4-5 years of growth are required for the oyster to reach a marketable size. On the other hand, in Gulf waters, a comparable size may be reached in 18 months.

Almost all of the oyster production in the Middle Atlantic results from private cultivations on lands leased to individuals by the State (Fig. 1). These practices have enabled the farmers to develop a high degree of skill in their operations. Unfortunately, the shellfish farmers have no control over pollutants which are placed in the water. Oyster larvae are sensitive to pollutants. Successful reproduction stops in polluted waters. Furthermore, since shellfish

Figure 1

feed on the microscopic materials in the water, they ingest the bacterial contaminants in waters heavily laden with fecal bacteria. At this point, such shellfish become unsuitable for raw consumption.

For the past 15 years, the oyster industry in the Middle Atlantic has been at a low level of production (Table 1). However, in New York, four commercial hatcheries are now growing seed (Fig. 2). Oysters already planted should boost production substantially in the next several years.

Table 1. Production of Oysters in the Middle Atlantic States From 1960-69 (in Thousands of Pounds)

Year	New York	New Jersey	Delaware	Total
1960	810	167	177	1,154
1961	788	1,100	33	1,921
1962	728	1,554	80	2,362
1963	394	516	41	951
1964	213	1,098	45	1,356
1965	200	523	34	757
1966	177	695	45	917
1967	101	994	61	1,056
1968	175	1,286	43	1,504
1969	213	1,015	51	1,279

Figure 2

Hard clams are far more adjustable to environmental deterioration. They also live in the lower estuaries. Strangely enough, the larval stages have proven to be more hardy than the young oysters. In Raritan Bay, which is heavily contaminated, hard clams still spawn and reproduce successfully. Oysters disappeared from this area many years ago. Inventories indicate a standing hard clam population there of several million bushels. But this clam crop is a hazard rather than an asset since these shellfish are unsafe to be eaten raw. Intensive policing is necessary to prevent these shellfish from being placed on the market. Similar conditions exist in various locations in the Middle Atlantic States. Hard clam production (Fig. 3) has risen greatly in New York over the past ten years (Table 2). This increase has resulted from a series of excellent sets in several bays along the south shore of Long Island.

The third shellfish species which has been of importance is the soft clam. Production of this species in both New York and New Jersey has been at a low level. The main center of soft clam production has shifted from the New

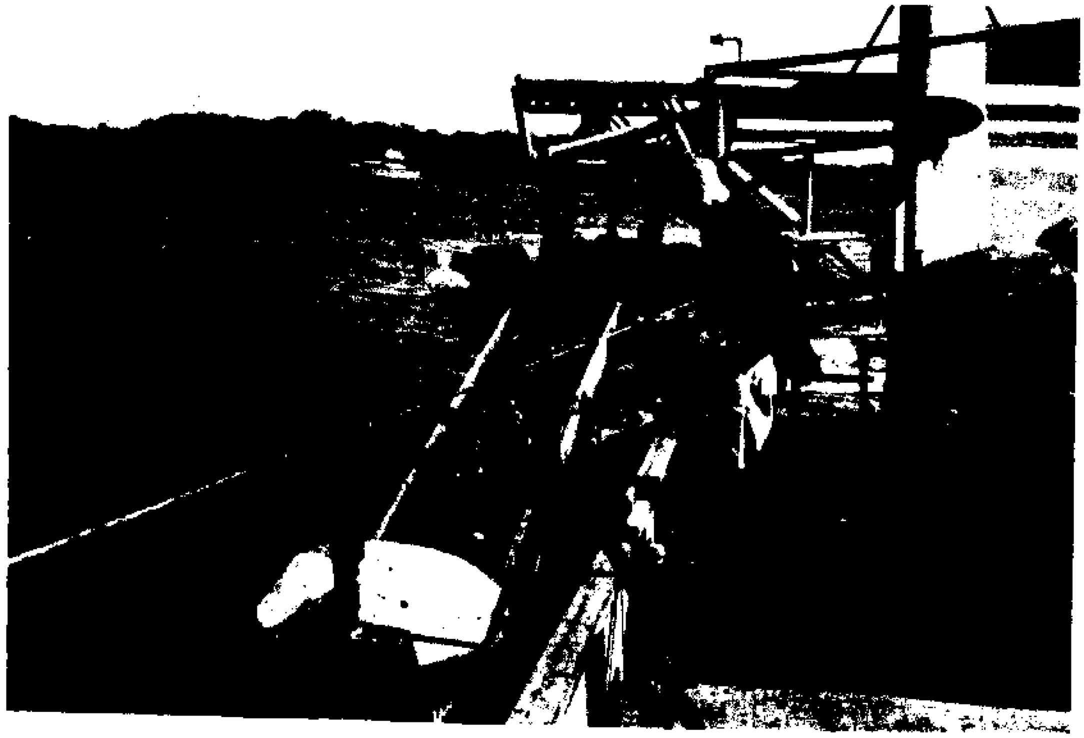

Figure 3

England and Middle Atlantic areas to the Chesapeake. Again, the probable causes of this decline have been pollution and physical changes in our estuaries.

IMPORTANCE OF WETLANDS

In the Middle Atlantic area, as elsewhere, estuaries are used for many purposes other than shellfisheries. They serve as highways for commerce,

Table 2. Production of Hard Clams in the Middle Atlantic States From 1960-69 (in Thousands of Pounds)

Year	New York	New Jersey	Delaware	Total
1960	3,888	2,552	484	6,924
1961	4,291	1,687	582	6,560
1962	4,836	1,340	378	6,554
1963	5,311	1,584	262	7,157
1964	5,402	1,894	418	7,714
1965	5,948	1,873	363	8,184
1966	6,581	2,675	264	9,520
1967	7,066	2,846	294	10,206
1968	6,986	2,525	239	9,750
1969	7,516	2,189	136	9,841

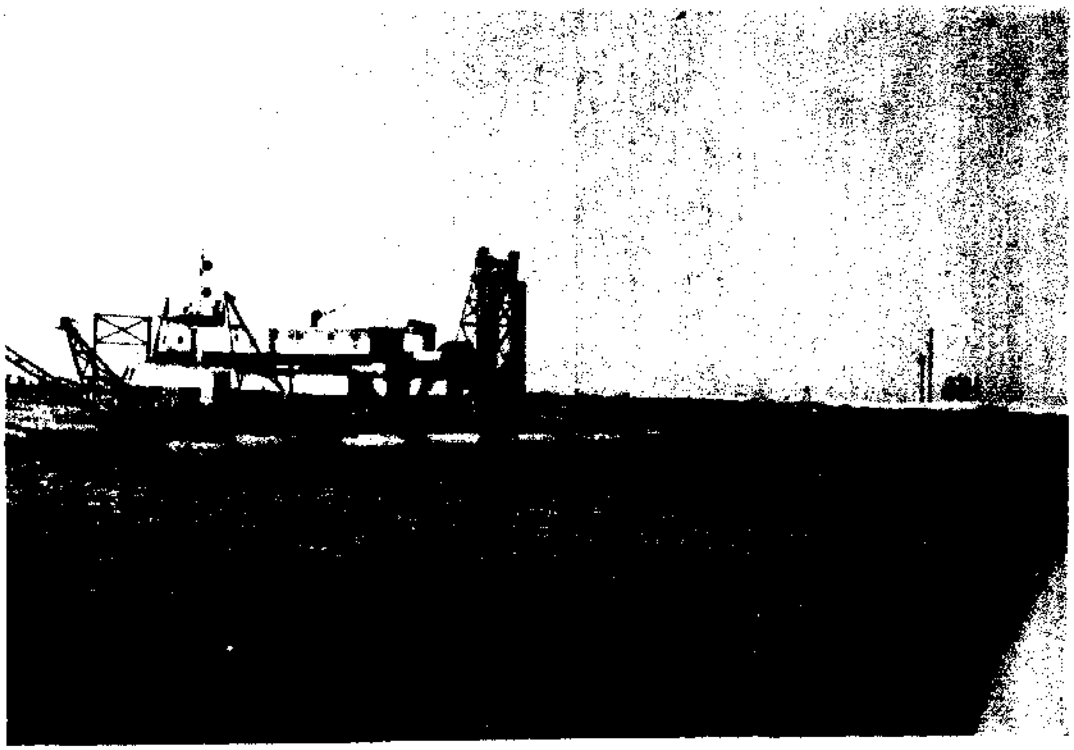

Figure 4

recreational boating and swimming, and as sources of sand and gravel for many purposes. Channels must be dredged for shipping (Fig. 4). As people have tried to move close to the estuaries to live, wetlands have been filled with sand pumped from the bays. Houses are often built on the filled wetlands, using septic systems for sewage disposal. These kinds of developments damage the estuaries in at least three ways. First, they destroy the natural leeching processes which add nutrients to the marine habitat. Wetlands are the food factories for our estuaries. As the tides wash over them, the nutrients are released gradually from these marshes to serve as the base for the food cycle in the water. As the wetlands are filled and bulkheaded, these sources of nutrients are eliminated and the productivity of the water is reduced. Secondly, the wetlands are usually filled with sand and gravel from the bays and estuaries. In this sand mining, the substrate necessary for the growth of shellfish is removed and the potential production is reduced accordingly. Thirdly, the leeching of contaminants from the septic systems back into the estuaries raises the level of pollution and further limits shellfish production.

Many scientists believe that the salt marshes (Fig. 5) in our coastal bays and tributaries are of critical importance to the ecology of these waters. They believe that these marshes must be preserved to maintain the basic productivity of these estuaries. Losses of wetlands in the last 15 years have taken place most rapidly in the urban and suburban areas adjacent to New York (Fig. 6). Since 1954, New

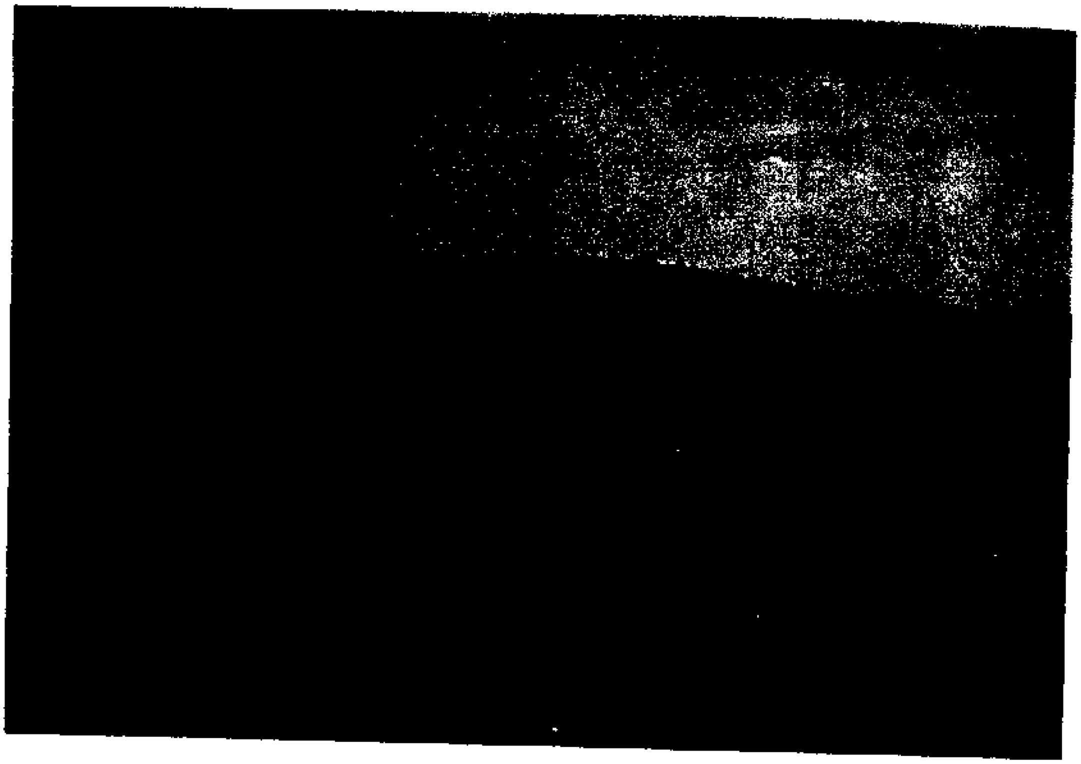

Figure 5

Figure 6

York has lost about 30 percent of its wetlands (Table 3). This has happened even though there are numerous enlightened public groups working to help save these marsh lands and adjacent underwater lands. The tide of destruction has turned in the last few years. Connecticut has passed laws giving the State strong powers to control wetlands. Both New Jersey and Delaware have had aggressive acquisition programs. In New York, the Long Island Wetlands Act authorizes the State to enter into cooperative agreements with local government to preserve and enhance wetlands.

Table 3. Extent of Coastal Wetlands in Middle Atlantic and Adjacent States and Losses Since 1954[1]

State	Total Acreage 1954	Estimated Acres Destroyed 1954-68	Percent Loss
Connecticut	14,744	3,200	21.7
New York	45,395	13,000	28.6
New Jersey	241,060	25,300	10.5
Delaware	114,048	4,600	4.0
Maryland	204,060	20,200	9.9

[1] From Spinner, George P., "A Plan for the Marine Resources of the Atlantic Coastal Zone," Am. Geog. Soc., 1969.

Under this program, some 16,000 of the remaining 32,000 acres are protected. Another 2,500 acres of wetlands are owned outright by the State or local government and are protected from destruction. Substantial acreages in New York are still privately owned and seem actually to beckon to the developer. Land for houses adjacent to the water is at a high premium, since very little remains.

The irony of this kind of development is that it ultimately destroys the very things that people are seeking as they try to move from the cities to the seashores to enjoy the good things in life.

In New York, there seems to be only one solution to this problem. The private wetlands can only be preserved for future generations through acquisition by some level of government.

Large areas of upstate New York have been set aside as forest preserves and are protected indefinitely by the State constitution. Preserves to protect the wetlands and thus to maintain the integrity of the wetlands must be developed as soon as possible.

THE FUTURE COURSE

The fashion today in almost everything being done by government is planning. Everyone is for planning. But planning can be a trap in the fast-moving

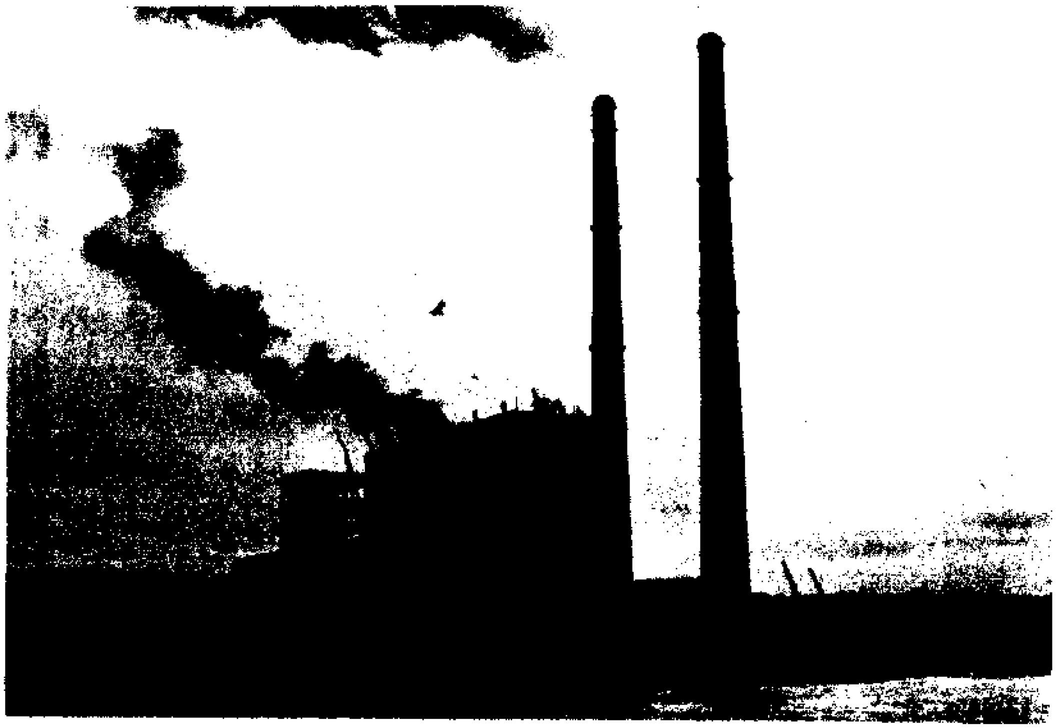

Figure 7

world of today. Our Middle Atlantic estuaries could become putrid deserts if we await for the next five years the results of studies as the basis for plans.

It seems to me that a safer course is to develop legislation which permits government to control directly the factors which deteriorate the estuarine environment while the studies as a basis for planning are being carried out. In this way, we may avoid arriving at the conclusions of the studies too late to effect a cure.

I believe that we will act aggressively and successfully in the Middle Atlantic States to accomplish this goal. New York has combined air and water pollution, solid waste disposal, pesticides control, and all resource management into a new Department of Environmental Conservation. New Jersey and Delaware have also restructured their programs to emphasize environmental protection and preservation. With this concerted emphasis on the environment, the estuaries will get a major share of the attention.

Along with the problems of sewage and industrial pollution, wetlands preservation, dredging for fill, etc., there are numerous other developments which will affect the estuaries. Policies to control the heated water effluents from power plants must be developed. Already, atomic power plants are being constructed using the waters from our estuaries for cooling purposes (Fig. 7). As the population grows even faster, pressures for more and more of these developments grow. New York has acted to establish rigid criteria for its coastal waters regarding heated water effluents from power plants. All States, who have not already done so, should act promptly to deal effectively with this problem.

Our youth today are concerned about the state of the world and the environment. And well they should be along with the rest of us. We must dedicate ourselves to preserve our habitat so that it remains compatible to man's needs.

THE EFFECTS OF POLLUTION ON ESTUARIES OF THE NORTHWEST PACIFIC COAST

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The people of the Pacific Northwest are becoming aware of the infallibility of the Law of the Conservation of Mass, which provides that the annual tonnage of discarded waste materials is exactly equal to the tonnage of natural materials—vegetable, mineral, and animal taken from the environment (Dales, 1968). The three corollaries to this law are also evident. First, in a "progressing" culture, material is not only produced locally but is also imported; hence, the discard is greater than the local production. Second, the more complex the society, the more complex the web of consumption. Finally, the more complex the web of consumption, the greater the wastage. Small packages of crackers and catsup are served after being unpacked from slightly larger packages, which were stored in larger packages after being shipped in still larger packages, and so almost *ad infinitum.*

Within the past days, we in the Pacific Northwest have created various State environmental commissions and councils, including a Nuclear Siting Evaluation Council. Also, we have considered several forms of seashore management legislation but its ultimate design has not been determined. Pollution in the Northwest is only infrequently a public health problem but, as Mr. Wallace pointed out, it is a social problem and must be treated as such.

ESTUARIES OF THE COAST

The Pacific Northwest, with the exception of the mouth of the Columbia River and Puget Sound, is remarkably poor in estuaries; therefore, the ones we do have Coos Bay, Willapa Harbor, Grays Harbor and Port Angeles Harbor—are well developed as shipping points and ports-of-call with their accompanying industries, principally those associated with lumber and pulp and paper. These industries, although fairly severe polluters in the past, are in the process of implementing measures in order to meet the fairly new (1967-68) state standards. The latter, in turn, have been approved by the appropriate Federal agencies, as provided by the Federal Water Pollution Control Act. This Act says, in essence, that either each State shall set its own water quality standards and have them approved by the Federal agency, or the Federal agency will set the standards (Anon., 1967).

From south to north, the areas of major importance are:

Toledo, Oregon—Georgia Pacific Corporation operates a Kraft process mill at Toledo, near Newport. The effluent is piped nine miles across land and 3,000 feet into the ocean. Oregon State University (J. Carter, Oregon Sanitary Authority, personal communication) conducted studies of the outfall area and found small amounts of fiber, but generally no real problem.

Columbia River—On February 2, 1970, another nuclear reactor of the original complex of nine at Hanford was shut down, and only one was left in operation. At one time, as many as 1,000 curies per day, of the 2,000 curies of radionuclides discharged into the river at Hanford, reached the estuary and the ocean (A. J. Seymour, University of Washington, personal communication). Some of these nuclides were picked up and concentrated by marine organisms to the extent that a relationship exists between the decline in radioactivity of some marine organisms and the schedule of shutdown of the reactors. Salmon using the Columbia plume as a habitat picked up the radioactivity and carried it in detectable levels at the time of capture in the northern California area (Kujala, et al., 1967).

Grays Harbor—Rayonier operates a sodium base paper plant and Weyerhauser operates a magnesium base paper plant in Grays Harbor. These particular processes are not involved in the Federal action. At times, particularly during low flow periods, it is felt that a significant pollution problem exists. Salmon planted low in the estuary consistently have shown higher survival rates than salmon planted in the watersheds of the estuaries. The direct effects of pollution and the interaction of predation have not been separated.

The latest of the problems to affect estuaries in the Northwest is that of landfill and development. Such has been proposed on a fairly large scale for Grays Harbor. Besides the usual loss of waterfowl habitat and nursery area for marine fishes, the effects of the loss of a transition area for the anadromous salmon and trout is not known. A major salmon-producing river enters into Grays Harbor in the area of the proposed fill, and undoubtedly the salmon and trout runs in the area are adapted to an existence that requires an estuary in their life history.

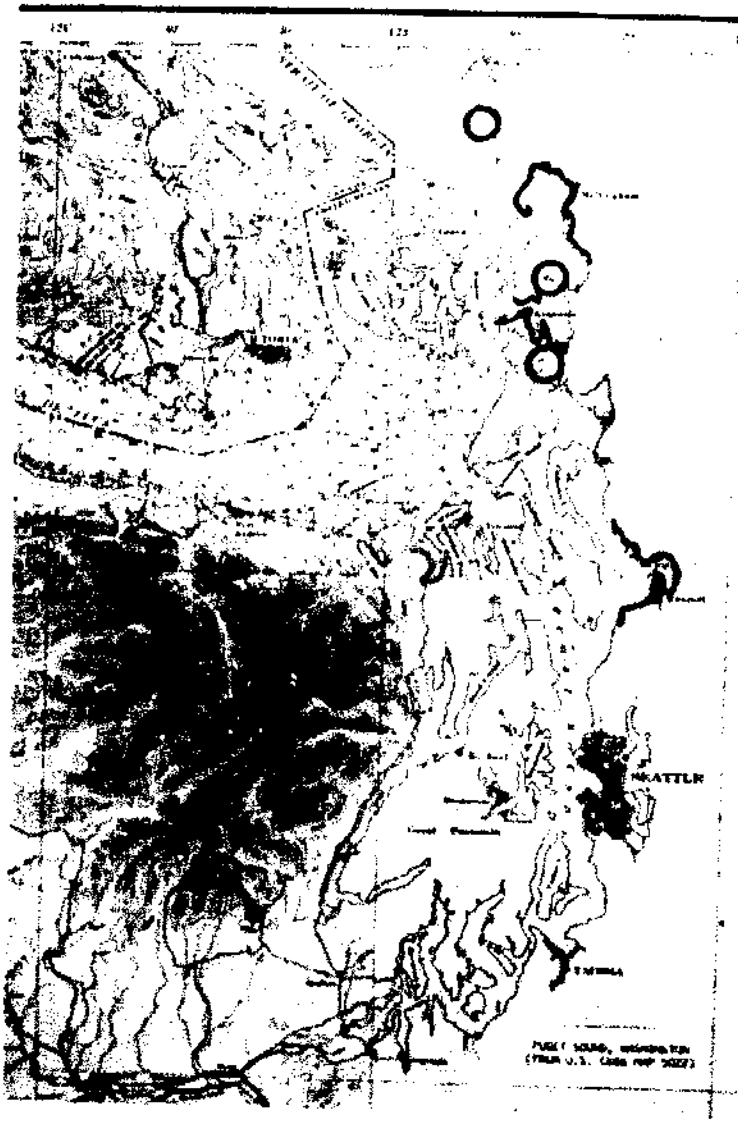

Figure 1

Port Angeles. The Crown Zellerbach plant at Port Angeles uses a kraft process which does not have the disposal problems of the sulfite process. Corrective measures, including primary treatment, submarine outfall, and the removal of sludge deposits, are being considered by the other plants (Fiberboard and Rayonier, Inc. of Port Angeles); however, the stages of negotiations are not known to us.

PUGET SOUND AS AN ESTUARY

Puget Sound Pulp Mills

The controversy involving the Puget Sound pulp mills (Fig. 1) is a long and bitter one, but one which is apparently going to end in a quite satisfactory conclusion. Past studies have shown that sulfite pulp-mill wastes are harmful in several ways (Anon., 1967b):

1. They may be injurious to juvenile salmon while migrating through harbors, as indicated by live box studies.
2. They may suppress phytoplankton activity in the harbor.
3. They may cause direct damage to oyster larvae.
4. They may inflict direct damage to the eggs of the English sole.
5. The sludge deposits are detrimental to bottom organisms; they degrade the waters and make them esthetically unattractive.

Suggested corrective measures include:

1. Primary treatment of sludge by removal of settleable solids.
2. Removal of 80 percent of the sulfite waste liquor from the mill effluents.
3. When applicable, the disposal and diffusion of residual wastes into deeper waters by means of submarine outfalls.
4. Removal of sludge beds by dredging.
5. Modification of the unloading of the barges of wood chips.

The pulp and paper mills in Bellingham Bay, Anacortes and Everett Bay, including Georgia Pacific Corp., Scott Paper Co., the Weyerhauser Corp., and the Simpson Lee Co., are in various stages of complying with the regulations, although some negotiations are still going on. The details of these complex problems are still being negotiated but we may assume that the problems associated with pulp mills will be defined, clarified, and solved.

Puget Sound is either one large estuary with three or four major parts, or a system of estuaries operating under the influence of one tidal mechanism and at least eight rivers of consequence. The basin drains some 11,000 square nautical miles, with Puget Sound proper covering about 767 square nautical miles. The Sound has many inlets and channels, but can be divided into four major areas—the main basin, or Northern Puget Sound, extending from Admiralty Inlet to the Tacoma Narrows; southern Puget Sound, from the Tacoma Narrows southward; Hood Canal and Dabob Bay, a narrow western finger of the Sound extending southward from Admiralty Inlet; and a series of waterways to the east of Whidbey Island.

Other Pollutants of Puget Sound

Four major types of wastes affect water quality in Puget Sound:

1. Wastes originating from the watersheds of the rivers that drain into Puget Sound.

Figure 2

2. Domestic wastes, treated or untreated.
3. Wastes discharged from commercial and recreational shipping.
4. Wastes from industrial firms (such as the pulp mills) located on the banks of the Sound.

Data on waste production have been obtained by multiplying regional economic forecasts by coefficients of waste per unit of production. These coefficients of waste production were developed for most of the important waste dischargers in the State of Washington, and the waste production for future years by area was then derived from the regional economic forecasts. The preliminary results of these analyses are now available for all of the major rivers emptying into Puget Sound.

The methods that have been developed for management of coastal waters and the "open waters" of Puget Sound are not applicable to smaller estuaries. The approaches used to define waste assimilation capacity and danger points is much more difficult to apply in the estuarine environment. Estimates have been made for Puget Sound as a whole and also for the major arms of Puget Sound, but many fragile embayments and river mouths are included in these larger areas.

The Pacific Northwest is rapidly approaching the point where rising demands for power must be met from thermal plants. Power demands indicate a market for non-hydroelectric power sources that is expected to require plants of approximately 1,000 megawatt capacity to be added each year in the Pacific Northwest over a period of at least 30 years, starting in the late 1970's. Siting

Figure 3

requires a lead time of at least 10 years. Thus, the first plants are being sited now. Locations under various stages of consideration include Cherry Point, Kiket Island (Fig. 2), Samish Island, Roosevelt Beach on the coast, and Dequim Bay on the Olympic Peninsula (Fig. 3).

The problem of finding a suitable site and obtaining permission to operate a thermal station is still a complicated one. In the case of a nuclear unit, there are many Federal restrictions that must be met, primarily those of the Atomic Energy Commission, and they narrow down its location to a considerable degree. These requirements are concerned with nearness to present or projected load centers, the configurations of land and the abundance of cooling water, and the matching of the site to the reactor-site criteria established by the AEC (Title 10, Code of Federal Regulations, Part 100). Proper consideration must also be accorded such factors as location and density of population, and geophysical (primarily seismic) and meteorological conditions.

At first screening, the potential areas for plant location are chosen by the general criteria of nearness to population centers, available water, and general seismic zones. Specific site location demands much closer scrutiny involving borings, drillings, studies of seasonal water currents, and the establishment of an on-site meteorological station. Unfortunately, these detailed studies are usually not feasible until after the utility company either has purchased the property or has announced its intention to build.

Figure 4

Almost without fail, the fulfillment of all of the physical criteria places the plant in either an esthetically pleasing area or one utilized by valuable commercial and recreational species of fish and shellfish, or both. Thus, the thermal plant becomes a part of the local environmental ecology and will change it. Not all changes need to be detrimental, however, and the degree of change can be controlled to a large extent by due consideration of the biological factors in its design and operation (Salo, 1969).

Intensive studies of the Kiket Island site are under way by the Fisheries Research Institute and the Department of Oceanography, University of Washington.

The Fisheries Research Institute has completed a three-year study on the Duwamish Estuary, which exists in the most heavily industrialized area of

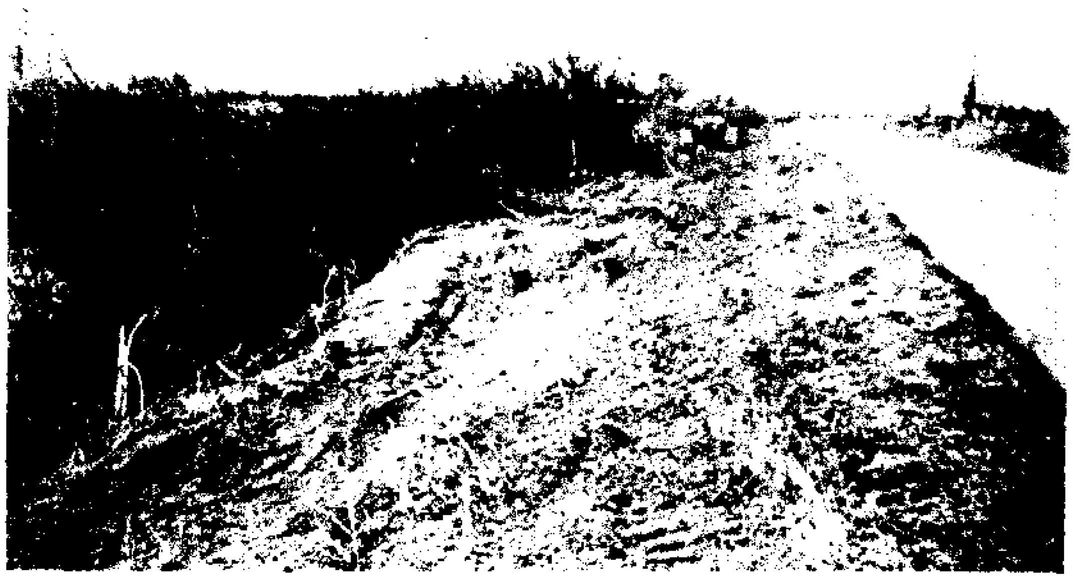

Figure 5

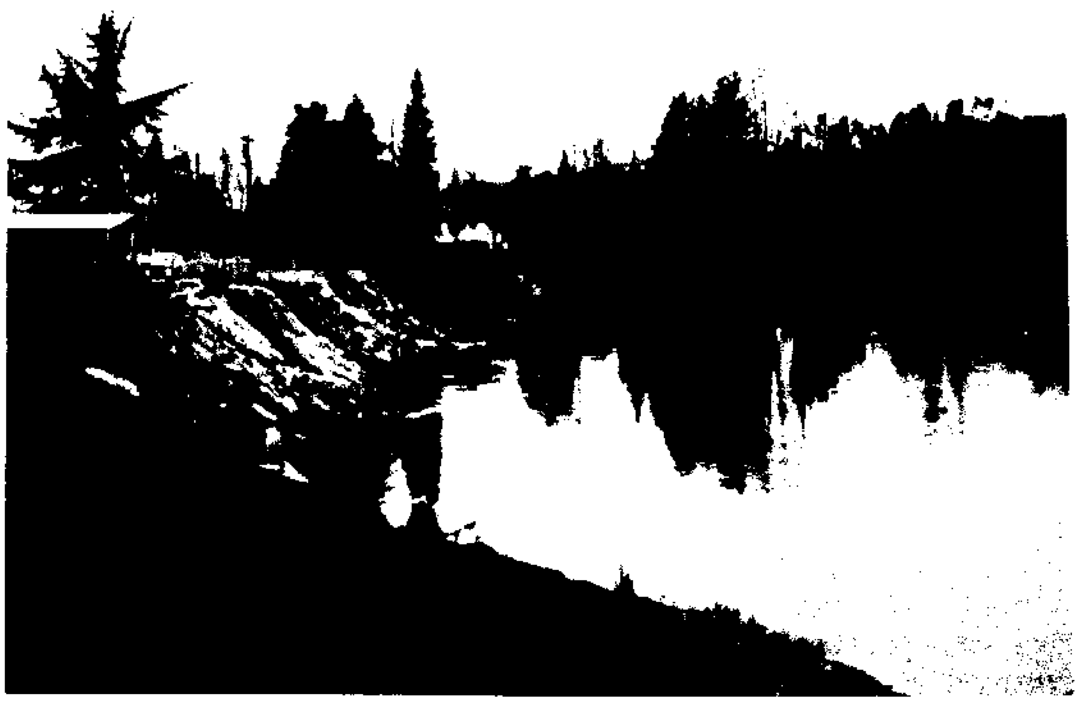

Figure 6

Figure 7

Seattle (Salo, Ms; Miller, et al., 1967). The Municipality of Metropolitan Seattle (METRO) was especially created to solve the sewage problems of the Seattle estuaries, as well as to halt the eutrophication of adjacent Lake Washington. During the past year, 95 percent of the untreated sewage has been diverted from the Duwamish River to a primary treatment plant.

Extensive damage has resulted to estuaries from land mismanagement (Figs. 4 and 5), but some of these occurrences are so commonplace that they are regarded as part of the seasonal ecology in many areas. Regulatory agencies and public opinion have been concentrating on the more obviously critical problem of industrial and domestic wastes (Fig. 6), so that many of the smaller but dangerously cumulative everyday influences have been overlooked.

Over the long run, the greatest threat to optimal use of the Puget Sound system is not posed by direct effects of industrial and municipal discharges of waste on water quality. On the contrary, it is posed by failure to identify and evaluate estuarine effects of land use, not only on the waterfront, but upstream. All of the important fish and shellfish resources of Puget Sound are vulnerable to this kind of careless development. Salmon, steelhead trout, and cutthroat trout require extensive systems of small feeder streams that are being systematically destroyed (Fig. 7) by improperly regulated land use far away from Puget Sound itself. Dyking and channel alteration, designed to improve the carrying capacity of rivers and to alleviate flood damages, may have serious adverse effects on fish spawning and resting areas. Although such effects are supposed to be assessed, in the course of review by the Department of Fisheries, it is only with the utmost vigilance that the Department can be sure that all instances are brought to its attention (Crutchfield, et al., 1969).

IN SUMMARY

The large problems of industrial and domestic pollution appear to be under control; however, the piece-meal destruction of the small estuaries continues. The principal offenders are municipal and port expansion, real estate developers, individual home owners that demand flood control, and protection from wave action. Of utmost importance are the changes brought about in the watersheds. The ocean in the Pacific Northwest is still a tremendous flusher and can assimilate considerable abuse. Nevertheless, the shoreline and the estuary are delicate and vulnerable and are being encroached upon steadily. Thus, it is entirely possible that Puget Sound can remain relatively cool and clean—with rigid, vertically-cut, rip-rapped banks—and be surrounded entirely by Municipalities and housing developments of doubtful esthetic and social fates (slums).

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THE SIGNIFICANCE OF AN ESTUARY ON THE BIOLOGY OF AQUATIC ORGANISMS OF THE MIDDLE ATLANTIC REGION

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The mid-Atlantic coast - the stretch from Cape Code to Cape Hatteras—includes a multitude of estuaries, among which are the lower reaches of the Connecticut, Hudson, and Delaware Rivers, Long Island Sound, Narragansett Bay (Rhode Island), Great South Bay (New York), Barnegat Bay (New Jersey), Assateague and Chincoteague bays (Maryland and Virginia), and the Pamlico-Currituck-Albemarle Sound system (North Carolina). The largest, most varied and most important estuary for aquatic organisms in the mid-Atlantic coastal area is the Chesapeake Bay. Therefore, this is the estuary that I shall use as an example in this discussion. Further. I am more familiar with the Chesapeake, having worked there for about 15 years.

CHESAPEAKE ESTUARY

The Chesapeake Bay is 195 miles long and varies in width from 3.5 to 35 miles. It includes 2,816,000 acres. Maximum water depth is 175 feet and mean depth of the estuary is 21 feet (Wolman, 1968). The major tributary is the Susquehanna River which empties into the north end of the Bay and contributes over one-half of the total freshwater inflow. The Bay itself is the drowned downstream part of the Susquehanna River valley which was inundated some 10,000 years ago by a rise in sea level. Other major tributaries include the Patuxent, Potomac, Rappahannock, York, and James rivers. Approximately 150 additional rivers and creeks flow into the Bay. The watershed drained by Chesapeake Bay tributaries covers 64,900 square miles in the States of New York, Pennsylvania, West Virginia, Delaware, Maryland, and Virginia.

Salinities range from near 30 parts per thousand (ocean salinity is 35 parts per thousand) in bottom waters at the mouth of the Bay to fresh water at the head of the Bay and in tributaries downriver from or at the head of the tide. Tidal range is about 3 feet at the mouth of the Bay with tidal currents of up to 3 knots.

Superimposed on the tidal currents is a non-tidal circulation pattern characterized by a seaward flow in the upper layers of the estuary and a flow directed up the estuary in the bottom layers (Pritchard, 1968). The non-tidal flow, generally only about one-fifth the magnitude of the tidal current, accelerates when freshwater runoff is high and becomes weaker during periods of drought (Norcross and Stanley, 1967). At times this inflowing bottom current is detectable as far as 35 miles offshore from the Bay mouth. This current is an important vehicle for transporting fish larvae and other small aquatic organisms from the ocean into the Bay and up the Bay toward freshwater tributaries (Pritchard, 1951). At the extreme upstream end of salt water penetration the bottom waters become mixed with surface waters. Sediment, detritus, nutrients, and small aquatic organisms often become trapped and recirculated in this highly productive part of the estuary.

The marshes and swamps bordering the Chesapeake and its tributary streams are extremely important components of the estuarine complex. Roughly one-third of a million acres of salt marsh habitat surround the Bay. A recently completed survey of Virginia tidal wetlands (Wass and Wright, 1969) showed there were 213,059 acres located in the Virginia portion of the Bay. The wetlands included 97,793 acreas of marsh, 55, 623 acres of open creeks, 38,058 acres of wooded marsh, and 12,857 acres of tidal flats. The remaining 8,728 acres were woodland, sand, ponds, and dredged areas.

The estuary is a transition zone in which the fresh water from the land becomes mixed with the ocean waters and is affected by both. Biologically it is a most productive area. McHugh (1967) pointed out that annual fish harvest from the Bay—both sport and commercial—amounts to about 125 pounds per acre. He further suggested that there is a potential for harvesting 600 pounds per acre from Bay waters.

AQUATIC ORGANISMS

Fish

In 1966, the commercial finfish harvest from the Chesapeake was 303.6 million pounds. Adding oyster and clam meats (27.8 million pounds) and blue crabs (95.1 million pounds), the commercial harvest totalled 426.5 million pounds (Lyles, 1968). Based on the results of sport fishing surveys for parts of Maryland in 1962 (Elser, 1965) and Virginia 1955-1960 (Richards, 1962), the estimated annual total sport catch from the Bay was about 22 million pounds (Stroud, 1965). Total fish harvest in recent years is thus close to one-half billion pounds.

In addition to providing some 325 million pounds of finfish directly to Chesapeake Bay fishermen, the Bay serves as a nursery area for fish caught from Maine to North Carolina. For the entire Atlantic coast, Clark (1967) lists 19 different kinds of commercial fish that are directly dependent on estuaries. The striped bass, weakfish, scup, black seabass, summer flounder, and king-whiting are examples of fish that may migrate to coastal waters after spending at least part of their first year in the nutrient-laden Bay waters.

Some 39 million pounds of striped bass could be attributed to the Chesapeake in 1965. Bay catch for that year was about 14 million pounds – the commercial harvest was nearly 6 million pounds and sport harvest was at least 8 million pounds. In addition to the Bay catch, striped bass migration studies (Merriman, 1941; Raney, 1952; Porter and Saila, 1969) have suggested that at least one-half of all the stripers taken in Atlantic coast waters originated in the Chesapeake. Some 50 million pounds may have been taken in coastal waters- sport catch from the North Atlantic was estimated as some 48 million pounds for 1965 (Deuel and Clark, 1968) and New England and mid-Atlantic commercial catch in 1965 was 2 million pounds (Lyles, 1967). Half of the striped bass in these catches probably originated in the Chesapeake.

Less abundant than in the 1930's and 1940's, the weakfish has been among the more prized of both game and commercial fish. Studies by Nesbit (1954) and Perlmutter et al. (1956) attributed the collapse of the fishery for weakfish in New York waters to the over-harvest of small weakfish in Virginia. The evidence strongly suggested that juvenile weakfish reared in Chesapeake waters migrated north to New York waters as they became larger, and provided a substantial portion of the New York harvest. Studies on the age composition of Bay-caught weakfish showed that commercial catches were dominated by one-year-old fish (Massmann, 1963).

In late spring and summer, scup move from ocean spawning grounds to nursery areas in southern Chesapeake Bay, where they are the most abundant bottom fish during summer months. Although most numerous in the Bay, young scup are also present in coastal waters. Therefore, the Bay is not the only nursery ground available to them (Clark et al., 1969). They leave the Bay in fall for wintering grounds in warmer, offshore waters. In spring, scup move north to coastal waters of Delaware, New Jersey, and New York (Neville and Talbot, 1964). A similar pattern of movements appears to occur in other fishes such as summer flounder, black seabass, and king-whiting. These examples illustrate the importance of the Chesapeake estuary to fish and fisheries of the Bay and of the Coastal waters beyond the Bay.

Estuarine Pests

Not all aquatic life of the Chesapeake is desirable. The jellyfish or sea nettle is probably the greatest deterrent to aquatic recreation, especially swimming and water skiing. The hordes of nettles that thrive in the Bay during summer are also a nuisance to commercial and sport fishermen, and compete for food or prey directly on larvae of both finfish and shellfish. A closely related but not so painful pest is the comb jelly or ctenophore. This walnut-sized animal produces brilliant, luminescent flashes when disturbed in the water at night. It is more voracious than the jellyfish and, in abundance, has been observed to severely reduce the amounts of planktonic animals, fish eggs and larvae, and jellyfish (Van Engel and Joseph, 1968).

Three additional elements in the aquatic estuarine fauna are destructive or annoying. These are the shipworms, which are not worms at all but molluscs. They cause extensive damage to the hulls of wooden vessels and to wooden piling. The barnacles are also a nuisance to boaters and often take up space that might otherwise be used by oysters for setting. The oyster drills are another of the detrimental aquatic organisms of the estuary.

Two of the insect inhabitants of estuarine marshes are so annoying and generally known that problems they cause need not be further described. The saltmarsh mosquito and green-headed fly are both aquatic inhabitants of the estuary during their early life stages. Extensive marsh diking, ditching, drainage, and filling activities are often done in response to the mosquito problem. Too, widespread pesticide spraying programs have in the past caused extensive damage to non-target estuarine animals including crabs, fish, and birds.

Estuarine Birds and Mammals

Waterfowl, shore birds, other aquatic birds, and aquatic mammals are closely associated with the Chesapeake and its marshlands. Some 350,000 Canada geese, 550,000 ducks, and many thousands of our whistling swans winter in the Chesapeake estuary. A few black ducks and the wood ducks remain for the summer breeding season. For the others, the Chesapeake is a great winter pasture. In the open Bay waters loons, scoters, and old squaw are most prevalent, while in less saline waters of the upper Bay the goldeneye, scaups, bufflehead, ruddy duck, canvasback, ring-necked duck, Canada goose, cormorant, mergansers, and grebes, are more numerous. In the fresher waters associated with the marshes the black duck, blue-winged and green-winged teals, mallard, gadwall, widgeon, pintail, shoveler, wood duck, rails, herons, and egrets are more common. The muskrat, mink, raccoon, and otter also live in these marshes. Porpoises generally enter the Chesapeake during the warm season, doubtless attracted by the abundance of fish. Only rarely have whales blundered into the Chesapeake Bay. Such infrequent occurrences, while they attract much attention, generally end tragically for the whale. Also associated with the Bay are the sea gulls, terns, snipes, sandpipers, and a host of other unique shore birds.

In the preceding discussion I have briefly described the Chesapeake estuary; indicated some of the more important aquatic organisms and pointed out their abundance, and shown by example that their impact often extends far beyond the Bay. In the following sections, I will indicate why the estuary is important and discuss some effects on aquatic organisms of major changes in the estuarine environment.

ROLE OF THE CHESAPEAKE

The Bay is a most productive area. It is especially important as a nursery ground for young fish—not only resident species such as white perch and white catfish, but also anadromous American shad, river herrings, and striped bass and fishes spawned offshore, including Atlantic menhaden, spotted hake, Atlantic croaker, and spot. Further, some sections of the estuary are far more important as fish nursery grounds than are other sections. The low salinity portions of the northern part of the Bay and the corresponding portions of the major tidal tributaries are the most productive zones. In these areas, the larvae of resident fish, those of fish from other parts of the Bay, and the larvae of offshore fish congregate and grow.

I pointed out earlier that the more saline, inflowing bottom layers of water transport fish larvae and other plankton to the Bay from offshore and up the estuary toward fresh water. Near the upper limit of salt water penetration, these currents recycle and trap nutrients, sediments, detritus, and planktonic organisms in the area (Schubel, 1968). The water in this most productive zone supports a large population of planktonic diatoms and algae. However, the most important production is from the marshes. Average summer water temperatures are higher in the highly productive areas and dissolved oxygen is lower than in other parts of the estuary (Van Engel and Joseph, 1968). Among the reasons for the higher temperatures and lower oxygen values could be that the extensive perimeter marshes hold large quantities of shallow, quickly warmed water and great amounts of organic material produced by marsh vegetation.

In most of the major tributaries, the shoreline in the highly productive areas is dominated by extensive cordgrass marshes interlaced with tidal creeks. The cordgrasses (*Spartina*) are the most abundant and most important of the marsh vegetation. Production of cordgrasses in Virginia's estuaries, as shown by the dry weight of grass harvested from sample plots, ranged from 3 to 10 tons per acre (Wass and Wright, 1968). Average production was 5.1 tons per acre annually. The dead cordgrass stems and leaves drop into the water. In time, tidal currents transport the decaying material into creeks and large estuary tributaries. Decay by bacteria and fungi breaks down the cordgrass detritus into small fragments and fine particles. In the process, the protein value of this material actually increases.

Experiments with Georgia cordgrass (Odum and de la Cruz, 1967) showed that the protein content quadrupled--protein for recently dead stalks was 6 percent while that for decayed stalks was 24 percent. The protein increase was caused by the bacteria, fungi, and other micro-organisms associated with the decay process. The effect is that of a "biological multiplier." Also, a single particle may be consumed by one organism, stripped of its micro-flora and, following elimination and bacterial recolonization, again be consumed. This process may be repeated a half-dozen times before the particle has been completely digested. Farther upriver, in the area where open marshes are replaced by forested swamps, dead leaves which end up in the water probably provide a forage function similar to that of the cordgrass. Principal direct beneficiaries of the particlate detritus provided by the cordgrass are gammarid amphipods (*Gammarus*) and opossum shrimps (*Neomysis*). Copepods, cladocerans, and other micro-crustaceans also feed on this material, as do isopods, crabs, clams, and oysters. The amphipods and opossum shrimps are among the most abundant of estuarine animals in this productive estuarine zone. This was also found to be the case in the low salinity portion of California's Sacramento-San Joaquin estuary (Kelley, 1966).

Fish larvae and juveniles feed heavily on the abundant crustaceans. Food studies by Van Engel and Joseph (1968), on the most abundant of the young fishes in this productive zone, showed that either mysid shrimp or amphipods, or both, were among the two most important foods for white perch, hogchoker, bay anchovy, white catfish, spot, Atlantic croaker, weakfish, silver perch, and southern kingfish. In spite of extensive preying on the crustaceans by small fish, the numbers of forage animals were not diminished. Weakfish and striped bass also fed heavily on the abundant larvae of bay anchovy and naked goby. Young striped bass in the Sacramento-San Joaquin estuary were also heavily dependent on both opossum shrimp and amphipods for food (Heubach, 1963).

Production of marine fouling organisms–the sessile plants and animals that attach to oyster shells, pilings, and other exposed surfaces–was found to be greatest at upriver, low salinity stations in the Patuxent River (Cory, 1967). During summer months–the period when production was greatest–the barnacles, hydroids, and amphipods from these stations produced more than three times as much dry weight as they produced at downriver stations.

Aquatic plant production is also greatest in low salinity areas, especially in the clearer waters in the northern part of the Bay. Best known as important waterfowl foods, the pond weeds, eel grass, widgeon grass, and other desirable aquatic plants also provide both food and shelter for invertebrates and fish. When they die, these plants also add to the organic detritus.

Two introduced aquatic plants, the Eurasian milfoil and water chestnut, have both reduced the production of desirable plants and animals, impeded water circulation, and clogged waterways. Fortunately, control measures have reduced the abundance of the water chestnut, and a disease has almost eliminated the Eurasian milfoil.

Production of phytoplankton is greater down river from the highly turbid, low salinity upriver areas. Stross and Strottlemyer (1965) also working on the Patuxent River found that, although the upstream area had the highest potential for production of chlorophyll "a," actual production was greatest in the more saline waters near the Patuxent River mouth. In this part of the river annual plant production was equivalent to about 2.9 tons per acre. The reason for the difference between potential and actual production was that high turbidities in upriver areas reduced light penetration and photosynthesis.

The oysters, clams, crabs, and fishes of the downriver areas receive substantial benefits from the down-estuary movement of fine detritus in the surface flow, as well as from vegetation from the shoreline marshes and creeks. Nevertheless, the most important production in the more salty part of the estuary is provided by phytoplankton.

Mysid shrimp are also present in numbers in the downriver and Bay waters. Studies in the Delaware River and Indian River Inlet (Delaware) estuaries demonstrated that, there, mysids are among the most abundant organisms. At the same time, they were one of the most important fish food organisms (Cronin et al., 1963; Hopkins, 1965). The Chesapeake Bay is probably similar in this respect.

The more saline downriver and Bay waters also provide feeding grounds for some of the larger predatory aquatic organisms--including fishes, crabs, jellyfish, and the comb jelly. Among the most significant findings from the Virginia estuarine study by Van Engel and Joseph (1968) was that the comb jelly, *Mnemeopsis*, is extremely effective in depleting zooplankton populations. Following the appearance of the comb jelly in the high salinity areas, zooplankton populations rapidly diminished. It is, therefore, a serious competitor of larval, postlarval, and juvenile fishes that are still feeding on smaller zooplankton. Ironically, a larger comb jelly, *Beroe*, feeds voraciously on *Mnemeopsis*. When *Beroe* appeared in the estuary, the smaller comb jelly was almost completely eliminated from the river, and zooplankton numbers again increased.

Low salinities in the productive upriver portion of the estuary provide a barrier, past which neither the jellyfish nor the comb jelly can move. Therefore, the larval fish are protected from both competition and predation by these animals. The highly turbid waters also help to reduce predation from other sources, because visibility is so poor.

A remarkable succession of fish occupy the low salinity nursery grounds. In earlier spring, postlarval menhaden move in from offshore spawning areas (Massmann et al., 1954). Young spot move into the entire Bay at this time and spread upriver as well as into other peripheral areas. Silver perch appear in summer, followed by young weakfish (Massmann et al., 1958). Postlarval croakers migrate up the Bay in fall and generally overwinter in the upriver nursery areas (Haven, 1959).

The tendency of young croakers to overwinter in upriver nursery areas is responsible for the substantial reductions in croaker populations that have occurred. During periods in which water temperatures drop rapidly, severe mortality occurs (Massmann and Pacheco, 1960). In some cases, an entire year class may be destroyed. Subsequent laboratory studies have demonstrated that juvenile croakers fail to feed at water temperatures of 5°C, and that mortality occurs when temperature approaches 0°C (Van Engel and Joseph, 1968). In Maryland waters of the Chesapeake, Dovel (1968) has indicated that predation by striped bass also causes significant mortality in croakers.

I have briefly indicated some of the reasons why the Chesapeake estuary is so essential to aquatic life, and why some parts of the estuary are more vital than other parts. The Bay environment can be changed. It is being changed now, and greater changes are in store for the future. I wish to discuss some of the changes and show their effects on aquatic organisms.

ESTUARY CHANGES

The Chesapeake Bay can be changed physically and chemically. Physical changes include filling, dredging, and temperature changes. Chemical changes include depletion of oxygen and pollution by municipal and industrial wastes, fertilizers, snow salts, biocides, etc.

Filling

Filling is occurring in the Bay at a more rapid rate than most people realize. The obvious landfill projects have been most evident in the vicinity of large cities—Baltimore, Washington, and Norfolk—where additional land for piers, parks, industry, housing, and airports has been created. Less noticeable has been the silt washed in from the tributaries. The Susquehanna River alone delivers 600,000 tons of silt to the Bay annually, and about 2.5 million tons originate in the Potomac River Basin. Shoreline erosion also contributes to the silt load. In the past 100 years some 6,000 acres of Maryland shoreline have slipped into the

Bay (Wolman, 1968). Between 1846 and 1948 silt deposition has reduced water depth 2.5 feet over a 32 square mile area at the north end of the Bay (Hollis, et al., 1964). Roughly one-half of the oyster grounds in the upper Bay have been destroyed or shifted downstream by sedimentation. Much of the channel dredging is done merely to maintain the depth in previously built channels.

Filling, carried to the extreme, would result in the Bay becoming a delta somewhat like the lower Mississippi River. It is likely that the Chesapeake Bay would be similar in appearance to the old Susquehanna River mouth as it was some 10,000 years ago—before the rise in sea level. Although many of the same kinds of fish would be present, the numbers would be much less because of the decrease in water volume.

On a smaller scale, the effects of filling depend largely on the location of the fill and the type of habitat to be covered. We have already pointed out the vital role of the marshes in maintenance of aquatic production. Filling the marshes, especially those located in the low salinity, productive zone, directly reduces the amount of food available to crustaceans which, in turn, reduces the abundance of young fish. On the other hand, filling in some locations with properly anchored material could be useful in creating new marshland, improving current patterns, or reducing extreme wave action.

Dredging

Dredging is often associated with filling since the material taken from the channels—the spoil—must be deposited somewhere. Dredging may be done to deepen waterways and channels or to create new waterways. Canals provided the most important early means of transportation. The Dismal Swamp canal, which connected Chesapeake Bay with Albemarle Sound, was begun in 1793. It probably influenced aquatic life but little. On the other hand, the cutoffs that eliminated the need to navigate around the large loops in the James River between Hopewell and Richmond have essentially destroyed the value of the ox-bow sections as spawning and nursery areas for shad and striped bass. Interestingly, the first of these cutoffs—Dutch Gap—was constructed in late 1864 by the Federal troops in an effort to by-pass powerful Confederate defensive positions.

The Chesapeake and Delaware Canal has provided a shorter shipping route to the Delaware River and coastal and European ports to the north. Striped bass and American shad also use the canal for migration. The deepening of this canal to 35 feet is expected to result in an increase in freshwater flow of from 900 to 3,000 cubic feet per second (Corps of Engineers, 1969). Rather than flowing south through the Chesapeake, diverted fresh water will flow north through the Canal into Delaware Bay. Reduction of the freshwater flow into the Chesapeake will increase Bay salinities and reduce the rate of both outflow of surface waters and inflow of bottom waters at the mouth of the Bay. While the damaging effects on shellfish will be greater than those on finfish, a reduction of inflowing ocean water into the Bay will probably result in fewer of the larvae of ocean-spawned fish reaching productive estuarine nursery grounds.

Freshwater Flow Reduction

I have already suggested two of the changes that may occur as a result of increased freshwater outflow through the Chesapeake and Delaware canal. This is not the only activity that will reduce freshwater and Bay circulation. The fact that the Susquehanna has been referred to as the last great untapped freshwater resource in the East shows that it is now being considered as a new water supply (Anon., 1967a, 1967b). Proposals have been made for the diversion of Susquehanna River water to Philadelphia, Wilmington, and other metropolitan areas outside of the river basin. Present flow rate averages about 40,000 c.f.s.

If freshwater flows were severely reduced, the productive, low-salinity nursery areas would be displaced up the estuary beyond the cordgrass marshes toward the head of the tide. The fish would lose much of the benefit from high productivity and the low salinity zones would occupy a far smaller volume of water and far less productive stretch of river. If freshwater inflow were reduced to the extent that salt water penetrated to the fall line, the spawning and nursery area of anadromous shad and striped bass would be eliminated.

Saltwater Flow Reduction

The increasing need for ever larger quantities of fresh water have led to proposals for the creation of salinity barriers in the Bay to provide large pools of readily available fresh water. Similar proposals have been made for large parts of San Francisco Bay and for Long Island Sound. In the Chesapeake, such structures have been advocated for the Potomac River downriver from Washington and the James River in the vicinity of Jamestown Island.

On a smaller scale a salinity barrier, Walkers Dam, is present on the Chickahominy River near Lanexa. This dam was built in 1943 as an auxiliary water supply for Newport News. Tidal flows in the river were eliminated upriver from the dam and severely reduced downstream. The Chickahominy shad run, formerly one of the best in Virginia, was substantially reduced (Walburg and Sykes, 1957). Currents are needed for spawning. On the other hand, glut herring populations virtually exploded. The ratio of juvenile shad to glut herring sampled in the Chickahominy River was 1:15,000, while this ratio for the nearby Pamumkey River was 1:41 (Massmann, 1953). Freshwater fishing in the impounded river improved substantially and has remained good. The anadromous shad and, probably, striped bass were reduced but herring and freshwater fish increased.

Water Pollution

The Chesapeake estuary has been less affected by pollution than either the Delaware or the Hudson. Even so, a total of 42,255 acres of shellfish grounds have been closed because of domestic sewage pollution (Anon., 1968). In addition, some 254,000 acres of the estuary are less desirable for finfish because of pollution.

Contamination of Bay waters by toxic substances is especially acute near Baltimore. Not only the water but the silt from the bottom of the harbor has been so poisoned that it cannot be redeposited in cleaner waters without damaging fish and shellfish. The introduction of foreign decomposible materials that utilize large amounts of oxygen can be especially harmful when it occurs in the vicinity of highly productive nursery areas, where oxygen levels are naturally low from decomposition of material from the marshes. The addition of heat to these waters—already warmer than waters of other parts of the estuary—could be more harmful than the addition of heat to waters in more saline parts of the estuary, for it further aggravates the oxygen balance as well as the heat balance.

CONCLUSION

I have described the Chesapeake estuary—largest of our Atlantic coastal estuaries. Although it could scarcely be considered as a typical mid-Atlantic estuary, it has most of the characteristics found in these estuaries.

Water circulation results from a combination of tidal currents and a net flow seaward of low salinity surface water and a net flow toward the head of the estuary of high salinity, bottom water. The rate of the non-tidal currents depends on the amount of fresh water entering the estuary. The non-tidal currents provide a vehicle for larval fish to move from ocean and Bay spawning grounds to favorable nursery areas in low salinity waters.

Chesapeake Bay provides a favorable nursery area for fishes of the Bay and for many other fishes, including striped bass, weakfish, and scup, that migrate to coastal waters north of the Bay. Further, the most productive nursery areas are those in low salinity waters, near the head of the Bay, or upriver in tidal tributaries. The cordgrass marshes provide much of the food consumed by the small crustaceans that, in turn, provide the forage for larval, postlarval, and juvenile fish.

Changes in the estuary reducing freshwater inflow, such as dredging and filling, or the introduction of various kinds of pollutants, all influence the estuarine animals in a variety of ways. A thorough knowledge of the relationships of the physical, chemical, and biological factors will enable us to avoid changes that will be most harmful, minimize the destructive effects of some changes, and even improve the estuary for production of desirable aquatic life.

The principal way in which this knowledge may be used is through the development of a comprehensive plan for the Chesapeake estuary—a plan that takes into consideration all of the Bay interests. Such a plan was developed and is being applied to San Francisco Bay. In that case, however, the Bay was greatly changed before a need for planning was accepted. In the case of the Chesapeake Bay, and some other mid-Atlantic estuaries, we should develop the information we need and adopt and implement a strong plan before great irreversible changes occur.

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CLOSING REMARKS BY SESSION CHAIRMAN

James E. Sykes

This afternoon our speakers have related the usefulness of the estuarine environment to many of the organisms living therein and have described some of the conflicts between civilization and estuarine productivity. We can be grateful that the Nation has such keepers of the environment as Dr. Salo, Mr. Wallace, and Mr. Massmann; men who have an understandingg of some of the complexities of estuarine systems, and who are dedicated to the task of keeping those systems in an operable condition in the face of extreme population growth on the United States coast.

Although wastes from industry and municipalities cause serious damage to aquatic species living along the coast, Dr. Salo has focused our attention on the unwise use of land on the waterfront and upstream. It is true that on the Pacific, Atlantic, and Gulf coasts contamination, damming, and general misuse of feeder streams have a collective and magnifying effect upon living resources of the coastal zone. There would be little advantage in controlling man's influences solely along the shoreline while ignoring his influences upon the relatively tiny streams farther inland. Apparently, the effects of large industrial-type operations on the estuary can be controlled and planned properly, whereas the accumulative effects of piecemeal estuarine alteration yields problems more difficult to solve.

Mr. Wallace, in appraising the middle Atlantic shellfish situation predicts that some species, particularly the New York hard clam, are destined to produce well during the foreseeable future. Harvests would be much greater now and in the future, however, were it not for sewage pollution which has closed many acres of producing beds. Both pollution and disease have reduced oyster harvest sharply in the middle Atlantic States.

Mr. Massmann described the tremendous biological carrying capacity of Chesapeake Bay and reviewed the fisheries contributions which that Bay makes to other parts of the Atlantic coast. The biological importance of Chesapeake Bay is readily apparent in statistical digests of United States fisheries (commercial harvest in 1966 was 426.5 million pounds and sport catch about 22 million pounds). He urged interagency cooperation, a consolidation of knowledge and early implementation of that knowledge, leading to effective management and control over estuaries to prevent otherwise irreversible changes.